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This report is published by authority of the State of Illinois. It is a contribution from the Section of Wildlife Research of the Illinois Natural History Survey.

Dr. Frank C. Bellrose is a Wildlife Specialist and Fred L. Paveglio, Jr., and Donald W. Steffeck are Research Assistants in the Section of Wildlife Research.

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Waterfowl Populations and the Changing Environment of the Illinois River Valley

Frank C. Bellrose, Fred L. Paveglio, Jr., and Donald W. Steffeck

THE VALUE OF THE ILLINOIS RIVER valley for waterfowl lies in its bottomland lakes that flank the relatively narrow river channel between Spring Valley and Meredosia and between Pearl and Grafton. These lakes originated in the most recent glaciation (Wisconsinan), which profoundly altered the ancient Mississippi and Illinois rivers and created the unique Illinois Valley that we find today. Up to the 1930's, the Illinois River valley was one of the nation's outstanding waterfowl hunting areas. Since then it has been in a state of decline for a variety of reasons, some of which will be discussed here.

GEOLOGICAL HISTORY

Prior to the Wisconsinan glaciation, the Mississippi River flowed down the Illinois Valley below the Big Bend at Hennepin, Illinois, by means of a now buried channel between Bureau and northeastern Rock Island counties (Willman & Frye 1970). About 21,000 years ago, the most recent ice sheet, the Wisconsinan, moved westward past the Big Bend and diverted the Mississippi River westward to its present channel south of Muscatine, Iowa (Willman 1973). As the Wisconsinan glaciation retreated, flood waters formed the Des Plaines and Kankakee rivers, which joined near Channahon to create the present Illinois River. From Channahon westward to the Big Bend at Hennepin, the Illinois carved a new valley. At the Big Bend, the flood waters of the glacial melt entered an ancient valley of the Mississippi River and followed this pathway southward to the present Mississippi River at Grafton.

Because the ancient Mississippi Valley through central Illinois had been broadened and deepened by repeated pre-Wisconsinan glacial melts, the Illinois River entered a much deeper valley below Hennepin than was warranted by its volume of water. The valley has also been considerably filled with sediment carried by the glacial meltwater. This origin resulted in a river with an unusually low rate of fall: 0.03 m per km (0.17 ft per mile) between Hennepin and Pekin, and 0.02 m per km (0.13 ft per mile) from Pekin to Meredosia. Forbes & Richardson (1920) reported that at ordinary levels the flow varied from 2.01 to 4.02 km (1.25–2.50 miles) per hour. Since 1938, navigation dams have further retarded the river velocity to about 1.0 km (0.6 mile) per hour (Starrett 1971). The gentle slope of the river below the Big Bend has resulted, during postglacial times, in the valley's aggrading rather than eroding, as do most river valleys.

The Illinois River's low volume of flow for its channel capacity and its low rate of fall combined to form the unique bottomland lakes associated with the Illinois Valley. Under overflow conditions, the faster-moving waters of the channel meet the slower-moving backwaters with the result that sediment is deposited more rapidly along this shear. Through eons of time natural levees rose, like barrier islands, to separate most of the channel waters from the adjacent bottomland waters. Thus evolved bottomland lakes, or backwater lakes, as the engineers term them (Fig. 1).

The very creation of bottomland lakes also set the stage for their extinction. The sedimentation that sep-

Fig. 1.—Illinois River north of Chillicothe, illustrating the natural banks that formed bottomland lakes in the Illinois Valley. The channel is shown meandering between Babbs Slough, Sawyer Slough, Big Meadow Lake, Wightman Lake, and Sparland Lake.

arated the lakes from the river channel is now rapidly engulfing them. Under pristine conditions, this extinction of individual bottomland lakes would probably have taken hundreds of years, and while one generation of lakes was being filled with sediment, another generation would have been formed by the growth of new natural levees. Man, through intensive use of the land, has greatly accelerated the process.

The Illinois Valley is especially subject to sedimentation because its tributary streams fall many times faster than does the main stream. For example, the slope of the Spoon River, an important tributary, varies from 0.19 to 0.57 m per km (1–3 ft per mile) (Evans & Schnepper 1977). Consequently, the rivers and creeks feeding the Illinois River transport enormous quantities of finely suspended soils to its waters. Since it flows more slowly, the Illinois in turn deposits a sizeable proportion of this load in its network of bottomland lakes during floods. At lower water stages the river waters mingle very little with the backwater lakes. Only Peoria Lake, through which the river flows, is continuously exposed to transported material.

HISTORICAL CHANGES

For 150 years following Pere Marquette's and Louis Joliet's ascent of the Illinois River in 1673, its valley was populated largely by Indians and a few white traders and trappers. In 1823 several white families lived at the present site of Peoria, and Chicago was known as a military and trading post (Barrows 1910). However, the establishment of steamboating in 1823 brought an influx of immigrants, so that by 1840 much of the Illinois Valley contained 6–18 people per square mile.

After 1840 the population of the

valley grew apace. By 1900 there were 3.3 million people in the Illinois basin, 95 percent of which lies within the state of Illinois. The basin embraces slightly over half the area of the state.

To facilitate transportation, a canal was constructed in 1848 from Lake Michigan at Chicago to the Illinois River at La Salle. In addition, three low navigation dams and locks were constructed on the Illinois River, at Henry in 1871, at Copperas Creek near Banner in 1877, and at La Grange in 1889. These changes appear to have had little effect upon the natural biota of the Illinois Valley; its lakes were still nearly pristine.

Detailed maps of the Illinois Valley made by J. W. Woermann, Corps of Engineers, U.S. Army, from 1902 to 1904 indicate that slightly over one-third of the meadows and wooded bottomlands had been cleared and placed in some form of cultivation.

During the late 1890's, the waters of the Illinois River still ran comparatively clear. Kofoid (1903:151) described a boat trip across a series of bottomland lakes above Havana during high water in late May. Despite the high stage, waters were surprisingly clear; aquatic and marsh plants were beginning to appear in abundance, with coontail still "at some depth below the surface." In the waters of Thompson Lake (one of the largest lakes in the valley), Kofoid could see schools of young fry feeding upon plankton. Its waters were described as "somewhat turbid but more from plankton than silt." The river channel was more turbid from silt and plankton than were the adjacent lakes.

Later in the summer, Kofoid (1903: 155) revisited the same lakes during low water. He found "the backwaters have been reduced to the lakes, sloughs, and marshes which abound everywhere in the bottomlands." Most of the lakes were choked with aquatic plants or rushes. His descriptions of bottom soils suggest that they were composed more of decayed plant material than of silt.

CHANGES DURING THE PRESENT CENTURY

From 1900 to the present, the natural habitats of the Illinois Valley have experienced a sequence of overlapping catastrophic events. Had the Illinois River and its backwater lakes been a fragile ecosystem, they would have passed into oblivion long ago. With varying degrees of success, the aquatic communities of the Illinois Valley have withstood the ravages of man.

The first pronounced change occurred in 1900 with the completion of the Chicago Sanitary and Ship Canal, which diverted water from Lake Michigan and sewage effluent from Chicago to the Illinois River. The diversion ranged from 82.1 cubic meters per second (cms) (2,900 cubic feet per second—cfs) in 1900 to 283.4 cms (10,010 cfs) in 1928; from 1900 to 1938, it averaged 204.5 cms (7,222 cfs). A U.S. Supreme Court decree limited diversion to 42.5 cms (1,500 cfs) after 1938, but a second decree in 1961 increased the rate to 90.6 cms (3,200 cfs).

Yearly water profiles at Peoria, 1868–1975, show that low-water levels climbed from 131.7 m (432 ft) mean sea level (msl) in 1899 to 132.1 m (433.5 ft) in 1900 and 133.2 m (436.9 ft) in 1902. Until the Peoria lock and dam became operational in 1938, low-water levels averaged about 133.5 m (438.0 ft) msl. The diversion of water into the Illinois River appears to have increased low-water levels at Peoria between 1.5 and 1.8 m (5 and 6 ft). Forbes & Richardson (1919:140–141) concluded that midsummer levels at Havana rose an average of 1.1 m (3.6 ft) above prediversion averages.

The diversion caused the flooding of thousands of hectares of bottomland forest during the growing season, killing the trees and enlarging the backwater lakes. Pin oaks and pecans, which had grown extensively in the valley below Peoria, were especially vulnerable to higher water. Their loss greatly reduced the mast food supply for mallards and wood ducks.

Overall, though, waterfowl benefited from the diversion of Lake Michigan water as the surface areas of lakes, sloughs, and marshes doubled. Prior to diversion, about 21,850 ha (54,000 acres) were in bottomland water areas, exclusive of the river channel. The diversion of Lake Michigan water expanded bottomland lakes and marshes to slightly over 48,560 ha (120,000 acres) in the 161,878-ha (400,000-acre) floodplain.

This expanded water area did not persist long but shrank due to man's next alteration of the Illinois River valley. Levee and drainage districts, largely initiated between 1903 and 1920, placed 82,962 ha (205,000 acres) of bottomland behind levees (Mulvihill & Cornish 1929). Natural lakes and marshes within the leveed tracts were drained. The land in three drainage districts—Partridge, Chautauqua, and Big Prairie, aggregating 3,238 ha (8,000 acres)—was not farmed successfully and reverted to a seminatural state (Fig. 2). Ironically, this drainage district loss increased the lake and marsh surface area to about 28,329 ha (70,000 acres), more than the prediversion 21,854 ha (54,000 acres). Irretrievably lost to waterfowl were the pin oak and pecan groves that had provided important food resources during floods.

At the same time that Illinois Valley lakes were being altered by the creation of levees and drainage districts, the aquatic biota was being threatened by yet another serious menace—that of urban wastes discharged into the Illinois River. Although a small amount of pollution had occurred before 1900, the opening of the Chicago Sanitary and Ship Canal in 1900 created a problem of catastrophic proportions for the river and its backwater lakes above Peoria (Mills et al. 1966). At first only the extreme upper reaches (above Marseilles) were affected. However, the zone of pollution steadily moved downstream until by 1922 the upper Illinois was essentially a dead river, devoid of important aquatic life as far south as Chillicothe (Mills et al. 1966).

Extensive beds of pondweeds, wild celery, and coontail, present in Peoria Lake between 1910 and 1914, had largely disappeared by 1920 (Richardson 1921). In 1921, Peoria Lake contained slight growths of pondweeds and algae, so little as to be overlooked by the casual observer (Purdy 1930).

A decline in urban and industrial pollution began with the operation of treatment plants by the Chicago Sanitary District in 1922. Pollution control was aided by the navigation dams that became operational in the upper river in 1933. These dams reduced the rate of flow, thereby resulting in bacterial decomposition of waste products within a shorter distance downstream. A gradual reduction in the urban pollution of the Illinois River has continued to the present time (Richard Sparks, Illinois Natural History Survey, personal communication).

The 9-foot (2.7-m) waterway for navigation became operational above the Starved Rock lock and dam in 1933 and below that point in 1938. The waterway below Starved Rock was created by dredging the channel deeper and raising the water levels by dams at Peoria, below Beardstown, and on the Mississippi River at Alton.

Even as the urban and industrial pollution abated, the Illinois River and its lakes were subjected to yet another degradation, that of pollution from sedimentation. The permanent and insidious nature of silt pollution makes it more harmful than urban pollution: although not as apparent, it is accumulative.

This report examines the role of

Fig. 2.—A portion of the abandoned Partridge Levee District located at the northern end of Upper Peoria Lake across from Chillicothe, showing a leveed area (center) dewatered for moist-soil plant development.

sedimentation in the Illinois Valley: its effects on aquatic, marsh, and moist-soil plants and its effects upon waterfowl abundance.

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Dr. David L. Gross, Illinois State Geological Survey, reviewed the section on Geological History and made pertinent suggestions. Dr. Vernon Wright, formerly with the Illinois Department of Conservation, provided guidance in the statistical analyses.

Forrest Loomis, now with the Illinois Department of Conservation, conducted field studies and made vegetation maps of bottomland lakes, 1955–1957.

Drs. Leigh Frederickson of the University of Missouri and David Trauger of the U.S. Fish and Wildlife Service reviewed the paper and offered suggestions for improvement.

A number of Illinois Natural His-

tory Survey staff members contributed to this paper: Lloyd LeMere, Technical Illustrator, drew the graphs. Dr. Glen C. Sanderson, Head, Section of Wildlife Research, Mrs. Eva Steger, and Harold Henderson did preliminary editing. Final editing and preparation of the paper for publication was done by Robert M. Zewadski, Technical Editor.

METHODS

Three diverse aspects of Illinois River habitat were measured for this report: (1) the rate of sedimentation in various bottomland lakes, (2) the abundance and distribution of aquatic, marsh, and moist-soil plants, and (3) the abundance of waterfowl as related to the availability of aquatic and moist-soil vegetation and mollusks (Fig. 3).

SEDIMENTATION

Reports on the sedimentation of three bottomland lakes have been issued by personnel of the Illinois State Water Survey (M. T. Lee. 1976. Sediment deposition of Lake Chautauqua, Havana, Illinois. Unpublished Xeroxed report. M. T. Lee and J. B. Stall. 1976. Sediment deposition in Lake DePue, DePue, Illinois and its implications for future lake management. Unpublished Xeroxed report. M. T. Lee, J. B. Stall, and T. A. Butts. 1976. The 1975 sediment survey of Lake Meredosia, Meredosia, Illinois. Unpublished Xeroxed report). In addition, we made sedimentation studies on these lakes: Senachwine, Sawmill, Billsbach, Sparland, Wightman, Babbs Slough, Upper Peoria, Rice, Chautauqua, Anderson, and Meredosia.

Comparisons between present-day water depths and earlier readings were possible because of soundings conducted in the Illinois Valley in 1902–1904 by J. W. Woermann, Assistant Engineer, Corps of Engineers, U.S. Army. Differences in water depths of lakes, sloughs, and marshes were used to determine the amount of sedimentation that has occurred during an interval of 73–75 years.

Fortunately, at three lakes sedimentation could be separated into two periods during this time span. At Lake Chautauqua, Stall & Melsted (1951) studied sedimentation between 1926 and 1950, and Lee (1976 unpublished) studied it during 1950–1976. The Peoria Project Office, U.S. Army Corps of Engineers, took soundings of Peoria Lake in 1965. These studies enabled us to calculate the sedimentation at Peoria Lake for two periods: 1903–1965 and 1966–1976. Soundings of Meredosia Bay were taken in 1956 by the State Division of Water Resources and by us in February 1978. Sedimentation rates were calculated for the periods 1903–1956 and 1957–1978.

WATER DEPTH

In our 1976 and 1977 soundings, 3–10 transects were established across each lake. Depths along the transects were taken at approximate intervals of 77.7 m (85 yards) except in Upper Peoria Lake, where the interval was 228.6 m (250 yards). The depth of water was related to the river stage (i.e., to the nearest gauge reading adjusted for the slope of the river). From these data the mean sea level (msl) elevation of each lake bottom was derived. The elevations of lake bottoms on the 1902–1904 J. W. Woermann maps were based upon the Memphis Datum (MD). The Memphis Datum was an arbitrary elevation at Memphis, Tenn., used as a reference point in measuring other elevations. The Memphis Datum was converted to msl (1929 general adjustment) by subtracting a correction factor varying from 2.26 to 2.27 m (7.43–7.45 ft) depending upon the location of the bench marks.

The areas of bottomland lakes in the Illinois River valley were determined by using a planimeter to measure the basin areas as delineated by the wooded-vegetation line on the U.S. Army Corps of Engineers 1933 revised series of the Woermann 1902–1904 maps.

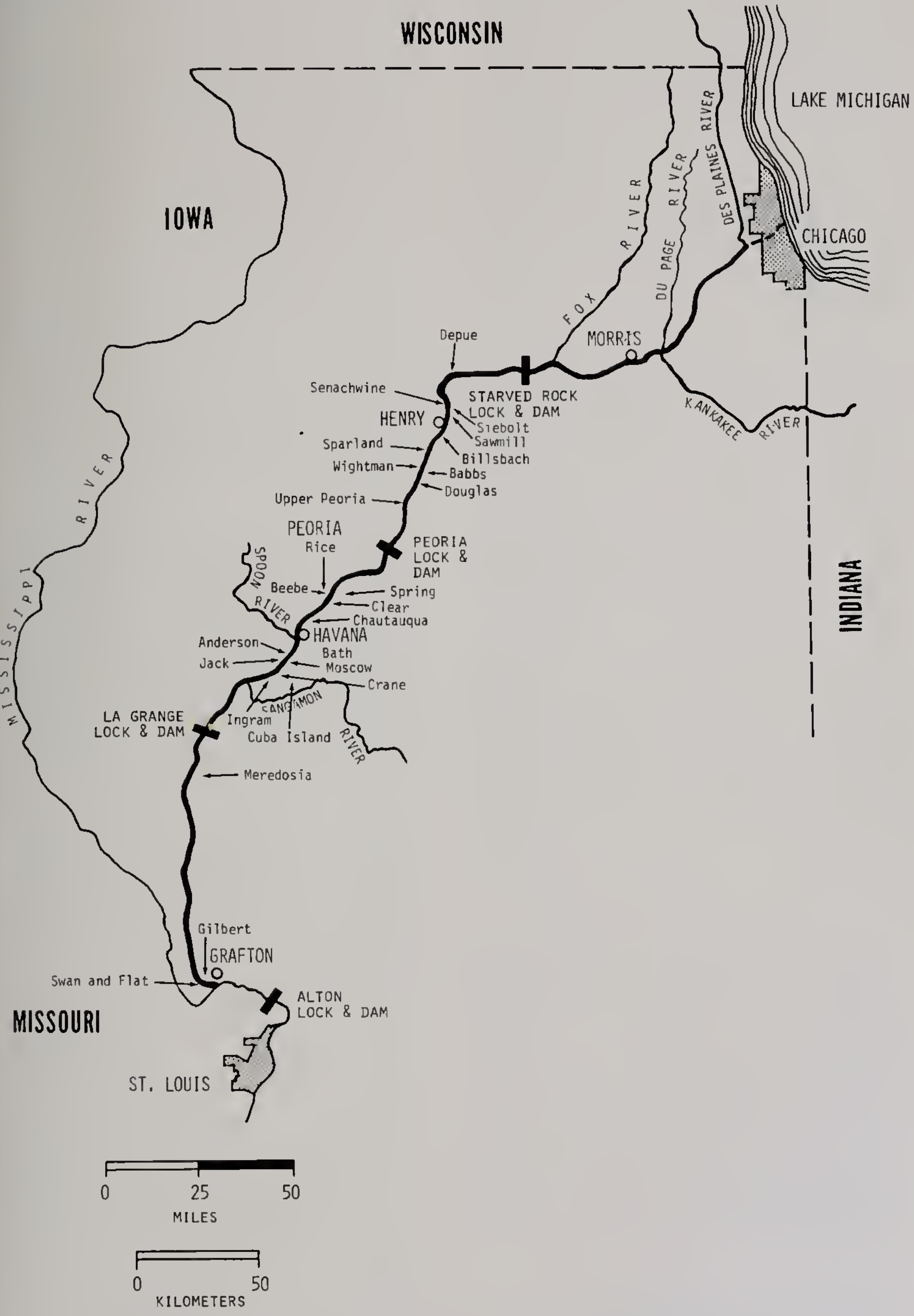

Fig. 3.—Map of the Illinois River valley, showing many of the bottomland lakes included in this study of wetland plants, sedimentation, and waterfowl abundance.

WETLAND VEGETATION

The areas of waterfowl food plants (aquatic, marsh, and moist-soil species) were taken from maps drawn by Frank Bellrose, 1938–1953, and by Forrest Loomis, 1955–1957. Waterfowl food plant beds were plotted by rough triangulation on the base maps provided by the U.S. Army Corps of Engineers 1933 map series scaled 1:12000 (Bellrose 1941). Later vegetation maps prepared for 1959 and 1976 were based upon aerial photographs interpreted by Bellrose.

Mapped plant beds were measured by planimeter to determine their sizes in acres. To weight areas devoid of vegetation, acreages of plants were divided by the acreage of the bottomland lake basin mapped each year to obtain the percentage of the area covered by waterfowl food plants. To compare annual changes in vegetation composition, the abundance of each plant species was determined and related to the entire lake basin. The measured acreage of each lake basin varied slightly from year to year, depending upon the specific area mapped. Recent information on the status of wetland plants on Gilbert and Swan lakes was derived from the files of the Mark Twain National Wildlife Refuge, Quincy, Illinois.

WATERFOWL POPULATIONS

Censuses of waterfowl were taken in the Illinois Valley 1938–1970 by Frank Bellrose and 1971–1976 by Robert Crompton. However, the data are better since 1949, when a light aircraft made it possible to cover the valley completely 1 day each week from 1 October to 1 December. Waterfowl numbers obtained from the weekly censuses were multiplied by seven to obtain the duck-days of use for each fall.

MOIST-SOIL WATER-LEVEL AND WATER-STABILITY INDICES

To evaluate the relationship of river levels to the abundance of wetland plants, a growth-period index was established for wetland plants and a water-level index was established by computing weekly averages from daily water-level gauge readings.

We converted National Oceanic and Atmospheric Administration Environmental Data and Information Service daily gauge readings to weekly averages. Because of the sluggish nature of the river, weekly averages adequately reflect its rise and fall.

The growth-period index was based upon the assumption that the earliest low-water stage that could benefit wetland plants is 12 18 June, the latest, 14–20 August. After that date too few days remain before the average date of the first heavy frost for plants to produce a meaningful amount of seeds. The weeks of this 10-week period were ranked in descending order with the week of 12–18 June ranked 10 and that of 14–20 August ranked 1.

Weekly average gauge readings were assigned water-level index values that increased as the water level receded from the wooded shoreline, exposing an area of lake basin for the development of moist-soil plants. The lower the river level, the larger the assigned water-level index. Water levels at or above the wooded shoreline were designated as 0. The upper limits of the wooded shoreline elevation on the Henry gauge is 135.0 m (443 ft) msl and on the Havana gauge it is 133.2 m (437 ft) msl.

Each water-level index was multiplied by the growth-period index. The resulting products were squared and then totaled for the 10-week period. The result is the Moist-Soil Water-Level Index. The products were squared because the exposure of mud flats is exponentially rather than linearly related to declining water levels. With the exception of Peoria Lake, lake basins of the Illinois River are shallow and platter shaped. Therefore, as water levels decline, an ever larger proportion of the lake basin is exposed as mud flats.

The Moist-Soil Water-Level Index was first compared with the moist-soil vegetation acreage over a 22-year period, 1938–1959, by linear regression. Secondly, the Moist-Soil Water-Level Index was compared by linear regression with the fall duck-day use of Illinois Valley lakes, 1949–1976.

On the other hand, to evaluate the effect of water levels on aquatic and marsh plants, a Water-Stability Index was calculated. A level 0.6 m (2 ft) above the prevailing low-water stage was judged to be optimum for aquatic plants. The absolute values of deviations from this level, based upon weekly gauge averages, were totaled for the growing season. The larger the Water-Stability Index, the more adverse were conditions for aquatic and marsh plant development.

WATERFOWL FOOD RESOURCES

A preliminary report on the waterfowl food resources of the Illinois Valley and the factors affecting them during the 1938–1940 period was made by Bellrose (1941). We present here those findings and others made since then.

From the earlier study (Bellrose 1941) it is apparent that the four most important factors affecting the abundance of duck food plants in bottomland lakes of the Illinois River are (1) fluctuating water levels, (2) turbidity, (3) water depth, and (4) competition by other plants that provide little or no duck food.

In the present study we sought to examine further the effects of each of these factors upon the vegetation of valley lakes, but we also recognize that all of the factors are interrelated. Turbidity stems from sedimentation, which in turn alters water depth and may encourage the growth of some weed species at the expense of more beneficial plants. When the river rises, more sediment is deposited and turbidity increases.

Fluctuating water levels can affect waterfowl habitats in opposite ways. Uncontrolled fluctuations result in minimal development of aquatic, marsh, and moist-soil plants. However, controlled fluctuations can result in highly productive food resources if they occur within the optimum 120-day summer growing period.

Because the degree of control of water levels is so important to the waterfowl food plant resources of the Illinois Valley, we have separated bottomland lakes into four classes according to their association with the river (Table 1):

Class I, areas whose water levels are completely controlled by changing river levels

Class II, areas that are separated from the river at low water stages

Class III, areas that remain separated from the river up to flood stage, when the river begins to overtop its natural banks

Class IV, areas that are above the river's designated flood stage (bank full)

Class III areas are further categorized according to management practices: Class IIIA, areas where water levels are stabilized at an optimum level below flood stage for aquatic and marsh plants, and Class IIIB, areas where the lake is dewatered for optimum production of moist-soil plants.

Under severe flooding all areas but Spring Lake, near Pekin, come under the influence of the river. The entire 520-ha (1,285-acre) basin of Spring Lake is separated from the river by high levees; water control structures added in 1977 will make it possible in the future to manipulate water levels on 261 ha (645 acres) of Spring Lake.

Other wetlands are separated to varying degrees from the influence of the river, either because of the elevation and formation of their basins, or because low levees isolate the areas. Low levees have been built by private duck clubs, the Illinois Department of Conservation, and the U.S. Fish and Wildlife Service to provide some low-level water control on wetlands under their respective ownerships. Most of the structures isolating the river waters are no higher than the natural banks of the river. Pumps are frequently employed to assist in the dewatering and reflooding of impounded wetlands.

Table 1.—Surface areas of Illinois River valley lakes in relation to the degree of separation from the influence of the river, 1977.[a] Figures are in hectares (2.471 acres/hectare).

Bottomland Lakes	Total Area	Class I (river control)	Class II (slight control)	Class III (moderate control)	Class IV (maximum control)
		Peoria Pool			
Banner Hill-Utica Pond	11.0	...	...	11.0	...
Split Rock Lakes	72.8	...	...	72.8	...
Huse Lake	19.7	...	19.7	...	...
Huse Slough and Pond	31.8	31.8	...	...	...
Treetop & Sadnick's lakes	23.1	...	23.1	...	...
Mud Lake area	33.8	...	33.8	...	...
River Mile 216–217	26.3	26.3	...	...	...
Turner Lake	140.9	...	140.9	...	...
Depue Lake & Hicks Slough	248.1	242.0	...	6.1	...
Lyons Lake	13.7	...	13.7	...	...
Spring Lake	238.2	125.7	...	112.5	...
Coleman Lake	52.6	...	...	52.6	...
North Hennepin area	38.4	...	...	38.4	...
Goose Pond	697.2	575.8	...	121.4	...
Senachwine Lake & Hunter's Slough	1,865.2	1,708.2	124.6	32.4	...
Siebolt Lake (French Slough)	178.0	...	80.9	97.1	...
Big Spring area	20.2	...	...	20.2	...
Sawmill Lake	309.3	309.3	...	...	...
Mud Lake	26.4	26.4	...	...	...
Town Lake area & Whitney Lake	37.6	7.2	...	30.4	...
Merdian Slough	19.3	19.3	...	...	...
Billsbach Lake	454.1	429.4	...	24.7	...
Weis Lake	132.9	132.9	...	...	...
Sparland Lake (Goose Lake)	451.9	451.9	...	...	...
Fisher's Slough	147.0	147.0	...	...	...
Sawyer Slough	200.0	200.0	...	...	...
Wightman Lake	258.2	258.2	...	...	...
Babbs Slough	777.2	777.2	...	...	...
Big Meadow Lake	274.6	274.6	...	...	...
Chillicothe Island	8.1	...	...	8.1	...
Douglas Lake–Rice Pond	912.6	323.7	...	588.9	...
Goose Lake	832.4	809.3	...	23.1	...
Upper Peoria Lake	3,738.9	3,725.1	...	13.8	...
Lower Peoria Lake	1,044.7	1,044.7	...	...	...
Beesaw Lake	77.0	77.0	...	...	...
		La Grange Pool			
Long Lake & Mud Lake area	197.8	197.8	...	...	...
Pekin Lake area	290.2	...	290.2	...	...
Boot Jack Lake area	105.8	105.8	...	...	...
Kingston Lake area	30.9	30.9	...	...	...
Spring Lake	520.0	...	...	...	520.0
Pond Lily Lake	28.3	...	...	28.3	...
Rice & Miserable lakes	661.2	...	...	539.8	121.4
Beebe Lake (Big Lake)	583.5	...	547.1	36.4	...
Goose Lake	333.1	...	214.1	119.0	...
Clear Lake	936.6	...	936.6	...	...
Chautauqua Lake	1,560.9	...	1,560.9	...	...
Liverpool Lake	74.7	74.7	...	...	...
Quiver Lake	112.2	112.2	...	...	...
Horseshoe Lake	9.5	9.5	...	...	...
Matanzas Bay area	197.1	...	175.2	21.9	...
Bath Lake	59.6	10.2	...	49.4	...

The arrangement of levees often separates wetlands into more than one category. Through the years 1938–1977, the percentage of the lake basins

Table 1.—Continued

Bottomland Lakes	Total Area	Class I (river control)	Class II (slight control)	Class III (moderate control)	Class IV (maximum control)
Moscow Lake	107.8	81.1	...	26.7	...
Grand Island: Grass, Goose, & Jack lakes	711.4	72.0	639.4	...	...
Anderson Lake	635.4	...	...	635.4	...
Patterson & Matthews bays	73.3	43.8	...	29.5	...
Snicarte Island area	45.8	...	...	45.8	...
Chain & Slim lakes	284.4	284.4	...	...	...
Stewart Lake	566.7	323.9	...	242.8	...
Ingram Lake	440.6	...	...	360.3	80.3
Crane & Pin Oak lakes	468.0	...	320.5	22.0	125.5
Rainbow Gun Club	69.6	...	...	69.6	...
Long Lake	60.1	...	...	60.1	...
Hickory Island	29.1	29.1	...	...	...
Sanganois Conservation Area	485.6	...	...	485.6	...
Cuba Island	594.1	...	...	594.1	...
Sangamon Bay	114.5	114.5	...	...	...
Treadway Lake	275.4	259.2	...	16.2	...
Sugar Creek Lake	74.6	74.6	...	...	...
Coleman's Lake	49.6	...	49.6	...	...
Big & Little lakes	63.0	63.0	...	...	...
Wood Slough	186.4	180.3	...	6.1	...
Muscooten Bay & Hager Slough	311.8	311.8	...	...	...
York Lake	159.0	159.0	...	...	...
South Beardstown Lake, River Mile 84	99.1	99.1	...	...	...
Big Prairie area	275.0	...	275.0	...	...
		Alton Pool			
Meredosia Lake area	655.1	...	588.1	67.0	...
Atkinson Lake	116.6	116.6	...	...	...
Barlow Lake	20.0	20.0	...	...	...
Smith Lake	71.1	...	71.1	...	...
Allens Lake	80.9	80.9	...	...	...
McCoe Lake	14.6	14.6	...	...	...
Jack Ellis Lake	7.7	7.7	...	...	...
Prairie Lake	8.9	8.9	...	...	...
Michael Lake	10.1	...	...	10.1	...
Hurricane Island	16.2	...	...	16.2	...
Godar's Swamp	36.4	...	...	36.4	...
Diamond Island	105.2	...	...	105.2	...
Helmbold Slough	27.9	...	...	27.9	...
The Glades area	78.1	...	...	78.1	...
Twelve Mile Island	8.1	...	...	8.1	...
Stump Lake area	494.1	...	...	494.1	...
Gilbert Lake	83.8	...	...	83.8	...
Swan Lake area	1,143.2	1,017.7	...	125.5	...
Calhoun National Wildlife Refuge	78.5	...	...	...	78.5
Calhoun Point	161.1	66.0	...	95.1	...
		Totals			
Peoria Pool	13,413.2	11,723.0	436.7	1,253.5	0.0
La Grange Pool	11,881.7	2,636.9	5,008.6	3,389.0	847.2
Alton Pool	3,217.6	1,332.4	659.2	1,147.5	78.5
Totals	*28,512.5*	*15,692.3*	*6,104.5*	*5,790.0*	*925.7*
Percentages	...	*55.04*	*21.41*	*20.31*	*3.25*

[a] Areas were obtained by measuring lake basins with a planimeter on U.S. Army Corps of Engineers (1933) map series of the Illinois River valley.

associated with the river has changed as some levees have been destroyed by floods and as others have been newly constructed. Table 1 shows the waters in the four categories of control as of the summer of 1977. However, for purposes of evaluating wetland vegetation in association with water levels, the degree of water level control at the time of the study is discussed. Local alterations in water level were made on certain lakes during this period, complicating their evaluation.

RIVER LEVELS

Three navigation dams, at Peoria, La Grange, and Alton, influence water levels, and thus bottomland lakes, in the Illinois River valley. These dams began operation late in 1938 and have influenced river levels and vegetation from the 1939 growing season to the present.

Although the Alton dam is on the Mississippi River 24.1 km (15 miles) below the mouth of the Illinois River, its navigational influence extends 128.7 km (80 miles) up the Illinois to the La Grange lock and dam. Similarly, the La Grange navigation pool extends 125.5 km (78 miles) to the Peoria lock and dam, and the Peoria navigation pool extends 117.5 km (73 miles) to the Starved Rock lock and dam near Utica. Other navigation dams—Marseilles, Dresden Island, Brandon Road, and Lockport—form additional navigation pools upstream, but they are only of incidental concern in this report.

Because of its great height, which resulted in raising the river level 8.4 m (27.7 ft), the Alton dam has had the most influence on the water levels of lakes upstream from the mouth of the Illinois River. Both La Grange and Peoria are low-level dams, 3.0 m (10 ft) and 3.4 m (11 ft), respectively, and have had relatively minor effects upon river levels. Of course, as with all dams, their greatest control over river levels is at the dam site, and their influence upstream declines according to their height and the rate of fall of their pools. River control progressively declines to the tailwaters of the next dam upstream, where water levels behave about as they did in preimpoundment days.

As far as we can ascertain, the Alton dam has little influence over river levels above Pearl, the La Grange dam above Havana, and the Peoria dam above Henry. One reason that they appear to have had so little influence on present-day water levels is that when they became operational in 1938 the diverted flow of water from Lake Michigan into the Illinois River was reduced from 141.6 cms (5,000 cfs) to 42.5 cms (1,500 cfs). In 1961, the discharge was raised to 90.6 cms (3,200 cfs). Both the Havana and Henry gauges are about midway in their respective navigation pools, and they thus provide the best record of changing water levels that influence wetland plants.

We consider the period 15 June–12 October to be the most favorable season for the development of marsh, aquatic, and moist-soil plants. An earlier period would be still better for aquatics, but the earlier the date, the less likely is low water, because of spring floods. The minimum period of dewatering (between 15 June and 12 October) within which moist-soil plants can produce mature seed (although not at top yields) is 70 days.

A review of river levels at Henry, 1938–1976, shows that during the period 15 June–12 October seasonal means ranged from 1.2 to 2.3 m (3.8–7.5 ft) (Table 2). Downstream at Havana during the same period, seasonal means ranged more widely, from 1.8 to 3.6 m (5.9–11.9 ft) (Table 2). This greater fluctuation results from large tributary streams adding their sizeable discharges to the Illinois River between Peoria and Havana.

The weekly mean gauge records for 15 June–12 October were averaged for each year, and standard deviations were computed. The lower the mean and its standard deviation, the more mud flats were exposed, and the longer

Table 2.—Water level fluctuations (in meters) in the Illinois River at two stations between 15 June and 12 October, 1938–1976.

Year	Henry Gauge[a]			Havana Gauge[b]		
	Seasonal Mean	SD	Range[c]	Seasonal Mean	SD	Range
1938	1.57	0.71	2.25	3.23	0.70	2.04
1939	1.25	0.12	0.55	2.19	0.62	1.68
1940	1.17	0.04	0.15	1.83	0.24	0.97
1941	1.32	0.41	1.74	2.18	0.72	2.83
1942	1.27	0.14	0.64	2.46	0.46	1.43
1943	1.49	0.55	2.13	2.67	1.14	3.99
1944	1.31	0.05	0.18	2.08	0.43	1.61
1945	1.44	0.21	0.76	2.74	0.87	2.83
1946	1.40	0.40	1.37	2.40	1.00	2.93
1947	1.50	0.61	2.29	2.65	1.39	4.08
1948	1.27	0.15	0.67	2.17	0.48	1.65
1949	1.23	0.11	0.40	2.14	0.40	1.19
1950	1.51	0.37	1.19	2.76	0.92	2.59
1951	1.68	0.75	2.41	3.15	1.12	3.20
1952	1.48	0.57	1.86	2.61	0.97	2.86
1953	1.28	0.19	0.70	2.13	0.58	1.95
1954	1.40	0.33	1.37	2.32	0.57	2.25
1955	1.40	0.36	1.28	2.25	0.64	2.32
1956	1.26	0.12	0.46	1.96	0.29	0.88
1957	1.61	0.58	2.29	2.56	1.02	2.77
1958	2.02	0.82	2.38	3.22	1.29	2.99
1959	1.26	0.09	0.37	1.96	0.30	1.16
1960	1.45	0.38	1.19	2.56	1.05	3.02
1961	1.56	0.61	2.16	2.62	1.03	3.29
1962	1.39	0.16	0.49	1.81	0.50	1.61
1963	1.26	0.10	0.33	1.83	0.19	0.76
1964	1.28	0.09	0.37	2.00	0.45	1.86
1965	1.45	0.24	0.91	2.50	0.77	2.22
1966	1.26	0.08	0.33	1.97	0.46	1.89
1967	1.34	0.17	0.64	2.24	0.57	1.74
1968	1.60	0.54	1.83	2.40	0.84	2.71
1969	1.59	0.29	0.76	2.81	0.86	2.41
1970	2.05	0.81	2.35	3.43	1.25	3.38
1971	1.37	0.09	0.46	2.00	0.23	0.88
1972	2.27	0.48	1.58	3.64	0.51	2.10
1973	1.75	0.71	2.32	2.94	1.24	3.63
1974	2.01	1.22	3.41	3.15	1.92	5.33
1975	1.65	0.61	2.01	2.63	0.99	2.86
1976	1.37	0.14	0.52	2.04	0.47	1.65

[a] On the Henry gauge O = 130.81 m (429.19 ft) msl.
[b] On the Havana gauge O = 129.31 m (424.28 ft) msl.
[c] Range is the difference between extremes.

they were exposed. Extreme means in weekly water levels attest (in most cases) to the wide range in river levels during the growing season. Because of the navigation dams, minimum levels were relatively constant from year to year; high water caused the wide range above the means. The Peoria and La Grange navigation dams combined with diverted water to stabilize the low-water profile of the river. Low-water records at Peoria, 1902–1938, averaged 133.4 m (437.5 ft) with a standard deviation of 0.3 m (1.1 ft); from 1939 to 1975, the elevation averaged 133.8 m (439.0 ft) with a standard deviation of only 0.1 m (0.3 ft).

WETLAND VEGETATION

Although Illinois Valley lakes have many similarities in gross appearance, subtle differences occur among them. Consequently, a classification system for the lakes is difficult to develop, but to facilitate our discussion, we use the following groups.

The lakes are grouped according to their water-level stability (Classes I–IV) and by periods: 1938–1942, 1943, and 1944–1959. The highest flood on record occurred during May and June of 1943. We sought to determine the effect of this tremendous flood on wetland vegetation both in the year it occurred and in following years.

Table 3 lists the areas covered by wetland plants in six lakes connected with the river at all stages (Class I) from 1938 to 1942. River bulrush was the most abundant species, covering an average of 7.3 percent of the lake basins; American lotus averaged 6.1 percent; and marsh smartweed and duck potato each had about 2 percent. Other wetland species were of only minor occurrence, and all species together covered only 24.2 percent of the lake basins.

Average areas covered by wetland plants in six lakes that were separated from the river by barriers at moderately low stages (Class II) are shown in Table 4. Many of the plant species in these lakes belong to an ecological com-

Table 3.—The average abundance by area of wetland plants in bottomland lakes connected with the Illinois River at all water stages (Class I), 1938–1942. Figures are in hectares (2.471 acres/hectare).

Species	Sawmill 1938–1941[a]	Sparland 1939–1941	Babbs 1941–1942	Quiver 1938–1941	Treadway 1938–1941	Muscooten 1938–1941	Total Average Hectares per Year in Vegetation[b]	Percent of Basin in Vegetation
Cattail	...	...	...	...	0.3	1.8	2.1	0.1
Giant bur-reed	...	...	...	...	2.4	4.5	6.9	0.3
Longleaf pondweed	...	...	0.9	trace	1.1	13.1	15.1	0.7
Leafy pondweed	...	...	...	...	...	0.1	0.1	trace
Sago pondweed	15.0	0.3	0.7	0.6	3.1	1.4	21.1	0.9
Southern naiad	...	...	...	...	...	0.1	0.1	trace
Duck potato	0.8	...	5.4	4.0	21.7	13.8	45.7	2.0
Waterweed	...	...	6.2	0.1	...	...	6.3	0.3
Rice cutgrass	...	...	...	0.9	...	0.7	1.6	0.1
Wild millet	...	...	...	5.3	...	...	5.3	0.2
Nutgrasses	0.5	...	...	9.1	...	...	9.6	0.4
American bulrush	...	...	...	1.4	...	...	1.4	0.1
Hardstem bulrush	...	...	...	...	0.3	...	0.3	trace
River bulrush	48.7	17.7	95.6	0.4	0.4	2.2	165.0	7.3
Spike rush	0.1	...	...	2.1	5.6	0.5	8.3	0.4
Duckweeds	4.0	...	40.3	...	...	...	44.3	2.0
Pickerel weed	...	0.4	...	...	...	...	0.4	trace
Water stargrass	...	...	0.1	...	...	1.0	1.1	0.1
Marsh smartweed	2.0	11.6	0.4	0.8	5.7	25.9	46.4	2.1
Nodding smartweed	...	1.0	...	...	...	...	1.0	trace
Water hemp	...	...	...	8.7	...	...	8.7	0.4
Coontail	...	...	13.6	trace	...	0.3	13.9	0.6
American lotus	24.0	...	...	...	30.1	84.3	138.4	6.1
Marsh mallow	0.2	1.1	...	...	...	...	1.3	0.1
Total vegetation	*95.3*	*32.1*	*163.2*	*33.4*	*70.7*	*149.7*	*544.4*	...
Lake basin area	398.6	419.3	339.9	212.5	253.7	628.1	2,252.1	...
Vegetation percentage	23.9	7.7	48.0	15.7	27.9	23.8	24.2	...
Open-water percentage	76.1	92.3	52.0	84.3	72.1	76.2	75.8	...

[a] Averages for the time period involved.
[b] Sum of the averages of all lakes.

Table 4.—The average abundance by area of wetland plants in bottomland lakes separated from the Illinois River at low-water stages (Class II), 1938–1942 and 1944–1959. Figures are in hectares (2.471 acres/hectare).

Species	Siebolt		Beebe		Clear		Anderson		Jack		Crane		Hectares[b] in Vegetation		Percent of Basin in Vegetation	
	1938–1942[a]	1956	1938–1942	1956	1938–1942	1944–1959	1938–1939	1955–1959	1938–1942	1956, 1959	1938–1941	1955, 1956	1938–1942	1944–1959	1938–1942	1944–1959
Giant bur-reed	...	...	0.2	...	...	...	...	...	...	...	...	...	0.2	...	trace	...
Longleaf pondweed	...	...	2.5	...	2.0	0.3	...	0.1	trace	...	trace	1.5	4.5	1.9	0.2	0.1
Sago pondweed	23.2	12.6	trace	...	30.8	31.0	...	1.6	5.2	32.6	0.7	66.6	59.9	144.4	2.0	4.9
Southern naiad	...	...	...	...	1.8	...	...	...	...	...	...	...	1.8	...	0.1	trace
Arrowleaf	...	...	...	...	22.9	29.8	...	...	...	...	...	24.2	22.9	54.0	0.8	1.8
Duck potato	0.1	...	trace	...	10.3	105.4	...	...	...	...	0.8	6.2	11.2	111.6	0.4	3.8
Wild rice	...	...	0.6	...	...	...	...	...	...	...	...	...	0.6	...	trace	...
Waterweed	...	...	...	...	0.3	...	...	...	...	...	...	...	0.3	...	trace	...
Teal grass	...	...	...	...	0.3	3.6	...	...	...	...	...	2.6	0.3	6.2	trace	0.2
Rice cutgrass	3.2	...	...	...	17.1	9.4	...	...	...	...	0.5	0.7	20.8	10.1	0.7	0.4
Wild millet	...	...	...	...	56.8	1.8	...	...	...	...	3.9	5.2	60.7	7.0	2.1	0.2
Japanese millet	...	96.8	...	...	...	6.6	...	...	...	59.6	3.2	10.9	3.2	173.9	0.1	5.9
Walter's millet	...	...	...	...	8.3	22.4	...	0.2	...	...	0.1	2.6	8.4	25.2	0.3	0.9
Nutgrasses	0.2	...	...	...	19.8	36.4	...	...	...	...	9.1	5.5	29.1	41.9	1.0	1.4
River bulrush	22.3	44.6	111.9	47.1	5.9	29.3	...	...	...	3.3	38.0	3.6	178.1	127.9	6.1	4.4
Spike rush	...	...	...	...	12.3	...	...	...	...	...	...	...	12.3	...	0.4	...
Duckweeds	12.1	12.6	3.3	...	...	...	...	...	5.7	...	...	...	21.1	12.6	0.7	0.4
Pickerel weed	...	...	0.7	...	...	...	...	...	...	...	...	...	0.7	...	trace	...
Nodding smartweed	...	...	...	...	41.0	4.0	...	...	...	...	0.1	...	41.1	4.0	1.4	0.1
Marsh smartweed	0.2	...	13.3	24.0	...	13.9	73.6	63.8	48.3	51.9	6.9	2.3	142.3	155.9	4.9	5.3
Largeseed smartweed	...	...	...	...	23.4	0.4	...	...	...	...	0.2	...	23.6	0.4	0.8	trace
Water hemp	...	...	...	...	124.5	64.9	...	...	0.3	41.2	19.9	8.4	144.7	114.5	4.9	3.9
Coontail	0.1	...	64.1	...	...	...	0.8	175.9	19.9	...	0.6	34.2	85.5	210.1	2.9	7.2
American lotus	...	...	179.0	328.8	...	...	58.1	51.8	170.3	...	91.3	123.1	498.7	503.7	17.0	17.2
Cocklebur	...	...	...	...	...	6.5	...	...	...	...	...	0.6	...	7.1	...	0.2
Spanish needles	1.0	...	...	...	...	0.4	...	...	...	...	...	...	1.0	0.4	trace	trace
Total vegetation	*62.4*	*166.6*	*375.6*	*399.9*	*377.5*	*366.1*	*132.5*	*293.4*	*249.7*	*188.6*	*175.3*	*298.2*	*1,373.0*	*1,712.8*	...	...
Lake basin area	208.4		484.0		938.5		371.5		469.0		458.9		2,930.3			
Vegetation percentage	29.9	79.9	77.6	82.6	40.2	39.0	35.7	79.0	53.2	40.2	38.2	65.0	46.8	58.4	46.8	58.4
Open-water percentage	70.1	20.1	22.4	17.4	59.8	61.0	64.3	21.0	46.8	59.8	61.8	35.0	53.2	41.6	53.2	41.6

[a] Averages for the time period involved.
[b] Sum of the averages of all lakes.

Fig. 4.—Extensive mud flats exposed on the west shore of Lake Chautauqua (Class II) a few miles north of Havana. Mud flats like these are colonized by plant species that belong to an ecological community termed moist-soil plants.

Fig. 5.—Lush stands of moist-soil plants at Spring Lake. These stands occurred when mud flats were exposed early during the summer growing season, 1978.

Table 5.—The average abundance by area of wetland plants in bottomland lakes isolated from the Illinois River at levels below flood stage (Class IIIA) in three periods, 1938–1942, 1943, and 1944–1959. Figures are in hectares (2.471 acres/hectare).

Species	Upper Douglas		Rice			Chautauqua			Cuba Island			Total Hectares[b] in Vegetation		Percent of Basin in Vegetation	
	1938–1942[a]	1950, 1956, 1959	1938–1942	1943	1944, 1950, 1953, 1955–1957	1938–1942	1943	1944, 1946, 1955, 1956, 1959	1938–1942	1943	1950, 1955, 1956	1938–1942	1944–1959	1938–1942	1944–1959
Giant bur-reed	...	...	1.6	...	...	trace	...	...	...	...	...	1.6	...	trace	...
Longleaf pondweed	trace	...	0.1	...	...	74.4	...	...	...	...	...	74.5	...	2.6	...
Leafy pondweed	...	...	...	...	...	7.0	...	0.2	...	...	0.1	7.0	0.3	0.2	trace
Sago pondweed	0.7	...	...	...	9.2	133.4	...	269.9	...	...	trace	134.1	279.1	4.6	9.6
Southern naiad	0.1	...	...	...	...	4.5	...	...	...	...	...	4.6	...	0.2	...
Duck potato	5.2	...	...	...	0.1	11.1	...	2.6	...	...	4.3	16.3	7.0	0.6	0.2
Waterweed	0.9	...	3.4	...	...	0.6	...	...	...	...	...	4.9	...	0.2	...
Rice cutgrass	...	...	...	...	0.6	...	...	...	11.2	...	74.9	11.2	75.5	0.4	2.6
Wild rice	14.4	0.5	3.8	...	0.1	...	...	...	...	...	...	18.2	0.6	0.6	trace
Duck millet	...	1.5	...	...	0.2	...	...	trace	...	...	4.2	...	5.9	...	0.2
Walter's millet	...	...	...	...	...	...	...	8.3	...	...	0.2	...	8.5	...	0.3
Nutgrasses	...	12.7	...	...	0.2	...	...	5.8	...	...	...	...	18.7	...	0.6
River bulrush	358.1	277.5	146.0	118.3	26.5	8.8	2.4	...	...	...	0.9	512.9	304.9	17.6	10.4
Duckweeds	2.7	1.5	35.4	...	...	...	...	...	0.8	...	...	38.9	1.5	1.3	trace
Pickerel weed	13.8	...	6.6	...	0.3	...	...	...	...	...	...	20.4	0.3	0.7	trace
Marsh smartweed	25.0	...	11.6	31.4	20.9	51.4	34.4	21.8	73.9	135.2	8.7	161.9	51.4	5.6	1.8
Swamp smartweed	1.8	...	...	...	...	...	...	...	5.1	1.6	...	6.9	...	0.2	...
Coontail	34.5	...	31.2	191.4	150.3	81.3	2.8	...	5.5	...	22.3	152.5	172.6	5.2	5.9
White water lily	17.0	2.5	0.4	5.9	23.4	...	3.2	...	...	...	...	17.4	25.9	0.6	0.9
American lotus	31.2	43.8	82.4	4.2	25.7	54.2	143.0	33.4	76.7	12.5	9.5	244.5	112.4	8.4	3.8
Total vegetation	*505.4*	*340.0*	*322.5*	*351.2*	*257.5*	*426.7*	*185.8*	*342.0*	*173.2*	*149.3*	*125.1*	*1,427.8*	*1,064.6*	...	
Lake basin area	671.0	671.0	382.8	382.8	382.8	1,436.7	1,436.7		427.4	427.4	427.4	2,917.8	2,917.8	...	
Vegetation percentage	75.3	50.7	84.2	91.7	67.3	29.7	12.9	23.8	40.5	34.9	29.3	48.9	36.5	48.9	36.5
Open-water percentage	24.7	49.3	15.8	8.3	32.7	70.3	87.1	76.2	59.5	65.1	70.7	51.1	63.5	51.1	63.5

[a] Averages for the time period involved.
[b] Sum of the averages of all lakes.

munity associated with mud flats, and are termed moist-soil plants (Fig. 4 and 5). These plants include: teal grass; rice cutgrass; wild, Japanese, and Walter's millet; nutgrasses; nodding and largeseed smartweed; water hemp; cockleburs; and Spanish needles. They covered 11.3 percent of the lake basins in 1938–1942, and 13.3 percent in 1944–1959. In contrast, the moist-soil species present in Class I lakes (Table 3) were limited to rice cutgrass, wild millet, nutgrasses, nodding smartweed, and water hemp; they aggregated a mere 1.1 percent of those lake basins from 1938 to 1942.

Arrowleaf covered averages of 0.8 and 1.8 percent of the Class II lake basins in 1938–1942 and 1944–1959, respectively. In both Class I and Class II lakes river bulrush covered almost the same average proportion of lake basins (7.3 and 5.3 percent, respectively), but American lotus expanded its coverage from 6.1 percent in Class I lakes to 17.1 percent in Class II lakes. Increases also occurred in the areas covered by aquatic pondweeds, southern naiad, waterweed, and coontail: they totaled 5.2 percent of Class II lake basins, 1938–1942, and 12.2 percent, 1944–1959, up from 2.5 percent present during the former period in Class I lakes. From 1938 to 1942 marsh smartweed more than doubled in abundance in Class II over Class I lakes, but duck potato was less abundant (probably because of competition with marsh smartweed). All wetland plants covered 46.8 percent of Class II lakes in 1938–1942, and 58.4 percent in 1944–1959.

Class III lakes are only affected by river levels when flood waters top the natural banks that lie between lake and river. Four lakes in Class IIIA were studied during 1938–1959 (Table 5). Species of wetland plants in Class IIIA lakes were similar to those found in Class II lakes; moreover, the proportion of wetland vegetation in the lake basins was similar to the percentage (46.8) in Class II lakes during the first period (48.9 percent) but was less in the second period (36.5 percent).

However, there were pronounced differences in the relative abundance of certain species of plants between Class IIIA and Class II lakes. Pondweeds, southern naiad, and waterweed were more abundant in Class IIIA lakes, covering 7.8 percent of the lake basins in 1938–1942, and 9.6 percent in 1949–1959, compared with 2.3 and 5.0 percent, respectively, in Class II lakes (Fig. 6). Coontail was more abundant in Class IIIA lakes than in Class II lakes during the first period but was less abundant in the Class IIIA lakes than in Class II lakes during the second period (Table 5). Wild rice and pickerel weed, unusual marsh plants in Illinois, were noticeably present prior to the 1943 flood. River bulrush was also proportionately more abundant in Class IIIA lakes than in lakes of the other classes.

Moist-soil plants were almost absent (0.6 percent) from Class IIIA lakes during the first period and of slight abundance during the second period (3.7 percent), much less than in Class II lakes.

Class IIIB lakes must be dewatered by 1 August in central Illinois to produce moist-soil plants consistently. Otherwise, the growing season is too short for the plants to mature and produce an abundant seed crop. Dewatering by 15 July provides a still more favorable growing period. Prolonged spring floods may make dewatering infeasible in certain years, and midsummer floods may wipe out moist-soil plants well along in growth. Some floods occur so late that the time remaining in the growing season is too short for the development of another plant generation.

Table 6 shows wetland vegetation areas, averaged for a number of years, at three Class IIIB lakes. Moist-soil species covered 41.7 percent of the lake

Fig. 6.—Abundant growth of aquatic plants, primarily coontail, present in Rice Lake (Class IIIA) during the summer of 1953

Table 6.—The average abundance by area of wetland plants in bottomland lakes separated from the Illinois River at levels below flood stage and intensively managed by dewatering (Class IIIB), 1946–1959. Figures are in hectares (2.471 acres/hectare).

Species	Bath	Moscow	Ingram	Hectares in Vegetation per Year[b]	Percent of Basin in Vegetation
	1946–1949[a]	1946, 1950, 1955, 1956, 1959	1955, 1956, 1959		
Longleaf pondweed	...	...	0.4	0.4	0.1
Sago pondweed	...	...	0.1	0.1	trace
Arrowleaf	...	...	8.0	8.0	1.3
Duck potato	0.3	1.0	0.7	1.0	0.2
Teal grass	1.7	1.1	10.1	12.9	2.1
Rice cutgrass	4.5	13.4	12.6	30.6	5.0
Wild millet	0.7	0.6	8.9	10.2	1.7
Japanese millet	8.5	14.5	79.6	102.6	16.9
Walter's millet	3.2	5.4	2.2	10.8	1.8
Nutgrasses	4.6	2.9	55.7	63.2	10.4
River bulrush	...	0.2	18.8	19.0	3.1
Marsh smartweed	...	0.4	5.8	6.2	1.0
Water hemp	2.0	1.4	8.8	12.2	2.0
American lotus	...	...	3.5	3.5	0.6
Cocklebur	1.0	...	7.0	8.0	1.3
Spanish needles	1.1	0.2	...	1.3	0.2
Other moist-soil plants	1.3	...	...	1.3	0.2
Total vegetation	*28.9*	*41.1*	*222.2*	*291.3*	...
Lake basin area	63.9	108.0	435.9	607.8	...
Vegetation percentage	45.2	38.0	51.0	47.9	47.9
Open-water percentage	54.8	62.0	49.0	52.1	52.1

[a] Averages for the time period involved.
[b] Sum of the averages of all lakes.

basins, and 6.2 percent was covered by other species. Artificially sown Japanese millet composed nearly half of all moist-soil plants; the other species occurred naturally. Nutgrasses, rice cutgrass, teal grass, water hemp, and Walter's millet and wild millet were the principal species, listed in descending order of abundance.

Marsh plants—river bulrush (3.1 percent), arrowleaf (1.3 percent), marsh smartweed (1.0 percent), and duck potato (0.2 percent)—aggregated 5.6 percent (Table 6) in Class IIIB, a much smaller proportion of the area than they covered in other classes of lakes.

Aquatic plants were almost nonexistent in Class IIIB lakes. Longleaf and sago pondweed (0.1 percent and trace, respectively) and American lotus (0.6 percent) totaled only 0.7 percent of the lake basins. These aquatics occurred because the lakes were never completely drained; usually from one-third to one-half of the lake basin retained a shallow residue of water surrounded by bare mud flats and shoreward, by zones of moist-soil plants.

EVALUATION OF THE SEVERANCE OF LAKES FROM THE RIVER

Data presented in Tables 3–6 show that the greater the separation of the lake basin from the Illinois River, the more productive the lake was of wetland plants. Although after the 1943 flood, the percentage of the lake basins covered by aquatic and marsh plants in Class IIIA lakes declined below levels in Class II lakes, this difference occurred for other reasons that will be discussed later under water depth and turbidity.

Not only did the quantity of wetland plants increase with the degree of isolation from the river water, but the quality of vegetation for waterfowl food also improved. In Class I lakes, river bulrush, American lotus, and marsh smartweed made up 64 percent of the wetland plants, but their production of waterfowl food was minute (Low & Bellrose 1944).

River bulrush produces a negligible amount of seeds; American lotus produces a moderate seed crop, but its seeds are too hard for ducks to eat during the fall (Bellrose & Anderson 1943); and marsh smartweed fails to produce seed when growing out of water (Low & Bellrose 1944), as it does in most Class I lakes.

Class II lakes produced more moist-soil plants than did Class IIIA lakes, but Class IIIA had a greater abundance of aquatic and marsh plants. The maximum waterfowl food plant production occurred in Class IIIB lakes because of the extensive development of moist-soil vegetation resulting from controlled drawdowns of water. Most moist-soil plants yield large crops of seed (Low & Bellrose 1944) that are preferred foods of most dabbling ducks (Bellrose & Anderson 1943).

Plants most typical of all classes of Illinois Valley lakes are river bulrush, American lotus, and marsh smartweed. These species in their respective niches are obviously the most adaptable to a regimen of fluctuating water levels.

Within each class of lakes, the abundance of wetland plants changes from year to year as the water level fluctuations vary.

EVALUATION OF SEASONAL CHANGES IN BOTTOMLAND LAKE WATER LEVELS

Effects on Moist-Soil Plants

A comparison of the yearly Moist-Soil Water-Level Index (described under Methods) and the development of moist-soil plants in the lake basins of the lower Illinois River valley is shown in Fig. 7. (At the time of the study, mud flats were not extensively exposed in the valley above Peoria because the Peoria lock and dam had raised water levels.) As the yearly Moist-Soil Water-Level Index rose, the proportion of all

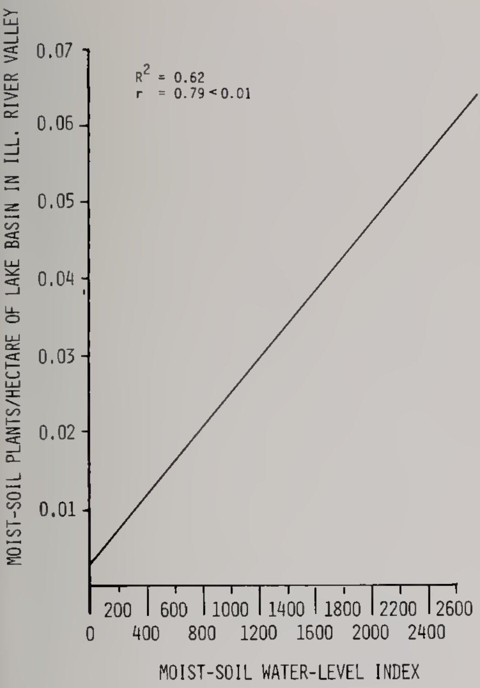

Fig. 7.—The linear relationship of the Moist-Soil Water-Level Index to the abundance of moist-soil plants per hectare of lake basin in the Illinois River valley.

lake basins covered with moist-soil plants likewise increased. The coefficient of determination ($R^2 = 0.62$) indicates that about 60 percent of the annual coverage of moist-soil plants was related to the Moist-Soil Water-Level Index.

Small rises in water during the growing season of moist-soil plants destroyed extensive areas of these plants, the extent depending upon the height of the rise and the lateness of the season. The havoc that these midsummer fluctuations wrought on the development of moist-soil plant beds is only partially measured by the Moist-Soil Water-Level Index and is the principal reason that it accounted for only 60 percent of the plants' coverage of lake basins. Once eradicated by a brief inundation, moist-soil plants might not have sufficient time to regenerate, or mud flat areas might be reduced.

Effects on Aquatic and Marsh Plants

Through the years, 1938–1959, only a small coefficient of determination occurred between the area covered yearly by aquatic and marsh plants and the yearly variation in the seasonal fluctuation of water levels. The Water-Stability Index for seasonal stability on all lakes studied compared with the development of marsh vegetation gave a coefficient of determination of 0.11 (11 percent of the variable accounted for by fluctuating levels); for aquatic plants it was 0.108 (10.8 percent).

Two items were proposed for further analysis: (1) Water levels had various effects on aquatic and marsh plants in different lakes that we attributed to different elevations and bottom topographies of the lake basins. (2) Factors other than the degree of water-level stability appeared to be more important in regulating the growth of aquatic and marsh plants.

To evaluate further the effects that yearly variation in the fluctuation of water levels had on aquatic and marsh plants, we examined particular Class IIIA lakes more closely.

Lake Chautauqua.—One of our longest series of aquatic plant studies was made at Lake Chautauqua, a national wildlife refuge. The 1,416-ha (3,500-acre) lake is enclosed by levees that minimize low-water fluctuations. A spillway at 133.4 m (437.5 ft) msl permitted river waters above that height to enter the lake during the years of the study. Unfortunately, refuge gauge records are available for only 8 of the 14 years studied.

The Water-Stability Index for those 8 years was compared to the occurrence of sago pondweed by linear regression. The coefficient of determination was 0.31, suggesting that water stability accounted for about 30 percent of the yearly change in abundance of sago pondweed. American lotus, coontail, river bulrush, and duck potato showed only a slight correlation between their abundance and the Water-Stability Index.

The highest flood on record in the Illinois River valley occurred in late May 1943. At Lake Chautauqua the flood crested on 25 May, 5.3 m (17.5 ft) above the normal lake level. It inundated other Class IIIA lakes to similar depths. Vegetation studies were made in late summer after the water level had returned to normal.

The flood eradicated all pondweeds from Lake Chautauqua (Table 5); coontail declined greatly in 1943 and never recovered in subsequent years; marsh smartweed and river bulrush also suffered losses in abundance that were never regained. American lotus increased in abundance but subsequently died out in the early 1960's.

Rice Lake.—At Rice Lake, coontail abundance increased markedly in 1943, apparently because of less competition from American lotus (Table 5). The high water lessened the area of river bulrush on lower sites, enabling marsh smartweed to invade stands of bulrush and increase in abundance. Flood waters submerged the growing plants of lotus so deeply that they failed to recover after the water subsided, perhaps enabling white water lily to increase.

Cuba Island.—Flood waters adversely affected the abundance of rice cutgrass, coontail, and American lotus at Cuba Island (Table 5). Marsh smartweed, however, increased as competition from other plants decreased.

Flat, Swan, and Gilbert Lakes.—Flat, Swan, and Gilbert lakes, part of the Calhoun Division of the Mark Twain National Wildlife Refuge, lie in the lower Illinois River valley a few miles above the river's confluence with the Mississippi River.

Several relatively small lakes occurred there before 1939. At that time the Alton navigation dam raised water levels, increasing the lakes' surface area from 445 to 1,943 ha (1,100–4,800 acres). By 1941, wetland plants had developed in a sizeable area where little but lotus had grown before the expansion of Flat, Swan, and Gilbert lakes in 1939 (Table 7).

However, the flood of 1943 caused a marked reduction in wetland vegetation, and the plants appeared late in the growing season after the flood had subsided. The comeback of wetland plants was retarded in 1944 by another high flood in the late spring.

During most of the 1960's, sago and longleaf pondweeds, southern naiad, and coontail flourished in Swan Lake. Beds of these aquatics aggregated 405 ha (1,000 acres) in 1965, but a late September flood reduced their fall availability to waterfowl. A high flood in April and a minor one in June

Table 7.—The abundance by area of wetland plants at Flat, Swan, and Gilbert lakes, 1941–1944. Figures are in hectares (2.471 acres/hectare).

Species	1941	1942	1943	1944
Cattail	. . .	29.3	0.4	. . .
Longleaf pondweed	10.0	. . .	. . .	. . .
Leafy pondweed	0.9	. . .	. . .	. . .
Sago pondweed	0.6	. . .	. . .	. . .
Southern naiad	16.8	. . .	. . .	. . .
Duck potato	0.8	. . .	8.7	. . .
Arrowleaf	18.0	6.3	9.6	10.8
Rice cutgrass	14.1	13.9	4.7	. . .
Wild millet	. . .	. . .	. . .	2.8
Nutgrasses	68.2	54.4	9.0	9.2
Softstem bulrush	0.4	0.3	. . .	. . .
Spike rush	2.4	. . .	0.2	. . .
Marsh smartweed	. . .	19.3	20.9	8.9
Coontail	22.0	. . .	. . .	. . .
White water lily	. . .	. . .	0.4	. . .
American lotus	34.2	. . .	13.2	61.2
Marsh mallow	. . .	. . .	0.2	. . .
Total vegetation	*188.4*	*123.5*	*67.3*	*92.9*

1967 resulted in turbid water through much of the growing season, limiting the growth of submerged aquatics but not that of American lotus or duck potato. Stable water levels prevailed during the growing season and fall of 1968, promoting an excellent growth of sago and longleaf pondweeds, southern naiad, and coontail.

Three floods occurred in 1969: spring, July, and October. After the spring flood, beds of submerged aquatics and American lotus began to appear, only to be destroyed by high, turbid water in July. In spite of favorable water levels in 1971 and 1976, aquatic plants did not reestablish themselves in Flat and Swan lakes. Large depositions of new sediments were resuspended by wave and fish activity, greatly increasing turbidity.

Yearly fluctuations in water levels have an influence on aquatic and marsh plants, but such fluctuations are less important to the welfare of these plants than they are to moist-soil species. It is also apparent that factors other than water-level stability have influenced the growth of aquatic and marsh plants. Therefore, we evaluated several other factors.

CHANGES IN WATER DEPTHS

Semipermanent changes in water depth profoundly affected the vegetation at several Illinois Valley lakes: Rice, Douglas, Spring, and Anderson.

Rice Lake

In 1945 an earthen dam was constructed at the outlet of Rice Lake, increasing its normal minimum depth by 0.4 m (1.3 ft). In 1953 the dam was raised an additional 0.5 m (1.5 ft) and another 0.4 m (1.3 ft) in 1961.

These increases in water level at Rice Lake severely altered its plant communities. With a depth increase of 0.4 m (1.3 ft) in 1945, river bulrush declined from covering over 33 percent of the basin to merely 1.7 and 1.0 percent in 1950 and 1953, respectively (Table 8). With low water levels in 1977 and 1978, about 10.1 ha (25 acres) of river bulrush have become reestablished. The abundance of marsh smartweed varied from year to year with spring water conditions; it covered a larger area in 1955–1956 after the water was raised an additional 0.5 m (1.5 ft) during 1953. Marsh smartweed invaded areas formerly occupied by river bulrush but could not tolerate the rising water and disappeared in the 1960's.

American lotus declined in abundance from 15.1 percent of the Rice Lake area in 1944 to a trace in 1956 and none in 1957. Small beds of lotus reappeared in 1977 and 1978 as water levels were lowered.

In the 1950's, coontail markedly increased in area as a result of the deeper water (Table 8). It invaded areas vacated by declining beds of lotus and river bulrush. However, the disappearance of river bulrush and lotus increasingly exposed a greater expanse of open water to wave action. Waves resuspend highly organic bottom materials, causing the waters to become much more turbid than before. As a result of increased turbidity, coontail vanished from Rice Lake in the mid-1960's and has not become reestablished.

White water lily increased in abundance as competition from lotus lessened and as water levels remained more stable. However, it could not tolerate the increasing wave action and turbidity of the early 1960's and eventually disappeared from the lake.

Douglas Lake

With the inauguration of the Peoria lock and dam in December 1938, the minimum water level at Douglas Lake was raised about 0.6 m (2 ft). At that time the area supported the largest river bulrush marsh in the state (364.1 ha, 899.7 acres; Table 9). Over the

Table 8.—The abundance by area of wetland plants in Rice Lake, 1938–1957. Figures are in hectares (2.471 acres/hectare).

Species	1938		1939		1940		1941		1942		1943	
	Hectares	Percent of Lake Basin[a]	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin
Giant bur-reed	...	...	...	...	...	...	...	...	7.8	2.0	...	...
Sago pondweed	...	...	trace	...	...	...	...	...	0.4	0.1	...	...
Duck potato	...	...	...	...	...	...	...	...	...	...	...	...
Waterweed	...	...	...	...	...	...	...	...	16.9	4.4	...	...
Rice cutgrass	...	...	...	...	...	...	...	...	...	...	...	...
Wild rice	...	...	0.2	trace	...	...	...	...	18.8	4.9	...	...
Wild millet	...	...	...	...	...	...	...	...	...	...	...	...
Nutgrasses	...	...	...	...	...	...	...	...	...	...	...	...
River bulrush	85.0	22.2	167.5	43.8	167.2	43.7	174.0	45.4	136.5	35.7	118.3	30.9
Duckweeds	...	...	...	...	121.4	31.7	55.7	14.5	...	...	...	...
Pickerel weed	...	...	...	...	4.0	1.0	7.0	1.8	22.3	5.8	...	...
Marsh smartweed	15.4	4.0	7.3	1.9	5.3	1.4	29.5	7.7	0.6	0.2	31.4	8.2
Coontail	69.8	18.2	40.1	10.5	1.2	0.3	13.5	3.5	31.4	8.2	191.4	50.0
Yellow pond lily	...	...	...	...	...	...	...	...	0.4	0.1	...	...
White water lily	0.8	0.2	0.8	0.2	0.1	trace	...	...	...	...	5.9	1.5
American lotus	19.4	5.1	25.9	6.8	128.5	33.6	101.9	26.6	136.2	35.6	4.2	1.1
Marsh mallow	...	...	...	...	...	...	...	...	...	...	0.3	0.1
Total vegetation	*190.4*	*49.7*	*241.8*	*63.2*	*427.7*	*111.7*[b]	*381.6*	*99.5*	*371.3*	*97.0*	*351.5*	*91.8*
Open water	192.4	50.3	141.0	36.8	0.0	0.0	1.2	0.5	11.5	3.0	31.3	8.2

Table 8.—Continued

Species	1944		1950		1953		1955		1956		1957		1944–1957 Average Hectares
	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin	
Giant bur-reed	...	...	...	...	...	...	...	...	...	...	...	...	...
Sago pondweed	...	...	...	...	...	...	52.2	13.6	3.2	0.8	...	...	9.2
Duck potato	...	...	...	...	...	...	0.6	0.2	...	...	...	...	0.1
Waterweed	...	...	...	...	...	...	...	...	...	...	...	...	...
Rice cutgrass	...	...	...	...	...	...	...	...	1.8	0.5	...	...	0.3
Wild rice	0.4	0.1	...	...	...	...	...	...	...	...	...	...	0.1
Wild millet	...	...	...	...	...	...	...	...	1.2	0.3	...	...	0.2
Nutgrasses	...	...	...	...	...	...	...	...	1.0	0.3	...	...	0.2
River bulrush	137.5	35.9	6.4	1.7	3.8	1.0	4.4	1.1	7.0	1.8	...	...	26.5
Duckweeds	...	...	...	...	...	...	...	...	...	...	...	...	...
Pickerel weed	0.4	0.1	...	...	...	...	...	...	0.8	0.2	...	...	0.2
Marsh smartweed	25.4	6.6	7.7	2.0	21.2	5.5	30.0	7.8	26.8	7.0	14.2	3.7	20.9
Coontail	65.8	17.2	160.0	41.8	233.6	61.0	124.3	32.5	155.6	40.6	162.9	42.5	150.4
Yellow pond lily	...	...	...	...	...	...	...	...	...	...	...	...	...
White water lily	23.5	6.1	24.8	6.5	18.9	4.9	44.0	11.5	22.2	5.8	7.0	1.8	23.4
American lotus	57.7	15.1	69.5	18.2	7.2	1.9	19.9	5.2	0.1	trace	...	...	25.7
Marsh mallow	...	. .	...	...	...	...	...	...	...	...	...	...	...
Total vegetation	*310.7*	*81.1*	*268.4*	*70.2*	*284.7*	*74.3*	*275.4*	*71.9*	*219.7*	*57.3*	*184.1*	*48.0*	
Open water	72.1	18.9	114.4	29.8	98.1	25.7	107.4	28.1	163.1	42.7	198.7	52.0	

[a] Lake basin = 382.8 ha (946 acres).
[b] Duckweeds floating among other plants account for the greater than 100 percent total.

Table 9.—The abundance by area of wetland plants in Douglas Lake, 1938–1959. Figures are in hectares (2.471 acres/hectare).

Species	1938		1939		1940		1941		1942		1950		1956		1959	
	Hectares	Percent of Lake Basin[a]	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin	Hectares	Percent of Lake Basin
Longleaf pondweed	trace	...	0.3	...	0.5	0.1	...	...	...	...	...	...	...	...	...	...
Sago pondweed	trace	...	2.7	0.4	4.2	0.6	1.6	0.2	0.9	0.1	...	...	...	...	...	...
Southern naiad	trace	...	0.2	...	trace	...	...	...	0.2	...	...	...	...	...	...	...
Duck potato	9.5	1.4	1.4	0.2	2.1	0.3	8.7	1.3	4.1	0.6	...	...	...	...	...	...
Waterweed	...	...	trace	...	2.6	0.4	0.2	...	1.6	0.2	...	...	...	...	...	...
Wild rice	trace	...	32.8	4.9	9.7	1.4	14.6	2.2	14.8	2.2	...	...	1.6	0.2	...	...
Japanese millet	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4.6	0.7
River bulrush	364.1	54.3	368.9	55.0	414.0	61.7	357.2	53.2	286.7	42.7	284.9	42.5	316.2	47.1	231.3	34.5
Duckweeds	...	...	...	...	22.1	3.3	...	...	5.6	0.8	...	...	4.4	0.7	...	...
Pickerel weed	...	...	trace	...	7.3	1.1	16.3	2.4	45.1	6.7	...	...	...	...	...	...
Marsh smartweed	26.7	4.0	8.5	1.3	20.3	3.0	49.4	7.4	20.2	3.0	39.7	5.9	...	...	...	...
Swamp smartweed	8.1	1.2	trace	...	...	...	0.7	0.1	0.1	...	...	...	...	...	...	...
Coontail	7.6	1.1	16.2	2.4	38.9	5.8	25.8	3.8	84.0	12.5	...	...	...	...	...	...
White water lily	1.5	0.2	21.8	3.2	10.0	1.5	17.5	2.6	33.9	5.0	7.5	1.1	...	...	...	...
American lotus	6.1	0.9	10.8	1.6	53.9	8.0	62.7	9.3	19.9	3.0	3.4	0.5	127.9	19.1	...	...
Total vegetation	*423.6*	*63.1*	*463.6*	*69.0*	*585.6*	*87.2*	*554.7*	*82.5*	*517.1*	*76.8*	*335.5*	*50.0*	*450.1*	*67.1*	*235.9*	*35.2*
Open water	...	...	...	...	...	...	...	...	153.7	23.2	335.2	50.0	220.7	32.9	422.2	64.8

[a] Lake basin = 670.9 ha (1,657.7 acres).

next 2 years the river bulrush area increased slightly, encroaching on the black willow zone as a result of the increased water depth. Then the higher water level began to have an effect; river bulrush declined from 414.0 ha (1,023 acres) in 1940 to 231.3 ha (571.5 acres) in 1959 and 199.1 ha (492 acres) in 1976.

Wave action increased turbidity as the retreat of the river bulrush left an expanding area of open water on the lake. By the 1950's, the several pondweeds and coontail had disappeared (Table 5). Marsh smartweed increased to 7.4 percent of the lake basin in 1941, as it invaded beds of river bulrush, but the increased water depth eventually extirpated it in the early 1950's. Wild rice became much reduced in area; only 1.6 ha (4.0 acres) were found in 1956 and none thereafter. Pickerel weed was gone by 1950 and failed to reappear in subsequent years (Table 9). White water lily increased as a result of the greater depth, reaching a peak in 1942 when 5 percent of the lake basin was covered (Table 9). White water lily decreased to only 1.1 percent of the basin in 1950 and disappeared thereafter. There was much yearly variation in the abundance of American lotus, but none was found in 1959, 1976, and 1977; only small beds appeared in other years. Apparently the increased wave action and turbidity were responsible for reducing the abundance of both aquatic and marsh plants.

Spring Lake

Spring Lake is a remnant of a large bottomland lake leveed and drained for agriculture in 1910. Because it was isolated from the Illinois River by a large levee and fed by spring waters, Spring Lake enjoyed highly stable water levels, and it contained extensive beds of aquatic plants in 1938 and 1941 (Table 10). In 1958 the lake level was raised 0.9 m (3 ft), doubling the lake area to its current size of 601.0 ha (1,485.1 acres).

Table 10.—The abundance by area of aquatic and marsh plants at Spring Lake, Tazewell County, 1938, 1941, and 1976. Figures are in hectares (2.471 acres/hectare).

Species	1938	1941	1976
Sago pondweed	trace	0.4	. . .
Longleaf pondweed	4.0	. . .	. . .
Southern naiad	31.6	22.6	. . .
Duck potato	10.1	6.5	. . .
Waterweed	29.1	1.8	. . .
Wild rice	0.2	0.2	. . .
River bulrush	12.1	5.1	. . .
Water stargrass	10.1	5.9	. . .
Coontail	78.1	46.7	4.0
American lotus	8.1	6.6	. . .
Total vegetation	*183.4*	*95.8*	*4.0*

The increase in water depth combined with an increase in turbidity to produce such unfavorable conditions that all but a minute portion of the aquatic plants disappeared (Table 10). Initially, water depths in the principal aquatic beds ranged from 0.6 to 1.5 m (2–5 ft); Secchi disk transparencies varied from 45.7 to 152.4 cm (18–60 inches). The increased lake size resulted in greater wave action. Because of the resulting turbidity, aquatics failed to reestablish themselves in the shallow, newly flooded area. The flooded lands were composed of highly organic material that was easily activated by waves. As a result, Secchi disk transparencies declined from previous readings of 45.7–152.4 cm by amounts of 30.5 to 40.6 cm (12–16 inches). Although water depths ranged from 0.5 to 1.2 m (1.5–4.0 ft) over 60.7 ha (150 acres), turbidity apparently prevented aquatics from developing in the shallow waters. Not only did turbidity increase as a result of wave action on light soils, but phytoplankton production also increased because of an increase in domestic pollution.

Anderson Lake

Structures placed at the outlet of Anderson Lake in 1950 helped stabilize low-water levels. This stabilization apparently enhanced growing conditions for coontail, for it was noticeably more abundant during 1955–1959 than in 1938–1939 (Table 4). Depths over much of the lake ranged from 50.8 to 101.6 cm (20–40 inches).

The lake level was raised 0.5 m (1.5 ft) in 1958 and an additional 0.5 m (1.5 ft) in 1964. American lotus disappeared from the lake in 1959 and has been virtually absent since. Coontail began decreasing in abundance in 1959 and by 1965 had all but disappeared from the lake. Marsh smartweed at first invaded areas vacated by willows as they retreated from the higher water level, but ultimately the area in smartweeds began a decrease that continued through the 1960's. By 1976 only fragments of the once extensive marsh smartweed beds remained.

EFFECTS OF TURBIDITY AND SEDIMENTATION

It is apparent from our studies of wetland vegetation in Illinois Valley lakes that fluctuating water levels, water depth, and turbidity have been the prime physical factors affecting its abundance. However, fluctuating water levels appear less responsible than other factors for the steady reduction in numbers of aquatic plants during the 1960's.

A linear regression of the average weekly water level fluctuations, 15 June–12 October, for five periods (1940–1949, 1950–1959, 1960–1969, 1970–1976, and 1938–1976) shows no significant trend in fluctuating water levels through the summer months (Table 11). Although water levels were generally higher between 1938 and 1976, the variation among years is so irregular that the correlation coefficient is not significant. Moreover, during the critical 1960's, when most of the aquatic plants disappeared from the Illinois Valley, the degree of summer fluctuations actually declined (Table 11). Therefore, we conclude that increased turbidity and sedimentation were responsible for the disappearance of most aquatic plants from lakes of the Illinois Valley during the 1960's.

Table 11.—Linear regression of average weekly water levels by yearly periods at the Havana gauge during 15 June–12 October, 1938–1976 (x = years in each period; y = range in average weekly water level fluctuations).

Years	Intercept	Slope	r
1940–1949	16.54	1.005	0.151
1950–1959	23.97	0.992	0.015
1960–1969	22.49	–0.904	0.233
1970–1976	30.37	1.581	0.092
1938–1976	17.18	0.326	0.168

Turbidity results indirectly from sedimentation. A study by Jackson & Starrett (1959) on the turbidity of Lake Chautauqua pointed out their close relationship. They found that a flocculent false bottom had been deposited over the original firm bottom. Fine silt and clay particles are readily resuspended in the lake's water by wave action and fish movements. Similar increases in wind velocity caused Jackson Turbidity Unit (JTU) readings to increase from 174 to 700 in the spring of 1953, but only from 50 to 78 in the summer of 1953. The much smaller increase in summer turbidities was attributed to dense beds of sago pondweed, which prevented the wind from agitating bottom materials. Activities of bottom-feeding fish, particularly carp, also resuspended bottom sediments, locally increasing the turbidity of Lake Chautauqua. The highly significant correlation between JTU's and water transparency measured by a Secchi disk in waters of the Illinois River valley is shown in Fig. 8.

Stall & Melsted (1951) had earlier studied the sedimentation at Lake Chautauqua. They reported that the capacity of the lake had been reduced 18.3 percent by sedimentation in 23.75 years. The average amount of sediment

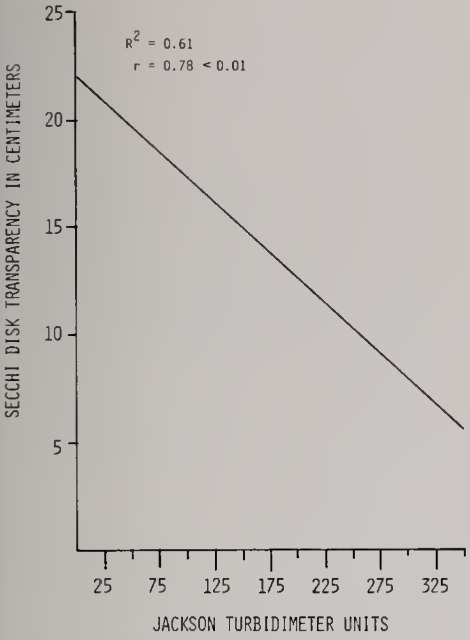

Fig. 8.—The linear relationship of Jackson Turbidimeter Units and Secchi disk transparency in waters of the Illinois Valley.

Table 12.—The number of Jackson Turbidimeter Units (JTU's) in water samples taken from tributary streams and the main channel of the Illinois River, 9 August 1977, and Lake Chautauqua, 9 May 1977.

Place	JTU
Mackinaw River	
Towerline Road[a]	865
Route 29[a]	712
Manito Road[a]	987
Spoon River, Route 24[a]	1,625
Illinois River, Havana[a]	545
Lake Chautauqua	
115–600 m[b]	149
800–1,600 m[c]	95

[a] Three separate measurements of one water sample averaged.
[b] The average of five water samples taken at 115–600 m from the river.
[c] The average of eight water samples taken at 800–1,600 m from where the river enters the lake.

deposited annually was 76,414 metric tons (84,230 tons). The sediment was brought into Lake Chautauqua by the Illinois River when it rose above the spillway level or overtopped levees.

Sedimentation in the Illinois river valley is particularly severe for three reasons. (1) Clay and fine silt particles enter the Illinois River as a result of sheet erosion on the intensively farmed Big Prairie region of Illinois, which is drained by numerous tributary streams. (2) The almost colloidal nature of the sediments and the velocity of the tributaries cause much of the sediment load to be transported to the main stem of the Illinois. (3) The sluggish flow of the main channel permits a high percentage of this sediment load to settle in the backwater lakes.

Table 12 shows the JTU readings near the mouths of the Spoon and Mackinaw rivers and in the Illinois River at Havana on 9 August 1977 and in Lake Chautauqua as flood waters entered it on 9 May 1977. The Spoon and Mackinaw rivers, important tributaries of the Illinois, were bankfull, and waters of the Illinois River were invading Lake Chautauqua.

The sediment load of the Illinois River was much less than the loads of the Spoon and Mackinaw rivers that enter it near Havana. The waters entering Lake Chautauqua steadily lessened in turbidity the farther the samples were taken from the point of entry. We interpret these findings as illustrating the loss of sediment load as velocity slackens.

The Mackinaw and Spoon rivers fall at much faster rates than does the Illinois River. The Illinois River drops at the rate of 0.01 m per km (0.04 ft per mile) from Peoria to Beardstown. The Mackinaw River falls at the rate of 0.70 m per km (3.7 ft per mile) from the upper sampling site to its mouth; the Spoon River falls at the rate of 0.57 m per km (3.01 ft per mile) from the sampling site to its confluence with the Illinois River.

These three factors—soil erosion, the high velocities of tributaries, and the sluggish flow of the main channel—together have brought about an environmental disaster: backwater lakes of the Illinois River are filling at a rapid rate leading to their early extinction.

Fig. 9 shows the sedimentation rates in seven lakes above Peoria. These lakes are lateral to the river channel, except Upper Peoria Lake, through which the river flows. The linear regressions show a high correlation between the depth of the water and the rate of sedimentation. Sedimentation increases as the water deepens because of the greater standing column of water from which sediments precipitate. The exceptionally high correlation coefficients (*r*) confirm this relationship.

Upper Peoria Lake has a lower sedimentation rate than the other lakes because the river transports more sediment through it than through lateral lakes. At 2.1 m (7 ft), the yearly rate of sedimentation is 0.01 m (0.056 ft) as compared with 0.024–0.027 m (0.078–0.090 ft) in the other lakes. The lateral lakes are inundated during floods. Reduced current velocity in these lakes allows more sediment to precipitate than can drop out at the higher velocities present in Upper Peoria Lake. There is amazingly little difference among the sedimentation rates in lateral lakes above Peoria. Fig. 9 indicates that at a water depth of 0.3 m (1 ft) in Upper Peoria Lake wave and ice action have an erosive effect on the shallow margins of the lake bed and transport bed material to other areas. The same action has affected the shore margins of some of the lateral lakes.

Below Peoria, sedimentation studies were made at Rice Lake, Lake Chautauqua, Anderson Lake, and Meredosia Bay (Fig. 10). These lakes have lower and more diverse sedimentation rates than the upper lakes.

The differences in sedimentation rates among lakes can be accounted for by their relative isolation from the river. The lakes above Peoria have only low, narrow peninsulas of land separating them from the river at levels below flood stage. All of the lateral lakes studied above Peoria have

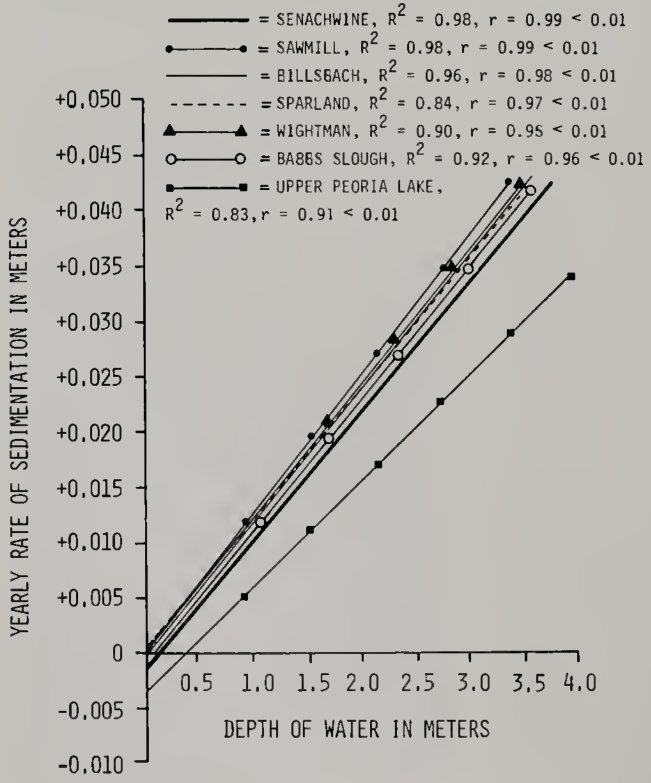

Fig. 9.—Linear relationships between the depth of water and the yearly rate of sedimentation in seven bottomland lakes in the upper Illinois River valley between Hennepin and Peoria.

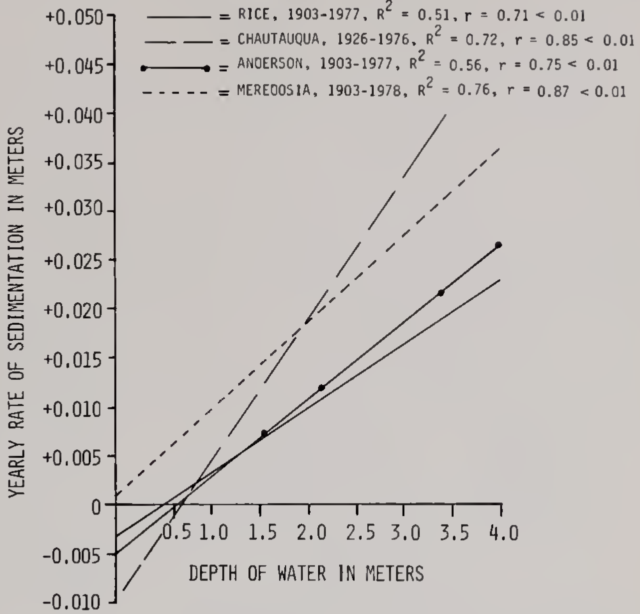

Fig. 10.—Linear relationships between the depth of water and the yearly rate of sedimentation in four bottomland lakes in the lower Illinois River valley between Banner and Meredosia.

broad inlets-outlets at their lower ends, connecting them to the river at all stages. Hence, they are subject to sedimentation from river waters at all stages above the minimum. The degree of separation of lateral lakes from the river is greater below Peoria, where sedimentation rates among the lakes studied are lower and more variable.

In this group, Rice Lake is the most isolated from the river, and it has the lowest sedimentation rate of all lakes studied. Anderson Lake is protected at its upper end by a large agricultural levee and on its river side by a natural levee 1.8 m (6 ft) above normal river level. Meredosia Bay is partially isolated from the river by an agricultural levee at its upper end and by a broad lateral peninsula of land that permits little ingress of river water until the river has risen 3 m (10 ft). Although surrounded by levees, Lake Chautauqua spillway elevations are 133.4 m (437.5 ft) msl, 2.2 m (7.3 ft) above normal river level. However, water was let into the lake through gates when projected river rises threatened to overtop the spillways; in recent years erosion has reduced the spillway level to 132 m (433 ft) msl. Once river water enters, it is trapped in Lake Chautauqua to a greater degree than in any natural lake; consequently, the sedimentation rate is higher than at Rice and Anderson lakes.

Data previously obtained at Upper Peoria Lake, Lake Chautauqua, and Meredosia Bay by the U.S. Army Corps of Engineers, the Illinois State Water Survey, and the State Division of Water Resources, and data obtained by us for 1976 and 1978 enabled us to calculate linear regressions for the two groups of years to determine periodic sedimentation rates (Fig. 11, 12, and 13). Sedimentation rates were appreciably higher in the more recent period at all three lakes.

The rise in sedimentation rates in the Illinois River valley in recent years indicates a pronounced increase in the sediment load of the river. The sediment load appears to have increased as a result of the intensified growing of row crops on the watershed of the river and an increase in tributary stream bank erosion.

In the early 1900's, lakes in the Illinois Valley had bottom profiles that

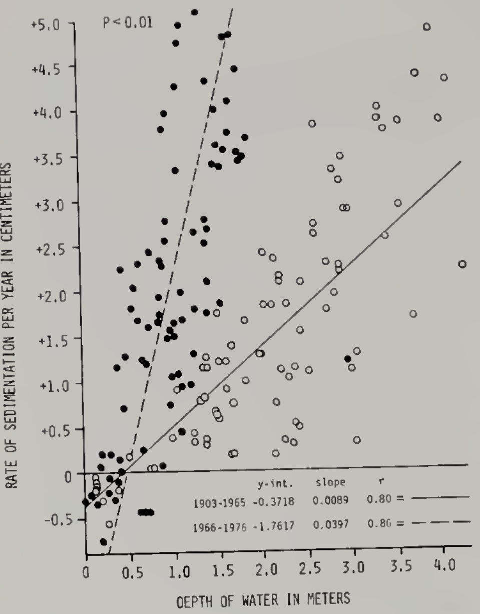

Fig. 11.—The linear relationship between the yearly rate of sedimentation and the depth of water in Upper Peoria Lake in each of two time periods, 1903–1965 and 1966–1976.

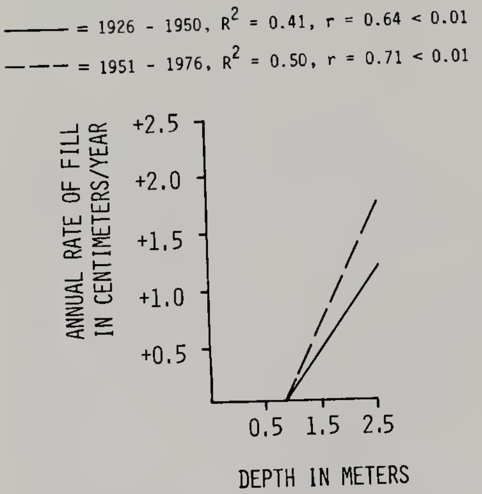

Fig. 12.—The linear relationship between the yearly rate of sedimentation and the depth of water in Lake Chautauqua in each of two time periods, 1926–1950 and 1951–1976.

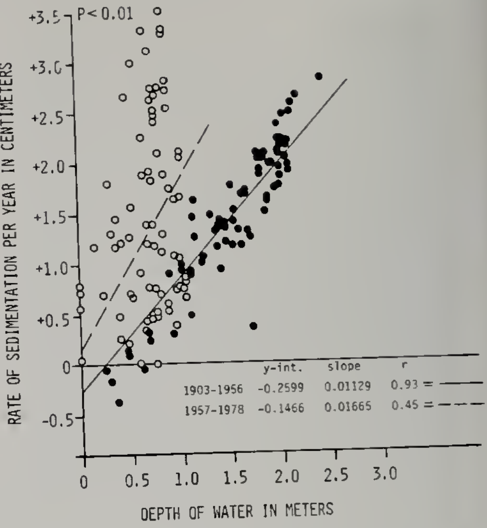

Fig. 13.—The linear relationship between the yearly rate of sedimentation and the depth of water in Meredosia Bay in each of two time periods, 1903–1956 and 1957–1978.

presented a diversity of elevations (Fig. 14 and 15). By the mid-1970's the bottom profiles had flattened into platter-shaped basins because of the greater deposition of sediment in the deeper waters. Because sedimentation is dynamic, the amount of silt deposited in a backwater lake changes as lake depths change. Other factors (such as the sediment load carried by the river) being equal, the total amount of sediment deposited per year in backwater lakes lessens as the lakes become shallower. Inasmuch as lake beds have different elevations, resulting in different degrees and time spans of inundations, sedimentation rates differ from lake to lake at comparable depths.

Table 13 shows the total amount of sediment deposited in 11 bottomland lakes during this century. The lakes that were originally deepest have received the greatest amounts of sediment. The total fill is staggering, leaving most bottomland lakes with shallow basins that are rapidly being filled as sediments "rain down" from the waters above. Because of its depth, Upper Peoria Lake in all likelihood will be the last lake remaining in the Illinois Valley. Rice Lake probably will fill more slowly than the other lateral lakes as a result of its distance from the river and the relatively high elevation of its basin.

Sawmill, Billsbach, Sparland, Wightman, Babbs Slough, and many other

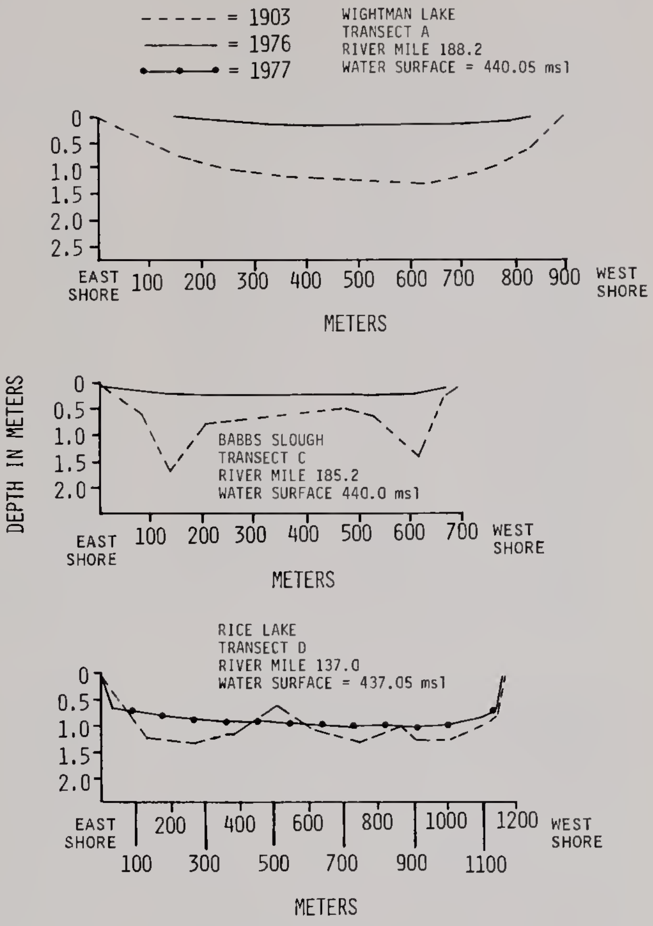

Fig. 14.—A cross section of each of three lakes—Wightman, Babbs Slough, and Rice—delineating the bottom contours in 1903 and in 1976 or 1977.

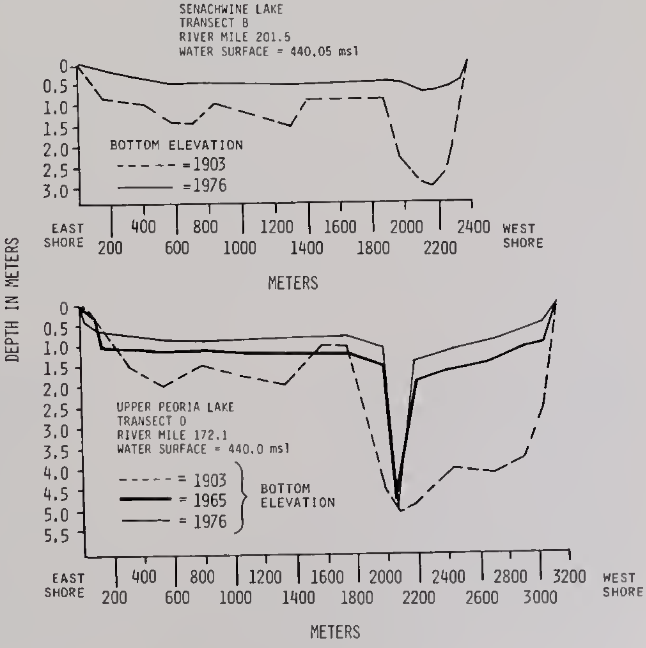

Fig. 15.—A cross section of Senachwine Lake, showing its bed in 1903 and 1976, and a cross section of Upper Peoria Lake, showing bottom elevations in 1903, 1965, and 1976. The deep trench in Upper Peoria Lake is the channel of the river. At Senachwine and other bottomland lakes, the river channel is lateral to their basins.

Table 13.—The total sedimentation, annual sedimentation, and average water depth in 1976 of 11 bottomland lakes in the Illinois River valley. Sediments and depths are recorded in centimeters at normal water levels.

Lake	Span of Measurement of Sedimentation in Years	Lake Surface Elevation[a] msl in meters	Total Sedimentation[b] in Centimeters	Average Sedimentation Per Year in Centimeters	1976 Average Water Depth in Centimeters
Senachwine	72	134.1	107.5	1.5	31.1
Sawmill	72	134.1	107.5	1.5	8.2
Billsbach	72	134.1	94.2	1.3	17.1
Sparland	72	134.1	84.3	1.2	12.5
Wightman	72	134.1	103.8	1.4	10.1
Babbs Slough	72	134.1	32.9	0.5	11.0
Upper Peoria	72	134.1	121.1	1.7	108.5
Rice	74	133.2	19.0	0.2	70.7
Chautauqua	50	132.6	43.2	0.9	79.9[c]
Anderson	74	132.4	30.6	0.4	81.7
Meredosia	75	129.3	97.4	1.3	88.4

[a] Fill and water depth calculations are based upon surface elevation in meters msl.

[b] Average sediment accumulations are based upon differences in depth soundings taken at each lake in two periods.

[c] From Lee (1976 unpublished).

lakes above Peoria evidently have short remaining lives (Table 13).

Lee & Stall (1976 unpublished) reported on the sedimentation of Lake Depue, a lake lateral to the Illinois River above Peoria. They projected that in 33 years the lake would fill with sediment to 134.4 m (441 ft) msl, the current normal lake surface elevation. They determined that the average lake depth in 1975 was 49.3 cm (19.4 inches).

The projected life of Lake Chautauqua, according to Lee (1976 unpublished), is 92 years, based upon the ratio of average depth to the current annual rate of rise in the lake bed. A sediment survey of Meredosia Bay by Lee et al. (1976 unpublished) led to the conclusion that its expected life is 90 years.

It is apparent that although total sediment deposits theoretically lessen as bottomland lakes become shallower, the yearly sedimentation rate per centimeter of water depth has actually increased. The intensive growing of row crops on Illinois River watershed lands has resulted in widespread sheet erosion. Unless a change occurs in land management practices, the years of life remaining to Illinois Valley lakes are numbered.

Between 1945 and 1976, row cropland in the Illinois River basin increased from 3,496,487 to 5,231,031 ha (8,639,700–12,925,700 acres), up 66.8 percent. In the entire state, row cropland rose from 4,811,883 ha (11,890,000 acres) in 1945 to 7,911,885 ha (19,550,000 acres) in 1976, an increase of 60.8 percent (Illinois Cooperative Crop Reporting Service 1968 and 1977). Most of the additional row crop area was devoted to growing soybeans. All row crops expose soils to more sheet erosion than do other kinds of crops, but soybeans provide even less protection to the land than corn provides.

EFFECTS OF FOOD RESOURCES ON FALL WATERFOWL POPULATIONS

For 40 years, Bellrose has observed that the availability of food is the most important factor affecting the abundance and distribution of waterfowl in the Illinois Valley. Yet, there are other variables affecting the local abundance of waterfowl. Moreover, as will be discussed, a regression analysis of the annual availability of natural food resources is difficult.

It is almost impossible to quantify seed yield, palatability, and availability of waterfowl food plants. A study of seed and vegetative yield by Low & Bellrose (1944) illustrated a wide diversity among species of wetland plants. The yield of any one species may vary from year to year, depending upon the growing period and competition from weed species. Fall floods may make seeds and other vegetative parts unavailable to dabbling ducks. Seeds produced in one year by moist-soil plants may still be available in bottom soils in the following year for ducks to feed upon at times when current moist-soil plant development is at a minimum. Mallards obtain a large proportion of their food from the waste corn left after harvest (Anderson 1959) and are, therefore, only partially influenced by the availability of naturally occurring foods. Many diving ducks, especially the lesser scaup, are influenced more by the availability of animal than plant food. Local duck populations are also influenced by yearly fluctuations in the continental and flyway populations of the various species.

These complex variables, combined with the failure of vegetation maps adequately to sample waterfowl food plant availability, make it difficult to compare the abundance of wetland plants with that of waterfowl. Nevertheless, we have found a relationship between the abundance of wetland plants and the abundance of some species of waterfowl in the Illinois Valley.

Fig. 16 shows a significant correlation between the abundance of moist-soil and marsh plants and the number of pintails. Anderson's (1959) study of the food preferences of the pintail in the Illinois Valley pointed up the primary importance of the seeds of moist-soil

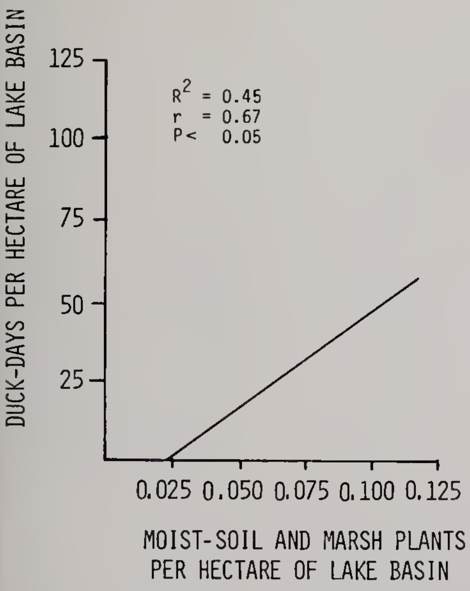

Fig. 16.—The linear relationship between the yearly abundance of pintails and the yearly abundance of moist-soil and marsh vegetation in the Illinois River valley.

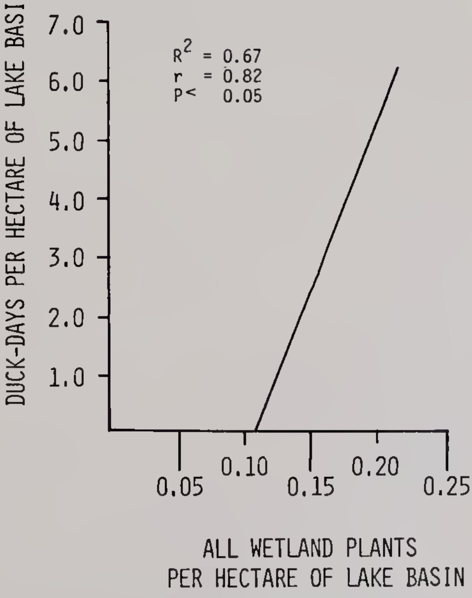

Fig. 17.—The linear relationship between the yearly abundance of American green-winged teals and that of all wetland plants in the Illinois River valley.

plants and the secondary importance of marsh plants in the diet of this species.

Green-winged teal numbers were influenced by the relative abundance of all wetland plants (Fig. 17) rather than by that of any particular plant group. Yet a food-preferences study of these ducks by Anderson (1959) revealed their preference for seeds of moist-soil plants.

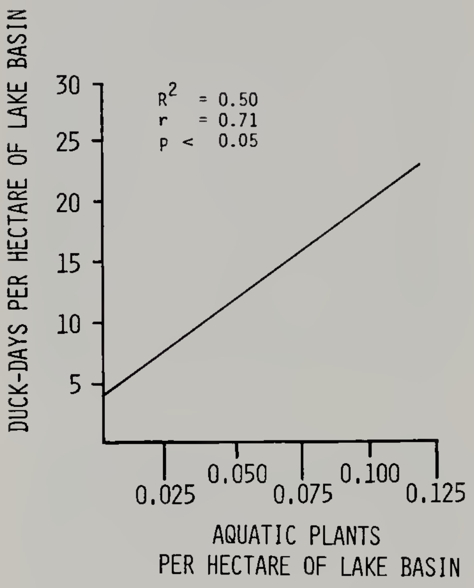

Fig. 18.—The linear relationship between the yearly abundance of American wigeons and that of aquatic plants in the Illinois River valley.

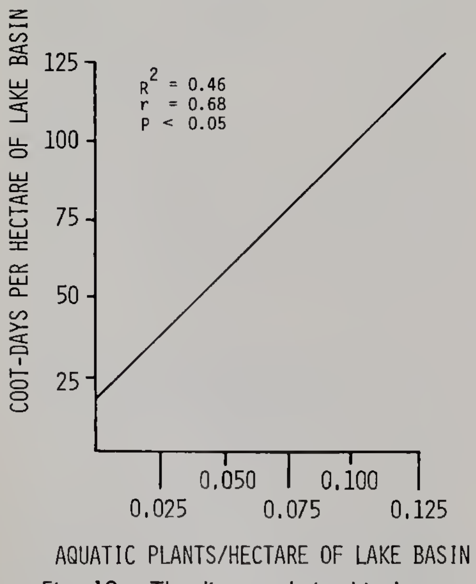

Fig. 19.—The linear relationship between the yearly abundance of coots and that of aquatic plants in the Illinois River valley.

As might be expected, wigeon and coot populations were significantly correlated with the yearly abundance of aquatic plants (Fig. 18 and 19). Food-preference studies by Anderson (1959) revealed the importance of the foliage of coontail, sago pondweed, and other aquatics in the diets of these species.

As sago pondweed, southern naiad, and coontail became more abundant in the mid-1960's at Swan, Gilbert, and adjacent lakes above Grafton, so did wigeon and coot populations (Fig. 20). The high water levels of 1965–1968

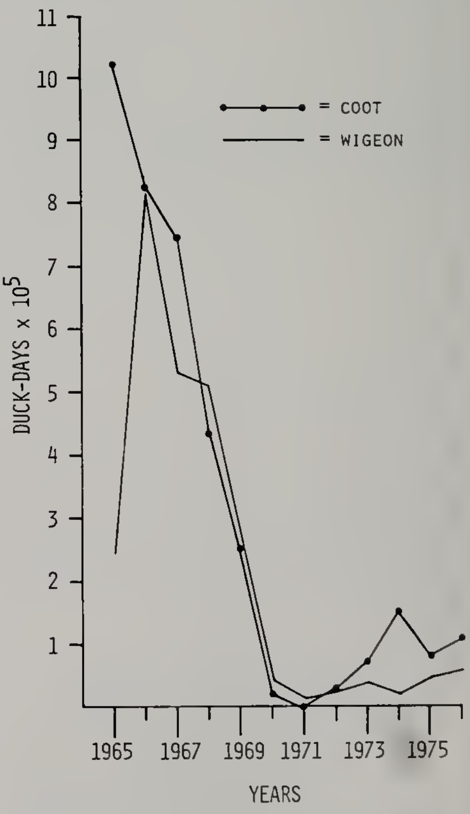

Fig. 20.—The yearly changes in coot and wigeon abundance on Gilbert and Swan lakes, Calhoun Unit of the Mark Twain National Wildlife Refuge, near Grafton, Illinois. The crash in numbers was associated with the disappearance of submerged aquatic plants.

resulted in the eradication of aquatic plants by 1969 (as previously described) and the consequent collapse of wigeon and coot populations. Aquatic plants had not recovered by 1976 and neither had the local wigeon and coot populations (Fig. 20).

SUMMER WATER LEVELS AND FALL WATERFOWL ABUNDANCE

We have previously shown the correlation between summer water levels and wetland plants and that between wetland plants and the fall abundance of certain species of waterfowl. However, our most precise and extensive data are on waterfowl abundance and water levels. Our evaluation of these factors is made on the assumption that summer water levels, used to calculate the Moist-Soil Water-Level Index, govern the growth of moist-soil food plants and that they in turn affect the abundance of fall waterfowl.

Fig. 21 demonstrates that the fall populations of several species of dabbling ducks are reflected in the Moist-Soil Water-Level Index. In the upper Illinois Valley, above Peoria, only the pintail showed a significant correlation between the Moist-Soil Water-Level Index and subsequent fall abundance. However, four species of dabbling ducks in the lower Illinois Valley (below Peoria) had significant correlations between fall population levels and the Moist-Soil Water-Level Index (Fig. 21).

The slopes of the linear regressions indicate that pintail numbers responded the most dramatically when a high Moist-Soil Water-Level Index occurred. (The higher the index, the longer the duration of low water.) Wigeon and green-winged teal populations responded less to these conditions, and fall blue-winged teal numbers responded only slightly to a high Moist-Soil Water-Level Index.

Fall populations of the mallard, the most abundant duck in the Illinois Valley, did not show a significant correlation with the Moist-Soil Water-Level Index for two reasons: (1)

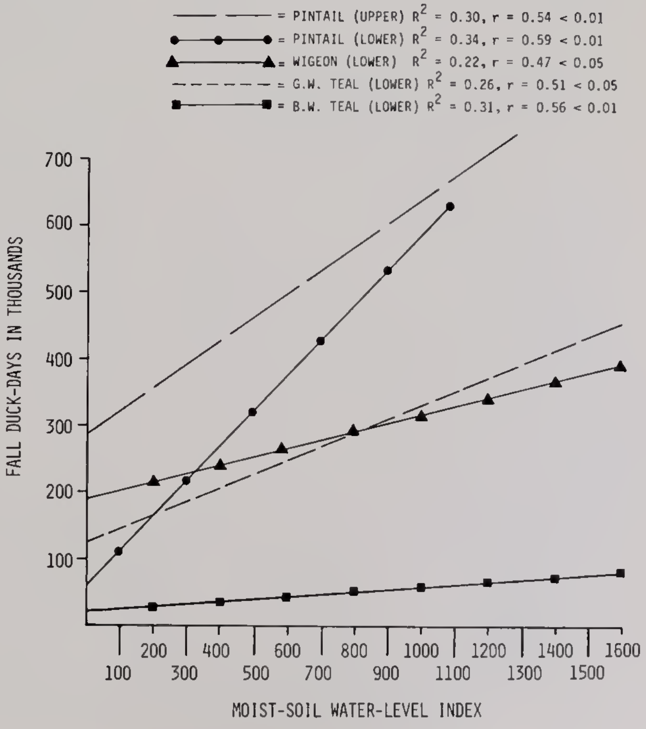

Fig. 21.—Linear relationships between the abundance of four species of dabbling ducks during the fall and the Moist-Soil Water-Level Index in the Illinois Valley. *Upper* refers to the upper Illinois River above Peoria, and *lower* refers to the river below Peoria.

changes in the continental abundance of mallards from year to year masked local population changes, and (2) the mallard obtains much of its food from waste grain in harvested corn fields and is, therefore, more independent of naturally occurring food resources than are other ducks.

We employed a multiple regression equation ($z = a_0 + a_1x + a_2y$) that incorporated the yearly continental mallard population as an independent variable, the Moist-Soil Water-Level Index as an independent variable, and mallard duck-day use as the dependent variable. Fig. 22 and 23 demonstrate that when these variables are evaluated, the Moist-Soil Water-Level Index also influenced mallard populations in the Illinois Valley.

The coefficient of determination (R^2) suggests that slightly over half of the yearly variation in mallard numbers in the Illinois Valley is accounted for by variations in the size of the continental population and the Moist-Soil Water-Level Index. The spread among the several Moist-Soil Water-Level Indices points up the effects that they have on mallard numbers in the upper and lower Illinois Valley. As with other dabbling ducks, the Moist-Soil Water-Level Index illustrates the influence of summer water levels on populations of mallards more in the valley below Peoria than above.

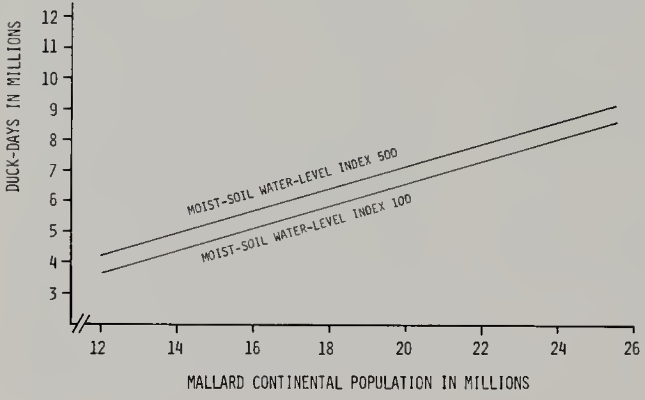

Fig. 22.—Multiple regression analysis of mallard abundance in the upper Illinois Valley in comparison with mallard continental abundance and the Moist-Soil Water-Level Index in the upper Illinois Valley.

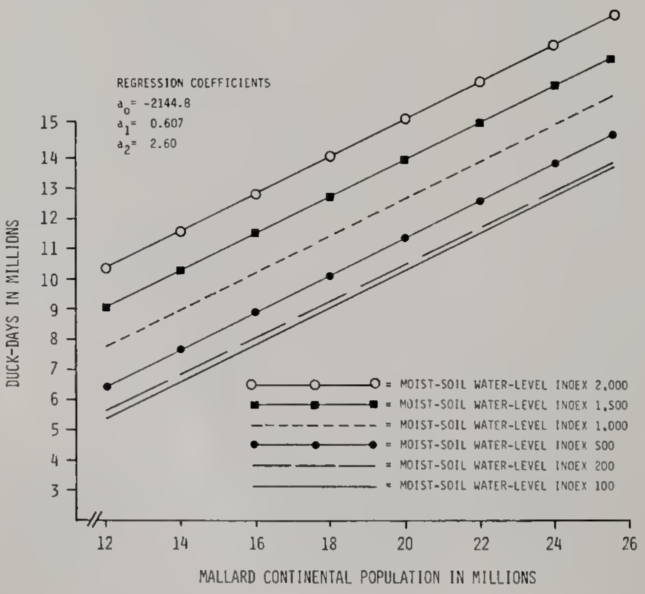

Fig. 23.—Multiple regression analysis of mallard abundance in the lower Illinois Valley in comparison with mallard continental abundance and the Moist-Soil Water-Level Index in the lower Illinois Valley.

We pointed out earlier that a high Moist-Soil Water-Level Index reflects more extensive mud flats and hence more moist-soil plant food resources in the lower valley. Therefore, it is not surprising that dabbling ducks respond more to low water levels in the lower than in the upper Illinois Valley.

We found no significant correlation between the Moist-Soil Water-Level Index and the abundance of diving ducks in the Illinois Valley. Studies of the food preferences of the several species of divers—lesser scaup, canvasback, ring-necked duck, and ruddy duck—by Anderson (1959) revealed that in the Illinois Valley they feed primarily on animal life. The effect of change in the abundance of a staple animal food item on diving duck abundance will be discussed later.

FALL WATER LEVELS

In the flat-basined lakes of the Illinois River valley, slight rises in fall water levels are advantageous in inundating moist-soil plant beds so that their seeds can be used by ducks. However, if the river rises too high, the moist-soil plant beds are covered too deeply for dabbling ducks to use their seed resources effectively. On the other hand, when waters remain low during the fall, tens of thousands of ducks can be observed feeding on mud flats and in shallow water early in the season. Examination of soil samples from these habitats reveals little animal life but multitudes of seeds of moist-soil plants that have been deposited in earlier years. It is assumed, therefore, that previous crops of moist-soil plant seeds are being consumed.

It was within this context that we analyzed the effect of fall water levels on fall populations of dabbling ducks in the lower Illinois Valley. Water levels were averaged yearly from 1949 to 1976 for the period 1 October–1 December, using the Havana gauge readings. These average fall water levels were compared, using a regression analysis, to the yearly fall waterfowl populations of several dabbling duck species (Table 14). The coefficient of determination (R^2) implies that fall water levels accounted for about 16 percent of the yearly variation in fall populations of mallards and green-winged teals, and for 6–8 percent of such variation in the abundance of pintails, blue-winged teals, and wigeon. In all these species (slope column, Table 14) the numbers of dabbling ducks decline when water levels rise above normal during the fall. Normal water level is considered to be at the tree line, and feeding conditions become unfavorable for dabbling ducks when this level is exceeded.

WATER LEVELS IN RELATION TO THE DURATION OF STAY OF DUCKS

The length of time a duck pauses in fall migration in the Illinois Valley is dependent upon several factors: (1) weather conditions, (2) shooting pressure and other disturbances, and (3) availability of food. Here we discuss only the availability of food—as re-

Table 14.—Average fall water levels[a] each year in relation to fall abundance of dabbling ducks in the lower Illinois Valley, 1949–1976.

Species	R^2	r[b]	Slope	y-Intercept
Mallard	0.16	0.40	–890,096	18,960,000
Pintail	0.06	0.24	–49,143	960,550
Green-winged teal	0.16	0.40	–47,412	619,770
Blue-winged teal	0.08	0.29	–6,284	96,290
Wigeon	0.07	0.26	–21,790	457,200

[a] The higher the average fall water level, the lower the fall abundance of dabbling ducks.
[b] r significant at 0.37, < 0.05; and 0.25, < 0.10.

flected by summer and fall water levels—in relation to the duration of stay of ducks.

A comparison of the peak weekly number of ducks observed with the number of duck-days each fall, 1949–1976 (Table 15), shows how long each particular population inhabits the Illinois Valley. The ratio of the mean peak number of ducks to the mean number of duck-days varies from 13.3 to 27.8 among different species and time periods (Table 15). In most instances the ratio of means varies between 19.6 (for the wigeon) and 22.5 (for the mallard). The implication is that during the fall season the number of duck-days equals about 21 times the number of ducks present at the peak of migration. Theoretically, if there were but one flight in and out of the valley, similar maximum numbers would occur over a 21-day period. However, because there are numerous flights of ducks arriving at and departing from the valley, the result is a period of increase followed by a period of decline. The chronology of fall duck populations assumes the shape of a bell curve (Bellrose 1944). Omitting the tails of the curve, the base roughly embraces the following number of days for these species: mallard 60, pintail 55, green-winged teal 60, wigeon 50, lesser scaup 55, ring-necked duck 55, and canvasback 55 (Bellrose, unpublished data).

An earlier analysis of mallard recovery data from bandings in the Illinois Valley led to the conclusion that fall migrants remain for 16–28 days, depending upon which of several sources of data was deemed the most reliable (Bellrose & Crompton 1970). On the basis of the earlier band recovery study, we interpret the 22.5 ratio of means for mallards (Table 15) as reflecting the average length of time migrating ducks remain during the fall in the Illinois Valley. Henceforth we refer to this ratio of mean peak number of ducks to mean duck-days in the fall as the Duration of Stay Index.

We surmised that between 1949 and 1976 almost all of the migrating ducks listed in Table 15 inhabited the Illinois Valley for similar periods of time, centering on 21 days. As shown by the standard deviation and range, the Duration of Stay Index varied by year. The variation among the years is least for the mallard and progressively higher for the green-winged teal, pintail, and wigeon.

We believe that some part of the yearly variation in the Duration of Stay Index results from the changing availability of native food resources. Beyond affecting peak numbers, food availability undoubtedly also influences

Table 15.—A comparison of the mean peak number of ducks recorded each year with the mean number of duck-days in the fall, 1949–1976.

Species	Mean Peak Number of Ducks	Mean Number of Duck-Days	Ratio			r
			Mean	Standard Deviation	Yearly Range	
Mallard	828,170	18,655,000	22.5	3.84	16.3–30.5	0.93
Pintail	34,460	739,800	21.5	6.57	8.2–36.3	0.93
Green-winged teal	14,000	389,460	27.8	5.37	13.5–40.3	0.96
Wigeon	20,170	395,000	19.6	9.08	13.5–54.8	0.80
Lesser Scaup[a]						
1949–1955	326,800	6,231,700	19.9	5.54	14.0–27.9	0.94
1956–1976	17,980	208,150	13.3	4.78	7.2–24.9	0.88
Canvasback[a]						
1949–1955	66,900	1,268,000	19.8	4.68	12.5–24.2	0.93
1956–1976	1,360	25,100	18.1	7.08	7.3–30.2	0.78

[a] Because of a crash in population levels between 1954 and 1956, the analysis is broken down into two periods: 1949–1955 and 1956–1976.

the duration of time that a given segment of a duck population spends in the valley. As previously discussed, summer water levels determine the development of moist-soil duck food, and fall water levels determine their availability.

Multiple regression coefficients (Table 16) compare increases in summer water levels as expressed by a decrease in the Moist-Soil Water-Level Index and increases in fall water levels (independent variables) with the Duration of Stay Index (dependent variable) for four species of dabbling ducks. The coefficient of determination (R^2) implies that rising summer and fall water levels had the greatest adverse effect on the green-winged teal, with progressively lessening influence on pintails, wigeons, and mallards.

The regression coefficients, Moist-Soil Water-Level Index (a_1) and yearly average fall water levels (a_2), imply that rises in summer water levels were more adverse than rises in fall water levels for the duration of stay by mallards and green-winged teals. But high fall water levels had the greater adverse effect on the pintail and wigeon Duration of Stay Indices.

Because of its small size and short neck, we would expect that the green-winged teal among dabbling ducks would have the greatest difficulty in feeding when water levels are high. Low summer water levels are needed either to produce the seeds of moist-soil plants or to make available mud flats that the teal gleans for previous seed crops. Pintails also feed upon mud flats in late summer and fall, but flooding in late summer is not as adverse for them as it is for the shorter necked green-winged teal. However, for unknown reasons, high fall water levels have a greater adverse effect upon the length of stay by pintails. High summer levels favor the wigeon, perhaps through the greater production of filamentous algae. Mallards, as expected, are more independent of water levels than are other dabblers because of their ability to obtain a large part of their food from waste corn left in harvested fields.

Table 16.—Multiple regression coefficients of the Duration of Stay Index in relation to summer and fall water levels in the Illinois Valley, 1949–1976.

Species	a_0[a]	a_1[b]	a_2[c]	R^2[d]
Mallard	28.2	−0.52	−0.11	0.07
Pintail	33.5	−0.12	−1.24	0.19
Green-winged teal	38.2	−1.13	−0.45	0.24
Wigeon	12.8	2.26	−1.38	0.11

[a] Point of intercept.
[b] Slope of summer water level.
[c] Slope of fall water level.
[d] Coefficient of determination.

Diving ducks are largely independent of fall water levels, because large numbers of lesser scaup and canvasbacks feed on animal life and are independent of moist-soil plant resources. However, a catastrophic loss of fingernail clams, their basic food in the Illinois Valley, during the mid-1950's (Mills et al. 1966) resulted in a dramatic decline in both peak numbers and duck-days (Table 15). The lower Duration of Stay Index, 1956–1976, when fingernail clams have been virtually nonexistent in the valley, points out that not only did the Illinois Valley fail to attract large populations of scaup and canvasbacks, but also those that stopped in migration remained more briefly than they formerly did.

The highly significant correlation coefficients (*r*) between mean peak numbers of ducks and mean numbers of duck-days (Table 15) implies that either expression adequately reflects yearly changes in the population status of ducks in the Illinois Valley. It also implies that shortly after arriving ducks detect the availability of food. If little food is available, they tarry but a day or two before continuing in migration. Many field observations by Bellrose on the behavior of migrating waterfowl support this contention. It is becoming more prevalent for large numbers of waterfowl that arrive one night to leave the following night because of food shortages.

MANAGEMENT PRACTICES AND CONSIDERATIONS

The prohibition of baiting in the mid-1930's greatly reduced the duck

Table 17.—Duck clubs in the Illinois River valley. Area figures are in hectares (2.471 acres/hectare).

County	Number of Clubs	Total Area of Clubs	Clubs Reporting on Water Management			
			Number	Area	Area Under Control	Percent Under Control
La Salle	18	1,035.6	9	784.3	140.8	18.0
Bureau	30	1,233.5	10	580.7	138.0	23.8
Putnam	29	3,055.8	18	2,346.7	1,437.5	61.3
Marshall	38	3,414.0	22	3,040.9	444.8	14.6
Woodford	26	1,649.9	17	1,217.3	341.2	28.0
Peoria	6	739.8	5	711.0	342.0	48.1
Tazewell	1	47.8	1	47.8	11.3	23.6
Fulton	7	620.8	4	216.5	141.6	65.4
Mason	62	8,663.7	38	7,182.9	2,907.7	40.5
Schuyler	2	502.7	2	501.8	170.0	33.9
Cass	21	2,536.0	18	2,525.3	381.6	15.1
Brown	1	85.0	1	85.0	72.8	85.6
Morgan	3	350.5	2	315.7	6.1	1.9
Pike	1	35.2	1	35.2	35.2	100.0
Scott	2	15.0	...	...	...	...
Greene	4	599.0	2	80.9	2.0	2.5
Calhoun	1	52.2	1	52.2	9.7	18.6
Total	*252*	*24,636.5*	*151*	*19,724.2*	*6,582.3*	*33.4*

Fig. 24.—A harvested corn field, with cleared areas in front of duck blinds for decoys, flooded to attract mallards during the hunting season. Note the small levees used to impound water pumped from adjacent wells.

kill by private clubs in the Illinois River valley (Bellrose 1944). It became necessary for duck clubs to develop alternative sources of duck food if they were to continue to enjoy a semblance of quality hunting. Although waste corn left after harvest by mechanical pickers temporarily filled the food requirements of mallards, their field feeding was not necessarily conducive to good hunting in bottomland lake habitats.

Consequently, in the late 1930's the more alert and affluent duck clubs began constructing levees to provide adequate water control, the key to increasing the growth of waterfowl food plants. World War II interrupted this development, but in subsequent years more and more tracts of bottomland have been brought under some degree of low-water control.

A questionnaire sent in September 1978 to 219 duck clubs in the Illinois Valley [those of the 252 clubs owning more than 16 ha (40 acres)] elicited information on impounded areas. About one-third of the lands controlled by private clubs have levees or other structures that permit a degree of water control (Table 17). The heights of the levees, as reported in the question-

Fig. 25.—Beds of Japanese millet sown from a light aircraft on mud flats by a duck club to attract waterfowl. To make seeds available for dabbling ducks, millet beds are flooded during the fall.

naire, varied from 0.9 to 1.8 m (3–6 ft). Although not high enough to keep out most spring floods, these structures are adequate to prevent flooding by many (but not all) rises during the summer.

Fig. 26.—Duck club impoundment on Goose Lake, north of Havana, where moist-soil duck food plants volunteered following dewatering.

Table 18.—Waterfowl lands under state and federal ownership in the Illinois River valley, with the area of impoundments subject to or available for dewatering. Area figures are in hectares (2.471 acres/hectare).

Location	State or Federal Ownership	Total Area	Water Area	Area Subject to Water Level Control	Percent of Water Area with Water Level Control
Lake Depue	S	826.0	212.1	10.1	4.8
Cameron Unit	F	257.6	157.0	0.0	0.0
Sparland, Marshall County, & Spring Branch	S	2,241.3	1,621.6	0.0	0.0
Woodford County	S	1,173.9	996.5	0.0	0.0
Pekin Lake	S	602.2	221.8	0.0	0.0
Spring Lake	S	801.6	520.0	300.0	57.7
Rice Lake	S	1,068.3	559.8	306.4	54.7
Lake Chautauqua	F	1,804.5	1,378.0	413.4	30.0
Anderson Lake	S	863.0	551.8	2.0	trace
Sanganois	S	3,487.5	689.3	1,099.6[a]	100.0
Meredosia Lake	F	748.7	63.1	30.6	48.5
Calhoun County & adjacent areas	S	4,509.9	1,375.9	752.7	62.3
Calhoun unit	F	2,043.7	1,094.6	74.9	6.8
Total		*20,428.2*	*9,441.5*	*2,989.7*	*31.7*

[a] The larger area under water level control results from the potential inundation of bottomland timber within the impoundment.

The duck clubs use some of the impoundments to grow corn that matures in 90 days, sorghum, buckwheat, or a combination (Fig. 24). However, most impoundments are used to develop moist-soil vegetation; either Japanese millet seed is broadcast on mud flats, or native plants are permitted to volunteer and grow naturally (Fig. 25). An increasing number of clubs are relying at least to some degree on nature to provide food from volunteer native species (Fig. 26).

State and federal waterfowl areas in the Illinois Valley have also been developed to provide control of water levels in the summer and fall. Data in Table 18 show the areas of impoundments on state and federal public shooting grounds and refuges. Nearly 20 percent of the government areas have water management, a lower proportion than the 33.8 percent of private duck clubs.

The degree to which these low levees permit dewatering in summer and flooding in the fall depends upon their height. The percentages of the years 1938–1976 in which water would have overtopped a particular elevation on the Henry gauge, Peoria Pool, between 15 July and 15 October were calculated from average gauge readings and are shown in Fig. 27. Similar data are shown for the Havana gauge, La Grange Pool (Fig. 28). To correct for locations upstream from the respective gauges, add 1.3 cm/km (0.8 inch/mile); downstream, subtract 1.3 cm/km.

At Henry any levee elevation up to 134.7 m (442 ft) msl would be overtopped about 1 year in every 3, and at 135.3 m (444 ft) msl, 1 year in every 5. Overtopping 132.1 m (433.3 ft) msl levees on the Havana gauge has occurred about every other year, and 133.3-m (437.3-ft) msl levees were overtopped 1 year in every 5. The La

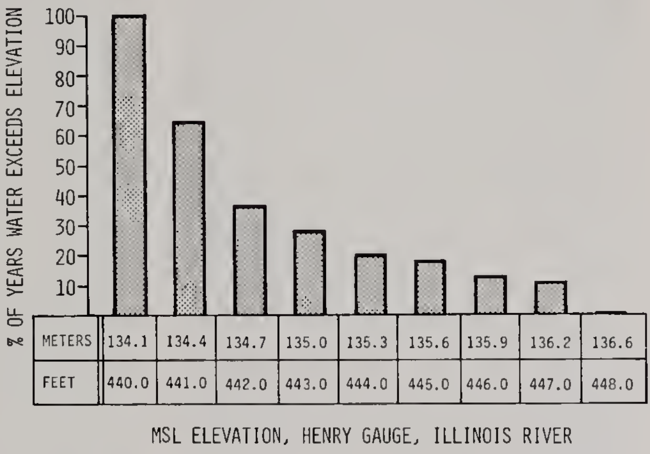

Fig. 27.—The percentage of years, 1938–1976, that water levels would have overtopped a levee of given elevation on the Henry gauge in the Peoria Pool from 15 July to 15 October.

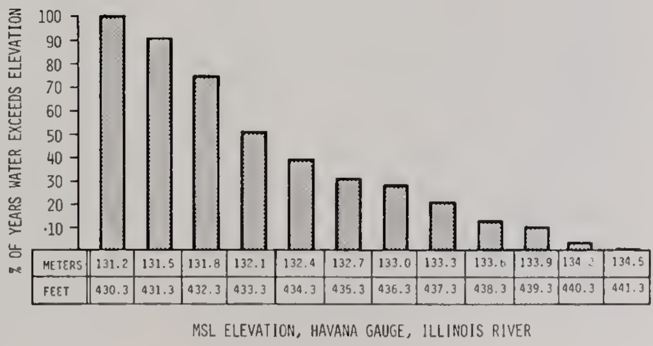

Fig. 28.—The percentage of years, 1938–1976, that water levels would have overtopped a levee of given elevation on the Havana gauge in the La Grange Pool from 15 July to 15 October.

Grange Pool is subject to more frequent flooding than the Peoria Pool because of the entrance of the Mackinaw and Spoon rivers below Peoria.

The lower the levee, the lower its initial cost and subsequent maintenance costs. Shallow waters limit the size of waves; as waters deepen, waves grow, as do their erosive effects on levees. Once flood waters overtop levees, their erosive force is diminished. Consequently, in determining the height of a levee, two opposing factors must be considered: The higher a levee, the more it will cost to build and maintain, but the more summer floods (15 July–15 October) it will exclude. To attempt to exclude summer floods in all years would be unrealistic.

DISCUSSION

The degradation of bottomland lakes in the Illinois Valley by sedimentation has adversely affected waterfowl. Aquatic and marsh vegetation declined almost to the point of extinction during the middle years of the study period (1938–1976). In the last decade, only remnant beds of the most tolerant plants—American lotus, river bulrush, and marsh smartweed—have persisted. Of all aquatic and marsh plants in the Midwest, these species are the best adapted to fluctuating water levels and turbidity. Unfortunately, they are poor duck foods. American lotus seeds are too hard to be palatable to most ducks (Bellrose & Anderson 1943). River bulrush and marsh smartweed produce little seed under the existing harsh conditions—even less than the yield reported earlier by Low & Bellrose (1944).

Aquatic and marsh plants used as food by waterfowl disappeared from the bottomland lakes of the Illinois Valley either because of altered water levels or because of increased turbidity. Altered water levels were of local importance, but turbidity increases were widespread and far more significant.

Turbidity increased because of increased sedimentation. According to a study by Jackson & Starrett (1959:166), waves produced by winds and movements of rough fish resuspended the fine bottom sediments. They concluded, "The resuspension of sediment particles, which were originally carried and deposited in the lake by flood waters of the Illinois River, caused the high turbidities at Lake Chautauqua." Stall & Melsted (1951) reported that although the largest sediment particles at Lake Chautauqua began to settle soon after disturbance ceased, much of the sediment took from 7 to 12 days to settle to the bottom.

Studies of sedimentation in bottomland lakes by Stall & Melsted (1951), Lee et al. (1976 unpublished), Lee & Stall (1976 unpublished), and by us demonstrate that these lakes are filling with sediment at an alarming rate. On three lakes—Upper Peoria, Chautauqua, and Meredosia—analyses of two different time periods show that the annual rate of sedimentation at a given water depth has increased. Because in two of the three lakes the earlier period (which showed a lower sedimentation rate) included more years, the sediments deposited in this period have been buried more deeply than more recently deposited sediments and thus may have been subjected to a greater degree of compaction (David L. Gross, Illinois State Geological Survey, personal communication). However, compaction alone cannot explain the great differences between the two periods' sedimentation rates. Hence, we conclude that streams tributary to the Illinois River are now transporting more sediment into the main channel than they previously did.

Sediment tends to make lake bottoms more uniform because more material is deposited on deep than on shallow bottoms. Whereas at the turn of the century bottomland lake beds had diversified depths, they now invariably slope almost imperceptibly from shore to center. At normal water level, average depths at the centers of 11 bottomland lakes now vary from 10.2 to 109.2 cm (4–43 inches) with a mean of 47.2 cm (18.6 inches). When water levels are at the margins of the wooded shorelines, it takes little additional reduction in water levels to expose large sections of the lake basins as mud flats. When water level reductions occur in early summer (up to 15 July), black willows, cottonwoods, and soft maples volunteer and grow rapidly on the newly exposed mud flats. In an amazingly short span of years, what had once been part of the lake basin accrues to the bottomland forest and is lost as potential mud flats for the development of moist-soil waterfowl food plants.

During the period 1933–1976, over 1,376 ha (3,400 acres) of water surface (4.2 percent of the total lake acreage) in the bottomland lakes below Spring Valley were lost to sedimentation. The bottomland forest invaded as the water surface shrank (Bellrose et al. 1977); this process is continuing at an accelerating rate. Lee & Stall (1976 unpublished) predicted that in 33 years sedimentation will entirely fill the basin of Lake Depue.

Lee (1976 unpublished) studied the filling of Lake Chautauqua by sediment and concluded that its life expectancy was 92 years. At Meredosia Bay, Lee et al. (1976 unpublished) reported that sediment will fill the lake in 90 years. Because Peoria Lake is quite deep and the Illinois River flows through it, Peoria Lake will be the last lake in the valley to become extinct from sedimentation.

The loss of aquatic and marsh duck food plants combined with the ever-shallower bodies of water have caused private duck clubs, the Illinois Department of Conservation, and the U.S. Fish and Wildlife Service to turn increasingly to dewatering as a method of producing moist-soil vegetation for duck food.

The dewatering technique requires that mud flats be exposed for 70–90 days between 15 July and 15 October. Dewatering can be accomplished either by below-normal river levels during this time span or by managers' pumping out excess water. Small levees must isolate the managed unit from the river to minimize minor river fluctuations and to impound waters for inundating moist-soil plant beds after 1 October. Our studies show that the more complete the separation of backwater areas from the river, the better the development of waterfowl food plants.

Under the most favorable summer water levels, a maximum of 44 percent of the 28,329 ha (70,000 acres) in lake basins of the Illinois Valley would be available for moist-soil plant development. Because small summer water rises frequently reflood mud flats, moist-soil plant development is usually limited to between 3 and 20 percent of the basin area in the valley. However, each year additional acreage is being brought under some degree of water level control by private duck clubs and the Illinois Department of Conservation, thereby increasing the potential area available for moist-soil plant development.

Although a number of marsh managers in the Illinois Valley sow agricultural crops on the drier sites and Japanese millet on the wetter sites, it is doubtful whether this practice is justified. Most volunteer moist-soil plants are used intensively by waterfowl, which find them highly palatable (Bellrose & Anderson 1943). Cocklebur is the most important exception, but this "weed" species can be controlled by a brief reflooding.

Other species of moist-soil plants of value as duck food are more tolerant of temporary flooding than is cocklebur. All moist-soil plant species considered in this study perish when completely inundated. However, after germination and early growth on mud flats, some species continue to grow with the basal part of their stems in water. Rice cutgrass and Walter's millet are species most tolerant of prolonged basal inundation.

It is imperative that the moist-soil waterfowl food resources of the valley be enhanced. This enhancement can only be accomplished through more extensive construction of low levees, which, in conjunction with the use of pumps, will enable lakes or parts of lakes to be dewatered during the summer and flooded during the fall.

Over the past four decades, mallards have been able to obtain a large proportion of their food from waste corn in harvested fields (Anderson 1959). However, fall plowing and reduced waste grain, stemming from more efficient combines and new plant varieties, have reduced the availability of corn to mallards. No doubt improvements in harvest equipment and plant varieties will continue to decrease the availability of waste grain. Therefore, if mallard populations are to be maintained at current levels, the native food resources will have to be enhanced. Because water turbidity suppresses the growth of aquatic duck food plants in the Illinois Valley, the development of moist-soil plant resources provides the only feasible means of accomplishing this objective.

Under present cultural practices, farmlands of the Illinois River basin will continue to be subject to severe sheet erosion, tributaries will continue to transport soil particles into the Illinois River, and turbidity and sedimentation will continue to degrade and fill the shallow bottomland lakes.

If the degradation of wildlife values of the Illinois Valley is to be minimized, present levels of soil erosion must be reduced. The single most effective means of accomplishing this goal would be the adoption of minimum tillage practices on slopes devoted to open row crops. Slopes that erode severely should be restricted to small grain, hay crops, or permanent pastures.

Stream bank erosion also merits attention. In the last decade, the removal of trees and other woody vegetation from hundreds of miles of stream banks has greatly accelerated soil loss. A protective "green belt" is needed along tributary stream banks if this source of sediment is to be reduced.

Unless stern measures are taken in the near future, the lateral bottomland lakes of the Illinois River are doomed to early extinction.

SUMMARY

1.—The bottomland (backwater) lakes of the Illinois River valley embrace about 28,500 ha (70,000 acres) and attract hundreds of thousands of waterfowl during their fall and spring migrations. All of these backwater lakes except Peoria Lake are lateral to the river channel.

2.—The Illinois River occupies a valley much older than the river itself as a result of a series of unique geological events. This valley in essence was the Mississippi River valley before the Wisconsinan glaciation. Its bottomland lakes developed because the river's remarkably low rate of fall resulted in its aggrading rather than degrading.

3.—Unfortunately, the very principles of sedimentation that created the lakes also set the stage for their extinction. Under pristine conditions this extinction would have taken hundreds, perhaps thousands, of years, but man, through intensive use of the land, has greatly accelerated the process.

4.—Aquatic and terrestrial habitats of the Illinois Valley have suffered a series of cataclysmic events since 1900: first, a permanent rise in water level from water diverted from Lake Michigan; second, the draining of more than half of the 161,878-ha (400,000-acre) floodplain through the construction of levees and pumping stations; third, an upsurge in untreated urban and industrial pollution during the 1920's; fourth, the creation of a 2.7-m (9-ft) channel and its attendant navigation dams in the 1930's; and fifth, an acceleration in sedimentation rates following World War II, apparently resulting from an increase in the amount of open row crops grown within the basin.

5.—Waterfowl food plant resources have been dramatically altered by the many changes wrought by man. Factors that have directly affected the species composition and abundance of the wetland plants are (1) fluctuating water levels, (2) water turbidity, (3) water depth, and (4) competition between plant species.

6.—Fluctuating river levels adversely affect the development of aquatic and marsh vegetation on those bottomland lakes connected with the river at all stages. In the early years of the study, the more the lakes were separated from the river, the more extensive were their aquatic and marsh plant beds.

7.—During the earlier years of the study, aquatic and marsh plants disappeared from those lakes connected with the river at all water stages (and thus subject to water-level fluctuations). During the later years of the study, aquatic plants disappeared and the area of marsh plants greatly declined in all lakes, even in those enjoying a degree of separation from the river and minimal water-level fluctuations. Increases in water turbidity and bottom softness, stemming from sedimentation, appear to be responsible.

8.—However, low levees and pumps have increasingly been used to dewater all or part of the lake basins. This procedure controls small summer fluctuations and exposes mud flats for the development of moist-soil plants between 15 July and 15 October. Moist-soil plants—millets, smartweeds, nutgrasses, rice cutgrass, water hemp, and teal grass—produce an abundance of seed palatable to many species of ducks. Low summer water levels permit or expedite dewatering. Summer rises that overtop low levees usually destroy moist-soil plant beds.

9.—Sedimentation is rapidly filling in the bottomland lakes of the Illinois Valley, reducing their size, degrading water quality, and minimizing the diversity of bottom depths. The fine silts and clays deposited on the bottoms when river waters invade bottomland lakes are readily resuspended by wave action and the activity of rough fish. The consequent turbidity reduces the euphotic zone to such a shallow depth that aquatic plants can no longer survive. Marsh plants have difficulty maintaining footings as bottom soils become softer.

10.—Sedimentation occurs at a higher rate in deep water than in shallow water. Thus, most lakes now possess a uniform bottom instead of the turn-of-the-century variation in bottom depths. (Peoria Lake, through which the river channel passes, is an exception.) Lake basins are now platter shaped. Estimated life expectancies are 33 years for Lake Depue, 92 years for Lake Chautauqua, and 90 years for Meredosia Bay.

11.—The abundance of certain species of waterfowl in the Illinois Valley is related to the abundance of native food resources. Among the dabbling ducks, the size of fall populations of the pintail, green-winged teal, and wigeon correlated with the abundance of wetland plants. Mallards feed extensively on waste grain in harvested fields, but even so, when annual variations in the continental mallard population were taken into account, moist-soil plant abundance influenced the abundance of mallards. Diving duck populations were unrelated to wetland plant abundance. However, when a catastrophic loss of fingernail clams occurred, diving duck numbers crashed. Neither this food resource nor the population of diving ducks has recovered in the ensuing two decades.

12.—Fall river levels determine the depths in bottomland lakes and thus the availability of moist-soil plant foods. If the river is low and mud flats are exposed, moist-soil plant seeds will be unavailable to waterfowl. If, on the other hand, the river is high and mud flats are too deeply submerged, the result is the same. The higher the fall rise in water, the greater the reduction in numbers of green-winged teal, with the same influence to a lesser degree on pintails, wigeons, and mallards.

13.—As a result of the disappearance of aquatic plants and the prohibition of baiting, private duck clubs, the Illinois Department of Conservation, and the U.S. Fish and Wildlife Service have placed increasing emphasis on controlled dewatering of wetland habitats. Private duck clubs control 23,198 ha (57,320 acres) of land and water in the Illinois Valley and have 6,723 ha (16,612 acres) under varying degrees of low water level control. State and federal agencies control 15,644 ha (38,656 acres) and have 4,688 ha (11,585 acres) under similar water-level management.

LITERATURE CITED

Anderson, H. G. 1959. Food habits of migratory ducks in Illinois. Illinois Natural History Survey Bulletin 27(4):289–344.

Barrows, H. H. 1910. Geography of the middle Illinois Valley. Illinois State Geological Survey Bulletin 15. 128 p.

Bellrose, F. C., Jr. 1941. Duck food plants of the Illinois River valley. Illinois Natural History Survey Bulletin 21(8):237–280.

———. 1944. Duck populations and kill: an evaluation of some waterfowl regulations in Illinois. Illinois Natural History Survey Bulletin 23(2):327–372.

———, and H. G. Anderson. 1943. Preferential rating of duck food plants. Illinois Natural History Survey Bulletin 22(5):417–433.

———, and R. D. Crompton. 1970. Migrational behavior of mallards and black ducks as determined from banding. Illinois Natural History Survey Bulletin 30(3):167–234.

———, R. E. Sparks, F. L. Paveglio, Jr., D. W. Steffeck, R. C. Thomas, R. A. Weaver, and D. Moll. 1977. Fish and wildlife habitat changes resulting from the construction of a nine-foot navigation channel in the Illinois Waterway from La Grange Lock and Dam upstream to Lockport Lock and Dam. U.S. Army Corps of Engineers District, Chicago. 120 p.

Evans, R. L., and D. H. Schnepper. 1977. Sources of suspended sediment: Spoon River, Illinois. North-Central Section, Geological Society of America meeting. Carbondale, Illinois. 9 p.

Forbes, S. A., and R. E. Richardson. 1919. Some recent changes in Illinois River biology. Illinois State Natural History Survey Bulletin 13(6):139–156.

———, and ———. 1920. The fishes of Illinois. 2nd ed. Illinois Natural History Survey. cxxxvi + 357 p.

Illinois Cooperative Crop Reporting Service. 1968. Illinois agricultural statistics, field crops by counties, twenty-one years, 1945–1965. Bulletin 68-4. Springfield. 155 p.

———. 1977. Illinois agricultural statistics annual summary 1977. Bulletin 77-1. Springfield. 106 p.

Jackson, H. O., and W. C. Starrett. 1959. Turbidity and sedimentation at Lake Chautauqua, Illinois. Journal of Wildlife Management 23(2):157–168.

Kofoid, C. A. 1903. Plankton studies. IV. The plankton of the Illinois River, 1894–1899, with introductory notes upon hydrography of the Illinois River and its basin. Part I. Quantitative investigations and general results. Illinois State Laboratory of Natural History Bulletin 6(2):95–629.

Low, J. B., and F. C. Bellrose, Jr. 1944. The seed and vegetative yield of waterfowl food plants in the Illinois River valley. Journal of Wildlife Management 8(1):7–22.

Mills, H. B., W. C. Starrett, and F. C. Bellrose. 1966. Man's effect on the fish and wildlife of the Illinois River. Illinois Natural History Survey Biological Notes 57. 24 p.

Mulvihill, W. F., and L. D. Cornish. 1929. Flood control report: an engineering study of the flood situation in the state of Illinois. Illinois Division of Waterways. 402 p.

National Oceanic and Atmospheric Administration Environmental Data and Information Service (U.S. Weather Bureau). 1939–1976. Daily River Stages Vol. 37–Vol. 72.

Purdy, W. C. 1930. A study of pollution and natural purification of the Illinois River. II. The plankton and related organisms. U.S. Public Health Service Bulletin 198. 212 p.

Richardson, R. E. 1921. The small bottom and shore fauna of the middle and lower Illinois River and its connecting lakes, Chillicothe to Grafton: its valuations; its sources of food supply; and its relation to the fishery. Illinois State Natural History Survey Bulletin 13(15):363–522.

Stall, J. B., and S. W. Melsted. 1951. The silting of Lake Chautauqua, Havana, Illinois. Illinois State Water Survey, in cooperation with Illinois Agricultural Expericent Station, Report of Investigation 8. 15 p.

Starrett, W. C. 1971. A survey of the mussels (Unionacea) of the Illinois River: a polluted stream. Illinois Natural History Survey Bulletin 30(5):267–403.

U.S. Army Corps of Engineers, U.S. Engineers Office, Chicago, Illinois. 1933. Illinois and Des Plaines Rivers from mouth of the Illinois River to Lockport, Illinois.

Willman, H. B. 1973. Geology along the Illinois Waterway—a basis for environmental planning. Illinois State Geological Survey Circular 478. 48 p.

———, and J. C. Frye. 1970. Pleistocene stratigraphy of Illinois. Illinois State Geological Survey Bulletin 94. 204 p.

Woermann, J. W. 1902–1904. Map of the secondary triangulation system of the Illinois and Des Plaines Rivers from Chicago, Illinois to the Illinois River. Corps of Engineers, Chicago Office, U.S. Army.

LIST OF COMMON AND SCIENTIFIC NAMES

With few exceptions the classification of the plants follows Gray's *New Manual of Botany,* seventh edition. The waterfowl classification follows Bellrose's *Ducks, Geese and Swans of North America,* second edition.

PLANTS

Algae	Chlorophyceae
Cattail	*Typha latifolia, T. angustifolia*
Giant bur-reed	*Sparganium eurycarpum*
Pondweeds	*Potamogeton* spp.
Longleaf pondweed	*Potamogeton nodosus*
Leafy pondweed	*Potamogeton foliosus*
Sago pondweed	*Potamogeton pectinatus*
Southern naiad (also called bushy pondweed)	*Najas guadalupensis*
Arrowleaf (also called arrowhead)	*Sagittaria calycina* (formerly *Lophotocarpus calycinus*)
Duck potato	*Sagittaria latifolia*
Waterweed (also called elodea)	*Anacharis canadensis*
Wild celery	*Vallisneria americana*
Teal grass (also called love grass)	*Eragrostis hypnoides*
Rice cutgrass	*Leersia oryzoides*
Wild rice	*Zizania aquatica*
Wild millet (also called duck millet, barnyard grass)	*Echinochloa crusgalli*
Japanese millet	*Echinochloa frumentacea*
Walter's millet	*Echinochloa walteri*
Sorghum	*Sorghum bicolor*
Corn	*Zea mays*
Soybeans	*Glycine max*
Nutgrasses	*Cyperus* spp.
American bulrush	*Scirpus americanus*
Softstem bulrush (also called roundstem bulrush)	*Scirpus validus*
Hardstem bulrush	*Scirpus acutus*
River bulrush	*Scirpus fluviatilis*
Spike rush	*Eleocharis palustris*
Duckweeds	*Spirodela polyrhiza, Lemna* spp.
Pickerel weed	*Pontederia cordata*
Water stargrass (also called mud plantain)	*Heteranthera dubia*
Black willow	*Salix nigra*
Cottonwood	*Populus deltoides*
Pin oak	*Quercus palustris*
Pecan	*Carya illinoensis*
Buckwheat	*Fagopyrum esculentum*
Nodding smartweed	*Polygonum lapathifolium*
Marsh smartweed	*Polygonum coccineum* (formerly *muhlenbergii*)
Largeseed smartweed	*Polygonum pennsylvanicum*
Swamp smartweed	*Polygonum hydropiperoides*
Water hemp (also called pigweed, hogweed)	*Amaranthus tuberculatus* (formerly *Acnida tuberculata*)
Coontail	*Ceratophyllum demersum*
Yellow pond lily	*Nuphar luteum* (formerly *Nymphaea advena*)
White water lily	*Nymphaea tuberosa* (formerly *Castalia tuberosa*)
American lotus	*Nelumbo lutea*
Soft maple (also called silver maple)	*Acer saccharinum*
Marsh mallow	*Hibiscus militaris*
Cocklebur	*Xanthium* spp.
Spanish needles	*Bidens* spp.

ANIMALS

Mollusca

Fingernail clams	Sphaeriidae

Fish

Carp	*Cyprinus carpio*

Birds

Wood duck	*Aix sponsa*
American wigeon	*Anas americana*
American green-winged teal	*Anas crecca carolinensis*
Mallard	*Anas platyrhynchos platyrhynchos*
Pintail	*Anas acuta acuta*
Blue-winged teal	*Anas discors*
Canvasback	*Aythya valisineria*
Ring-necked duck	*Aythya collaris*
Lesser scaup	*Aythya affinis*
Ruddy duck	*Oxyura jamaicensis rubida*
Coot	*Fulica americana*

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BULLETIN

Primary Insect Types in the Illinois Natural History Survey Collection, Exclusive of the Collembola and Thysanoptera

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This report is printed by authority of the State of Illinois. It is a contribution from the Section of Faunistic Surveys and Insect Identification of the Illinois Natural History Survey.

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UNION LABEL 5

Dr. Herbert H. Ross, 1908-1978. A lifetime of work and dedication to the study of systematics and evolu

Primary Insect Types in the Illinois Natural History Survey Collection, Exclusive of the Collembola and Thysanoptera

Donald W. Webb

SINCE ITS BEGINNING as the Natural History Society of Illinois in 1858 and its subsequent development as the Illinois Museum of Natural History and the State Laboratory of Natural History, the Illinois Natural History Survey has carried on research pertaining to the systematics and natural history of the fauna and flora of Illinois. Much of the early material and stimulation for the development of a state insect collection within the Natural History Survey during the late 1800's can be attributed to Stephen A. Forbes. His strong interest in the development of the insect collection was continued by subsequent Chiefs of the Natural History Survey and by the heads and staff of the Section of Faunistic Surveys and Insect Indentification.

In 1927 T. H. Frison published a list of all the insect types in the collections of the Illinois Natural History Survey and the University of Illinois and the Bolter collection. This list contained 1,067 primary types. Type-specimens in the University of Illinois have subsequently been transferred to the collection of the Illinois Natural History Survey. In the past 50 years 2,113 primary types have been added to the Survey's collection, primarily through the systematic research of T. H. Frison in Plecoptera and Hymenoptera; H. H. Ross in Trichoptera, Plecoptera, Homoptera, and Hymenoptera; H. B. Mills in Collembola; and L. J. Stannard, Jr., in Thysanoptera. The acquisitions of the personal collections of J. W. Folsom in Collembola and C. A. Robertson in Hymenoptera added numerous primary types to the Survey's collections. In addition, several active workers have periodically, or occasionally, deposited their types in the Survey's permanent collection upon completion of specific revisionary studies. Recently, Gerdes (1977) and Mari Mutt (1978) have published lists of all of the types of Thysanoptera and Collembola, respectively, in the Natural History Survey collection.

In this list only primary types currently located in or on loan from the Illinois Natural History Survey collection are listed along with the original citation for each species. The literature citation for the designation of each neotype and lectotype is also cited. To clarify the type-designation within the bees of the Robertson collection, lectotype specimens have been designated by W. E. LaBerge for those species not previously designated in the literature. The genera under which the species are listed are those under which they were originally described. Where possible the sex of each type is given. The term *syntype* is used in the sense of Article 73c of the International Code of Zoological Nomenclature (1964) and replaces the term *cotype* used by Frison (1927).

For simplicity, the various families within each order are arranged alphabetically, the genera are arranged alphabetically within each family, and the species are arranged alphabetically within each genus.

ACKNOWLEDGEMENTS

I am indebted to the many specialists who responded to queries about their own designations and to my associates in the Section of Faunistic Surveys and Insect Identification for serving as an editorial committee for this paper. They are J. K. Bouseman, G. L. Godfrey, W. E. LaBerge, P. W. Smith, and J. D. Unzicker. Each conducted a spot check on references within his specialty. The manuscript was typed by Mrs. Lois Webb and Mrs. Bernice P. Sweeney. Technical Editor Robert M. Zewadski edited the manuscript for publication.

COLLEMBOLA

See Mari Mutt 1978

THYSANURA

Lepismatidae

Ctenolepisma urbana Slabaugh 1940 Entomol. News 51:95. Holotype ♀

EPHEMEROPTERA

Ametropodidae

Metreturus pecatonica Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:147. Holotype nymph.

Baetidae

Baetis anachris Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:133. Holotype ♂

Baetis baeticatus Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:129. Holotype ♂

Baetis cleptis Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:130. Holotype ♂

Baetis elachistus Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:127. Holotype ♂

Baetis harti McDunnough 1924 Can. Entomol. 56.7. Holotype ♂

Baetis herodes Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:130. Holotype ♂

Baetis ochris Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:132. Holotype ♂

Baetis pallidula McDunnough 1924 Can. Entomol. 56:8. Holotype ♂

Baetis phyllis Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:134. Holotype ♂

Pseudocloeon myrsum Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:139. Holotype ♂

Pseudocloeon veteris McDunnough 1924 Can. Entomol. 56:8. Holotype ♂

Caenidae

Caenis gigas Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:53. Holotype ♂

Tricorythodes peridius Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:48. Holotype ♂

Ephemerellidae

Ephemerella argo Burks 1947 Can. Entomol. 79:232. Holotype ♂

Ephemerella berneri Allen & Edmunds 1958 J. Kans. Entomol. Soc. 31:224. Holotype nymph

Ephemerella bifurcata Allen 1971 Can. Entomol. 103:524. Holotype ♂ nymph

Ephemerella crenula Allen & Edmunds 1965 Misc. Publ. Entomol. Soc. Am. 4:277. Holotype nymph

Ephemerella denticula Allen 1971 Can. Entomol. 103:525. Holotype nymph

Ephemerella frisoni McDunnough 1927 Can. Entomol. 59:10. Holotype ♂

Ephemerella keijoensis Allen 1971 Can. Entomol. 103:526. Holotype nymph

Ephemerella kohnoi Allen 1971 Can. Entomol. 103:524. Holotype ♂ nymph

Ephemerella lita Burks 1947 Can. Entomol. 79:235. Holotype ♀ nymph

Ephemerella maxima Allen 1971 Can. Entomol. 103:526. Holotype nymph.

Ephemerella ora Burks 1947 Can. Entomol. 79:235. Holotype ♂

Ephemerella rossi Allen & Edmunds 1965 Misc. Publ. Entomol. Soc. Am. 4:278. Holotype nymph

Ephemerella simla Allen & Edmunds 1965 Misc. Publ. Entomol. Soc. Am. 4:277. Holotype nymph

Ephemeridae

Campsurus primus McDunnough 1924 Can. Entomol. 56:7. Holotype ♂

Heptageniidae

Heptagenia diabasia Burks 1946 Ann. Entomol. Soc. Am. 39:610. Holotype ♂

Heptagenia integer McDunnough 1924 Can. Entomol. 56:9. Holotype ♂

Heptagenia patoka Burks 1946 Ann. Entomol. Soc. Am. 39:612. Holotype ♂

Iron frisoni Burks 1946 Ann. Entomol. Soc. Am. 39:608. Holotype ♂

Iron namatus Burks 1947 Ann. Entomol. Soc. Am. 39:607. Holotype ♂

Stenonema areion Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:163. Holotype ♂

Stenonema ares Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:170. Holotype ♂

Stenonema lepton Burks 1946 Ann. Entomol. Soc. Am. 39:614. Holotype ♂

Stenonema metriotes Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:174. Holotype ♂

Leptophlebiidae

Atalophlebia sepia Thew 1960 Pan-Pac. Entomol. 36:130. Holotype ♂

Deleatidium vittatum Thew 1960 Pan-Pac. Entomol. 36:130. Holotype ♂

Paraleptophlebia sticta Burks 1953 Ill. Nat. Hist. Surv. Bull. 26:92. Holotype ♂

Thraulodes daidaleus Thew 1960 Pan-Pac. Entomol. 36:119. Holotype ♂

Thraulodes traverae Thew 1960 Pan-Pac. Entomol. 36:120. Holotype ♂

Ulmeritus adustus Thew 1960 Pan-Pac. Entomol. 36:126. Holotype ♂

Ulmeritus balteatus Thew 1960 Pan-Pac. Entomol. 36:124. Holotype ♂

Ulmeritus patagiatus Thew 1960 Pan-Pac. Entomol. 36:128. Holotype ♂

ODONATA

Aeschnidae

Gomphus lentulus Needham 1902 Can. Entomol. 34:275. Holotype ♂

Libellulidae

Somatochlora macrotona Williamson 1909 Entomol. News 20:78. Holotype ♂

ORTHOPTERA

Acrididae

Melanoplus macneilli Hart 1907 Bull. Ill. State Lab. Nat. Hist. 7:261. Lectotype ♂ designated by Frison (1927:143)

Melanoplus scudderi texensis Hart 1906 Entomol. News 17:158. Lectotype ♂ designated by Frison (1927:143)

Mesochlora unicolor Hart 1906 Entomol. News 17:157. Lectotype ♂ designated by Frison (1927:143)

Spharagemon saxatile Morse 1894 Proc. Boston Soc. Nat. Hist. 26:229. Syntypes 2♂, 1♀

Trimerotropis saxatilis McNeill 1901 Proc. U. S. Natl. Mus. 23:440. Lectotype ♂ designated by Frison (1927:143)

Gryllidae

Nemobius funeralis Hart 1906 Entomol. News 17:159. Holotype ♀

Oecanthus forbesi Titus 1903 Can. Entomol. 35:260. Holotype ♂

PLECOPTERA

Capniidae

Allocapnia aurora Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:159. Holotype ♂

Allocapnia brooksi Ross 1964 Entomol. News 75:169. Holotype ♂

Allocapnia cunninghami Ross & Ricker 1971 Ill. Biol. Monogr. 45:42. Holotype ♂

Allocapnia curiosa Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:268. Holotype ♂

Allocapnia forbesi Frison 1929 Bull. Ill. State Nat. Hist. Surv. 18:397. Holotype ♂

Allocapnia forbesi cornuta Frison 1935 Ill. Nat. Hist. Surv. Bull. 20:363. Holotype ♂

Allocapnia frisoni Ross & Ricker 1964 Trans. Ill. State Acad. Sci. 57:90. Holotype ♂

Allocapnia fumosa Ross 1964 Entomol. News 75:174. Holotype ♂

Allocapnia illinoensis Frison 1935 Ill. Nat. Hist. Surv. Bull. 20:365. Holotype ♂

Allocapnia indianae Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:162. Holotype ♀

Allocapnia jeanae Ross 1964 Entomol. News 75:171. Holotype ♂

Allocapnia loshada Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:163. Holotype ♂

Allocapnia malverna Ross 1964 Entomol. News 75:170. Holotype ♂

Allocapnia mohri Ross & Ricker 1964 Trans. Ill. State Acad. Sci. 57:91. Holotype ♂

Allocapnia mystica Frison 1929 Bull. Ill. State Nat. Hist. Surv. 18:399. Holotype ♂

Allocapnia ohioensis Ross & Ricker 1964 Trans. Ill. State Acad. Sci. 57:92. Holotype ♂

Allocapnia ozarkana Ross 1964 Entomol. News 75:172. Holotype ♂

Allocapnia pechumani Ross & Ricker 1964 Trans. Ill. State Acad. Sci. 57:88. Holotype ♂

Allocapnia peltoides Ross & Ricker 1964 Trans. Ill. State Acad. Sci. 57:91. Holotype ♂

Allocapnia perplexa Ross & Ricker 1971 Ill. Biol. Monogr. 45:44. Holotype ♂

Allocapnia polemistis Ross & Ricker 1971 Ill. Biol. Monogr. 45:24. Holotype ♂

Allocapnia rickeri Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:269. Holotype ♂

Allocapnia sandersoni Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:165. Holotype ♂

Allocapnia smithi Ross & Ricker 1971 Ill. Biol. Monogr. 45:46. Holotype ♂

Allocapnia stannardi Ross 1964 Entomol. News 75:174. Holotype ♂

Allocapnia tennessa Ross & Ricker 1964 Trans. Ill. State Acad. Sci. 57:90. Holotype ♂

Allocapnia unzickeri Ross & Yamamoto 1966 Entomol. News 77:267. Holotype ♂

Allocapnia virginiana Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:269. Holotype ♂

Allocapnia warreni Ross & Yamamoto 1966 Entomol. News 77:265. Holotype ♂

Allocapnia wrayi Ross 1964 Entomol. News 75:170. Holotype ♂

Allocapnia zekia Ross 1964 Entomol. News 75:171. Holotype ♂

Allocapnia zola Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:166. Holotype ♂

Capnia barbata Frison 1944 Trans. Am. Entomol. Soc. 69:153. Holotype ♂

Capnia distincta Frison 1937 Ill. Nat. Hist. Surv. Bull. 21:86. Holotype ♂

Capnia elevata Frison 1942 Pan-Pac. Entomol. 18:64. Holotype ♂

Capnia jewetti Frison 1942 Pan-Pac. Entomol. 18:63. Holotype ♂

Capnia limata Frison 1944 Trans. Am. Entomol. Soc. 69:155. Holotype ♂

Capnia melia Frison 1942 Pan-Pac. Entomol. 18:61. Holotype ♂

Capnia oregona Frison 1942 Pan-Pac. Entomol. 18:63. Holotype ♂

Capnia pileata Jewett 1966 Wasmann J. Biol. 24:104. Holotype ♂

Capnia projecta Frison 1937 Ill. Nat. Hist. Surv. Bull. 21:87. Holotype ♂

Capnia promota Frison 1937 Ill. Nat. Hist. Surv. Bull. 21:88. Holotype ♂

Capnia umpqua Frison 1942 Pan-Pac. Entomol. 18:65. Holotype ♂

Capnia wanica Frison 1944 Trans. Am. Entomol. Soc. 69:151. Holotype ♂

Capnia willametta Jewett 1955 Wasmann J. Biol. 13:147. Holotype ♂

Capnura venosa Banks 1900 Trans. Am. Entomol. Soc. 26:245. Syntype 1♀

Eucapnopsis vedderensis Ricker 1943 Indiana Univ. Publ. Sci. Ser. 12:86. Holotype ♂

Isocapnia abbreviata Frison 1942 Pan-Pac. Entomol. 18:71. Holotype ♂

Isocapnia agassizi Ricker 1943 Indiana Univ. Publ. Sci. Ser. 12:90. Holotype ♂

Isocapnia hyalita Ricker 1959 Can. J. Zool. 37:648. Holotype ♂

Isocapnia missourii Ricker 1959 Can. J. Zool. 37:651. Holotype ♂

Isocapnia spenceri Ricker 1943 Indiana Univ. Publ. Sci. Ser. 12:91. Holotype ♂

Isocapnia spenceri thujae Ricker 1943 Indiana Univ. Publ. Sci. Ser. 12:92. Holotype ♂

Chloroperlidae

Alloperla autumna Hoppe 1938 Univ. Wash. Publ. Biol. 4:152. Holotype ♂

Alloperla banksi Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:343. Holotype ♂

Alloperla caudata Frison 1934 Can. Entomol. 66:27. Holotype ♂

Alloperla chloris Frison 1934 Can. Entomol. 66:27. Holotype ♂

Alloperla concolor Ricker 1935 Can. Entomol. 67:256. Holotype ♂

Alloperla delicata Frison 1935 Trans. Am. Entomol. Soc. 61:334. Holotype ♂

Alloperla diversa Frison 1935 Trans. Am. Entomol. Soc. 61:333. Holotype ♂

Alloperla dubia Frison 1935 Trans. Am. Entomol. Soc. 61:338. Holotype ♂

Alloperla elevata Frison 1935 Trans. Am. Entomol. Soc. 61:335. Holotype ♂

Alloperla exquisita Frison 1935 Trans. Am. Entomol. Soc. 61:337. Holotype ♂

Alloperla fraterna Frison 1935 Trans. Am. Entomol. Soc. 61:334. Holotype ♂

Alloperla lateralis Banks 1911 Trans. Am. Entomol. Soc. 37:337. Syntype 1♂

Alloperla lodgei Frison 1935 Trans. Am. Entomol. Soc. 61:340. Holotype ♂

Alloperla mediana Banks 1911 Trans. Am. Entomol. Soc. 37:336. Syntypes 1♂, 1♀

Alloperla medveda Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:177. Holotype ♂

Alloperla nanina Banks 1911 Trans. Am. Entomol. Soc. 37:336. Syntype 1♀

Alloperla neglecta Frison 1935 Trans. Am. Entomol. Soc. 61:336. Holotype ♂

Alloperla nimbilis Hoppe 1938 Univ. Wash. Publ. Biol. 4:155. Holotype ♂

Alloperla occidens Frison 1937 Ill. Nat. Hist. Surv. Bull. 21:96. Holotype ♂

Alloperla oregonensis Frison 1935 Trans. Am. Entomol. Soc. 61:332. Holotype ♂

Alloperla pintada Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:186. Holotype ♂

Alloperla tamalpa Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:182. Holotype ♂

Alloperla thalia Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:178. Holotype ♂

Alloperla townesi Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:184. Holotype ♂

Alloperla urticae Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:185. Holotype ♂

Alloperla usa Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:178. Holotype ♂

Alloperla vostoki Ricker 1948 Trans. R. Can. Inst. 26:413. Holotype ♂

Chloroperla irregularis Klapalek 1923 Ann. Soc. Entomol. Belg. 63:28. Syntype 1♀

Chloroperla orpha Frison 1937 Ill. Nat. Hist. Surv. Bull. 21:91. Holotype ♂

Chloroperla terna Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:339. Holotype ♂

Hastaperla chilnualna Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:190. Holotype ♂

Utaperla sopladora Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:174. Holotype ♂

Leuctridae

Leuctra alabama James 1974 Ann. Entomol. Soc. Am. 67:964. Holotype ♂

Leuctra alta James 1974 Ann. Entomol. Soc. Am. 67:964. Holotype ♂

Leuctra claasseni Frison 1929 Bull. Ill. State Nat. Hist. Surv. 18:404. Holotype ♂

Leuctra cottaquilla James 1974 Ann. Entomol. Soc. Am. 67:964. Holotype ♂

Leuctra crossi James 1976 Ann. Entomol. Soc. Am. 69:882. Holotype ♂

Leuctra forcipata Frison 1937 Ill. Nat. Hist. Surv. Bull. 21:85. Holotype ♂

Leuctra grandis Banks 1906 Can. Entomol. 38:338. Syntype 1♂

Leuctra moha Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:169. Holotype ♂

Leuctra projecta Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:260. Holotype ♂

Leuctra rickeri James 1976 Ann. Entomol. Soc. Am. 69:882. Holotype ♂

Megaleuctra kincaidi Frison 1942 Pan-Pac. Entomol. 18:15. Holotype ♀

Perlomyia sobrina Frison 1936 Ann. Entomol. Soc. Am. 29:262. Holotype ♀

Perlomyia solitaria Frison 1936 Ann. Entomol. Soc. Am. 29:261. Holotype ♂

Zealeuctra arnoldi Ricker & Ross 1969 Can. J. Zool. 47:1114. Holotype ♂

Zealeuctra fraxina Ricker & Ross 1969 Can. J. Zool. 47:1117. Holotype ♂

Zealeuctra hitei Ricker & Ross 1969 Can. J. Zool. 47:1117. Holotype ♂

Zealeuctra narfi Ricker & Ross 1969 Can. J. Zool. 47:1118. Holotype ♂

Zealeuctra wachita Ricker & Ross 1969 Can. J. Zool. 47:1119. Holotype ♀

Zealeuctra warreni Ricker & Ross 1969 Can J. Zool. 47:1120. Holotype ♂

Nemouridae

Amphinemura puebla Baumann & Gaufin 1972 Nat. Hist. Mus. Los Ang. Cty. Contrib. Sci. 226:12. Holotype ♀

Nemoura besametsa Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:48. Holotype ♂

Nemoura chila Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:55. Holotype ♂

Nemoura decepta Frison 1942 Pan-Pac. Entomol. 18:13. Holotype ♂

Nemoura delosa Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:18. Holotype ♂

Nemoura dimicki Frison 1936 Ann. Entomol. Soc. Am. 29:256. Holotype ♂

Nemoura foersteri Ricker 1943 Indiana Univ. Publ. Sci. Ser. 12:70. Holotype ♂

Nemoura haysi Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:58. Holotype ♂

Nemoura linda Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:22. Holotype ♂

Nemoura lobata Frison 1936 Ann. Entomol. Soc. Am. 29:260. Holotype ♂

Nemoura mockfordi Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:24. Holotype ♂

Nemoura obscura Frison 1936 Ann. Entomol. Soc. Am. 29:258. Holotype ♂

Nemoura perplexa Frison 1936 Ann. Entomol. Soc. Am. 29:259. Holotype ♂

Nemoura pseudoproducta Frison 1942 Pan-Pac. Entomol. 18:11. Holotype ♂

Nemoura rossi Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:45. Holotype ♀

Nemoura stylata Banks 1920 Bull. Mus. Comp. Zool. 64:324. Syntypes 1♂, 1♀

Nemoura tina Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:35. Holotype ♂

Nemoura tuberculata Frison 1937 Ill. Nat. Hist. Surv. Bull. 21:84. Holotype ♂

Nemoura tumana Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:29. Holotype ♂

Nemoura varshava Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:25. Holotype ♂

Nemoura weberi Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:46. Holotype ♀

Peltoperlidae

Peltoperla laurie Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:154. Holotype ♀

Peltoperla mariana Ricker 1943 Indiana Univ. Publ. Sci. Ser. 12:47. Holotype ♂

Peltoperla zipha Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:247. Holotype ♂

Perlidae

Acroneuria filicis Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:275. Holotype ♀

Acroneuria mela Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:274. Holotype ♀

Acroneuria perplexa Frison 1937 Ill. Nat. Hist. Surv. Bull. 21:79. Holotype ♀

Anacroneuria chiapasa Jewett 1958 Am. Midl. Nat. 60:166. Holotype ♀

Anacroneuria crenulata Jewett 1958 Am. Midl. Nat. 60:171. Holotype ♀

Anacroneuria dampfi Jewett 1958 Am. Midl. Nat. 60:165. Holotype ♀

Anacroneuria flavominuta Jewett 1958 Am. Midl. Nat. 60:167. Holotype ♀

Anacroneuria nigrolineata Jewett 1958 Am. Midl. Nat. 60:163. Holotype ♀

Paragnetina fattigi Ricker 1949 Ann. Entomol. Soc. Am. 42:282. Holotype ♂

Perla modesta Banks 1908 Trans. Am. Entomol. Soc. 34:255. Syntype 1♀

Perla subvarians Banks 1920 Bull. Mus. Comp. Zool. 64:317. Syntypes 1♂, 1♀

Perla trictura Hoppe 1938 Univ. Wash. Publ. Biol. 4:151. Holotype ♂

Perla yakimae Hoppe 1938 Univ. Wash. Publ. Biol. 4:150. Holotype ♂

Perlodidae

Arcynopteryx walkeri Ricker 1943 Indiana Univ. Publ. Sci. Ser. 12:118. Holotype ♂

Arcynopteryx watertoni Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:75. Holotype ♂

Dictyopterygella knowltoni Frison 1937 Ill. Nat. Hist. Surv. Bull. 21:89. Holotype ♂

Diploperla arina Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:309. Holotype ♂

Diploperla bulbosa Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:307. Holotype ♂

Diploperla fraseri Ricker 1943 Indiana Univ. Publ. Sci. Ser. 12:106. Holotype ♂

Diploperla pilata Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:305. Holotype ♂

Hydroperla dorata Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:295. Holotype ♂

Hydroperla harti Frison 1935 Ill. Nat. Hist. Surv. Bull. 20:423. Holotype ♂

Hydroperla nalata Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:293. Holotype ♂

Hydroperla parallela Frison 1936 Ann. Entomol. Soc. Am. 29:261. Holotype ♂

Isogenus hansoni Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:111. Holotype ♂

Isogenus krumholzi Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:112. Holotype ♂

Isogenus tostonus Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:97. Holotype ♂

Isoperla bellona Banks 1911 Trans. Am. Entomol. Soc. 37:335. Syntypes 2♂, 1♀

Isoperla burksi Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:332. Holotype ♂

Isoperla cascadensis Hoppe 1938 Univ. Wash. Publ. Biol. 4:158. Holotype ♂

Isoperla chrysannula Hoppe 1938 Univ. Wash. Publ. Biol. 4:156. Holotype ♂

Isoperla confusa Frison 1935 Ill. Nat. Hist. Surv. Bull. 20:441. Holotype ♂

Isoperla conspicua Frison 1935 Ill. Nat. Hist. Surv. Bull. 20:445. Holotype ♀

Isoperla cotta Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:144. Holotype ♂

Isoperla davisi James 1974 Ann. Entomol. Soc. Am. 67:966. Holotype ♂

Isoperla decepta Frison 1935 Ill. Nat. Hist. Surv. Bull. 20:447. Holotype ♂

Isoperla dicala Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:321. Holotype ♂

Isoperla fumosa Neave 1933 Can. Entomol. 65:235. Holotype ♀

Isoperla insipida Hoppe 1938 Univ. Wash. Publ. Biol. 4:157. Holotype ♂

Isoperla jewetti Szczytko & Stewart 1976 Great Basin Nat. 36:215. Holotype ♂

Isoperla lata Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:334. Holotype ♂

Isoperla mohri Frison 1935 Ill. Nat. Hist. Surv. Bull. 20:455. Holotype ♂

Isoperla namata Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:327. Holotype ♂

Isoperla orata Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:323. Holotype ♀

Isoperla patricia Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:313. Holotype ♂

Isoperla pinta Frison 1937 Ill. Nat. Hist. Surv. Bull. 21:92. Holotype ♂

Isoperla richardsoni Frison 1935 Ill. Nat. Hist. Surv. Bull. 20:459. Holotype ♀

Isoperla tokula Hoppe 1938 Univ. Wash. Publ. Biol. 4:157. Holotype ♂

Isoperla truncata Frison 1937 Ill. Nat. Hist. Surv. Bull. 21:94. Holotype ♀

Isoperla ventralis Banks 1908 Psyche 15:66. Syntype 1♂

Pteronarcidae

Pteronarcys scotti Ricker 1952 Indiana Univ. Publ. Sci. Ser. 18:147. Holotype ♂

Pteronarcys shelfordi Frison 1934 Can. Entomol. 66:25. Holotype ♂

Taeniopterygidae

Brachyptera limata Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:255. Holotype ♂

Brachyptera rossi Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:254. Holotype ♂

Brachyptera zelona Ricker 1965 J. Fish. Res. Board Can. 22:477. Holotype ♂

Strophopteryx appalachia Ricker 1975 Can. J. Zool. 53:149. Holotype ♂

Strophopteryx arkansae Ricker 1975 Can. J. Zool. 53:150. Holotype ♂

Strophopteryx cucullata Frison 1934 Can. Entolmol. 66:29. Holotype ♀

Strophopteryx inaya Ricker 1975 Can. J. Zool. 53:150. Holotype ♂

Strophopteryx ostra Ricker 1975 Can. J. Zool. 53:151. Holotype ♂

Taeniopteryx burksi Ricker & Ross 1968 J. Fish. Res. Board Can. 25:1425. Holotype ♂

Taeniopteryx kincaidi Hoppe 1938 Univ. Wash. Publ. Biol. 4:164. Holotype ♂

Taeniopteryx lita Frison 1942 Ill. Nat. Hist. Surv. Bull. 22:249. Holotype ♂

Taeniopteryx lonicera Ricker & Ross 1968 J. Fish. Res. Board Can. 25:1427. Holotype ♂

Taeniopteryx metequi Ricker & Ross 1968 J. Fish. Res. Board Can. 25:1431. Holotype ♂

Taeniopteryx ugola Ricker & Ross 1968 J. Fish. Res. Board Can. 25:1437. Holotype ♂

MALLOPHAGA

Columbicola extincta Malcomson 1937 Ann. Entomol. Soc. Am. 30:55. Holotype ♂

Machaerilaemus complexus Malcomson 1937 Ann. Entomol. Soc. Am. 30:53. Holotype ♀

Myrsidea bonariensis Malcomson 1929 Ann. Entomol. Soc. Am. 22:728. Holotype ♀

Philopterus cristata Malcomson 1929 Ann. Entomol. Soc. Am. 22:729. Holotype ♀

HEMIPTERA

Coreidae

Carorhintha flava Fracker 1923 Ann. Entomol. Soc. Am. 16:171. Holotype ♂

Cydnidae

Corimelaena harti Malloch 1919 Bull. Ill. State Nat. Hist. Surv. 13:215. Holotype ♂

Corimelaena interrupta Malloch 1919 Bull. Ill. State Nat. Hist. Surv. 13:214. Holotype ♂

Corimelaena minutissima Malloch 1919 Bull. Ill. State Nat. Hist. Surv. 13:214. Holotype ♂

Corimelaena polita Malloch 1919 Bull. Ill. State Nat. Hist. Surv. 13:213. Holotype ♀

Galgupha aterrima Malloch 1919 Bull. Ill. State Nat. Hist. Surv. 13:211. Holotype ♂

Lygaeidae

Geocoris frisoni Barber 1926 Bull. Brooklyn Entomol. Soc. 21:38. Holotype ♂

Miridae

Agnocoris rossi Moore 1955 Proc. Entomol. Soc. Wash. 57:176. Holotype ♂

Bolteria amicta Uhler 1887 Entomol. Am. 3:34. Syntypes 10

Cyrtopeltocoris illini Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:117. Holotype ♂

Horcias illini Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:172. Holotype ♂

Hyaliodes brevis Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:58. Holotype ♂

Hyaliodes harti Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:57. Holotype ♂

Illnacora illini Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:83. Holotype ♂

Lopidea chandleri Moore 1956 Entomol. News 67:40. Holotype ♂

Lopidea wisteriae Moore 1956 Entomol. News 67:42. Holotype ♂

Lygus atritibialis Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:152. Holotype ♂

Lygus frisoni Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:151. Holotype ♂

Neolygus geminus Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:163. Holotype ♂

Orthotylus rossi Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:102. Holotype ♂

Orthotylus taxodii Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:101. Holotype ♂

Parthenicus taxodii Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:76. Holotype ♂

Phytocoris arundinicola Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:198. Holotype ♂

Pilophorus taxodii Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:121. Holotype ♂

Plagiognathus syrticolae Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:31. Holotype ♂

Polymerus illini Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:168. Holotype ♂

Reuteria platani Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:95. Holotype ♀

Strongylocoris mohri Knight 1941 Ill. Nat. Hist. Surv. Bull. 22:81. Holotype ♀

Nabidae

Nabis elongatus Hart 1907 Bull. Ill. State Lab. Nat. Hist. 7:262. Holotype ♂

Pentatomidae

Euschistus subimpunctatus Malloch 1919 Bull. Ill. State Nat. Hist. Surv. 13:191. Holotype ♀

Thyanta elegans Malloch 1919 Bull. Ill. State Nat. Hist. Surv. 13:218. Holotype ♂

Phymatidae

Phymata mystica Evans 1931 Ann. Entomol. Soc. Am. 24:717. Holotype ♂

HOMOPTERA

Aleyrodidae

Aleurodes aceris Forbes 1884 Rep. State Entomol. Ill. 14:110. Syntypes 3♀

Aphididae

Amphorophora nebulosa Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:275. Holotype ♀

Amphorophora rossi Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:277. Holotype ♀

Amphorophora sensoriata Mason 1923 Proc. Entomol. Soc. Wash. 25:189. Syntypes 6♀

Amphorophora singularis Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:279. Holotype ♀

Aphis bonnevillensis Knowlton 1928 Ann. Entomol. Soc. Am. 21:262. Syntype 1♀

Aphis caliginosa Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:182. Holotype ♀

Aphis carduella Walsh 1862 Proc. Entomol. Soc. Phila. 1:300. Neotype slide designated by Hottes & Frison (1931:184)

Aphis cari Essig 1917 Univ. Calif. Publ. Entomol. 1:317. Syntype 1♀

Aphis cephalanthi Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):11. Neotype slide designated by Hottes & Frison (1931:186)

Aphis chetansapa Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:186. Holotype ♀

Aphis cucumeris Forbes 1883 Rep. State Entomol. Ill. 12:83. Holotype ♀

Aphis decepta Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:192. Holotype ♀

Aphis fraternus Strom 1938 Ann. Entomol. Soc. Am. 31:473. Holotype ♀

Aphis funesta Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:194. Holotype ♀

Aphis gregalis Knowlton 1928 Ann. Entomol. Soc. Am. 21:259. Syntype 1♀

Aphis hiltoni Essig 1922 Pomona Coll. J. Entomol. Zool. 14:61. Syntype 1♀

Aphis illinoisensis Shimer 1866 Prairie Farmer 18:316. Neotype slide designated by Hottes & Frison (1931:199)

Aphis impatientis Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):12. Syntype 1♀

Aphis knowltoni Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:199. Syntypes 2♀

Aphis luridis Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:200. Holotype ♀

Aphis nyctalis Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:206. Holotype ♀

Aphis pseudobrassicae Davis 1914 Can. Entomol. 46:231. Syntype 1♀

Aphis pulchella Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:212. Holotype ♀

Aphis signatis Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:219. Holotype ♀

Aphis vernoniae Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):10. Lectotype ♀ designated by Hottes & Frison (1931:223)

Aphis zilora Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:224. Holotype ♀

Asiphonaphis anogis Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:225. Holotype ♀

Calaphis betulella Walsh 1862 Proc. Entomol. Soc. Phila. 1:301. Neotype slide designated by Hottes & Frison (1931:244)

Callipterus caryaefoliae Davis 1910 Entomol. News 21:198. Lectotype ♀ designated by Frison (1927:154)

Capitophorus corambus Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:281. Holotype ♀

Capitophorus oestlundii Knowlton 1927 Can. Entomol. 59:235. Syntype 1♀

Capitophorus pakansus Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:286. Holotype ♀

Capitophorus patonkus Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:287. Holotype ♀

Cerosipha rubifolii Thomas 1879 Rep. State Entomol. Ill. 8:121. Neotype ♀ designated by Hottes & Frison (1931: 231)

Chaitophorus flavus Forbes 1884 Rep. State Entomol. Ill. 13:42. Lectotype ♀ designated by Frison (1927:155)

Chaitophorus neglectus Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:161. Holotype ♀

Chaitophorus negundinis Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):10. Syntype 2♀

Chaitophorus populicola Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):10. Syntype 1♀

Chaitophorus pusillus Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:163. Holotype ♀

Chaitophorus salicicola Essig 1911 Pomona Coll. J. Entomol. Zool. 3:532. Syntype 1♀

Cinara difficilis Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:153. Holotype ♀

Drepanaphis keshenae Granovsky 1931 *in* Hottes & Frison Bull. Ill. State Nat. Hist. Surv. 19:248. Syntypes 2♀

Durocapillata utahensis Knowlton 1927 Ann. Entomol. Soc. Am. 20:229. Syntypes 4♀

Eichochaitophorus populifolii Essig 1912 Pomona Coll. J. Entomol. Zool. 4:722. Syntype 1♀

Eriosoma mimica Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:353. Holotype ♀

Forda occidentalis Hart 1894 Rep. State Entomol. Ill. 18:95. Lectotype ♀ designated by Frison (1927:155)

Fullawaya saliciradicis Essig 1912 Pomona Coll. J. Entomol. Zool. 4:737. Syntype 1♀

Geoica squamosa Hart 1894 Rep. State Entomol. Ill. 18:102. Lectotype ♀ designated by Frison (1927:155)

Idiopterus nephrelepidis Davis 1909 Ann. Entomol. Soc. Am. 2:199. Lectotype ♀ designated by Frison (1927:155)

Lachnus taxifolia Swain 1918 Trans. Am. Entomol. Soc. 44:11. Syntypes 2♀

Lachnus vanduzei Swain 1919 Univ. Calif. Publ. Entomol. 3:50. Syntype 1♀

Macrosiphum anomalae Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:298. Holotype ♀

Macrosiphum coryli Davis 1914 Can. Entomol. 46:48. Syntype 1♀

Macrosiphum erigeronensis Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):7. Neotype slide designated by Hottes & Frison (1931:305)

Macrosiphum illini Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:309. Holotype ♀

Macrosiphum illini crudae Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:311. Holotype ♀

Macrosiphum illini sangomonensis Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:312. Holotype ♀

Macrosiphum kickapoo Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:312. Holotype ♀

Macrosiphum packi Knowlton 1928 Pan-Pac. Entomol. 4:169. Syntype 1♀

Macrosiphum pallens Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:315. Holotype ♀

Macrosiphum ribiellum Davis 1919 Can. Entomol. 51:231. Syntype 1♀

Macrosiphum ruralis Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:321. Holotype ♀

Macrosiphum sanguinarium Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:323. Holotype ♀

Macrosiphum tapuskae Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:327. Holotype ♀

Macrosiphum tardae Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:329. Holotype ♀

Macrosiphum venaefuscae Davis 1914 Can. Entomol. 46:77. Syntype 1♀

Macrosiphum zinzalae Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:332. Holotype ♀

Megoura solani Thomas 1879 Rep. State Entomol. Ill. 8:73. Holotype ♀

Melanoxantherium antennatum Patch 1913 Maine Agric. Exp. Stn. Tech. Bull. 213:87. Syntype 1♀

Minuticornis gravidis Knowlton 1928 Fla. Entomol. 12:60. Syntypes many

Monellia californicus Essig 1912 Pomona Coll. J. Entomol. Zool. 4:767. Syntype 1♀

Monellia nigropunctata Granovsky 1931 *in* Hottes & Frison Bull. Ill. State Nat. Hist. Surv. 19:252. Syntypes 14♀

Mordwilkoja vagabunda Walsh 1862 Proc. Entomol. Soc. Phila. 1:306. Neotype slide designated by Hottes & Frison (1931:361)

Myzocallis hyperici Thomas 1879 Rep. State Entomol. Ill. 8:108. Lectotype ♀ designated by Hottes & Frison (1931:232)

Myzus aquilegiae Essig 1917 Univ. Calif. Publ. Entomol. 1:314. Syntype 1♀

Myzus thomasi Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:343. Holotype ♀

Neosymydobius memorialis Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:262. Holotype ♀

Pemphigus ephemeratus Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:365. Holotype ♀

Pemphigus fraxinifolii Thomas 1879 Rep. State Entomol. Ill. 8:146. Syntypes 3♀

Pemphigus rubi Thomas 1879 Rep. State Entomol. Ill. 8:147. Syntypes 2♀

Pemphigus tartareus Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:369. Holotype ♀

Pergandeidia corni Tissot 1929 Fla. Entomol. 13:2. Syntype 1♀

Phymatosiphum monelli Davis 1909 Ann. Entomol. Soc. Am. 2:197. Lectotype ♀ designated by Frison (1927:156)

Plocamaphis terricola Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:173. Holotype ♀

Rhizobius spicatus Hart 1894 Rep. State Entomol. Ill. 18:104. Syntypes 12♀

Rhopalosiphum enigmae Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:235. Holotype ♀

Rhopalosiphum enigmae parvae Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:237. Holotype ♀

Rhopalosiphum tulipae Thomas 1879 Rep. State Entomol. Ill. 8:80. Syntype 1♀

Saltusaphis wanica Hottes & Frison 1931 Bull. Ill. State Nat. Hist. Surv. 19:266. Holotype ♀

Schizoneura panicola Thomas 1879 Rep. State Entomol. Ill. 8:138. Syntype 1♀

Schizoneura pinicola Thomas 1879 Rep. State Entomol. Ill. 8:137. Holotype ♀

Siphonophora acerifoliae Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):4. Lectotype ♀ designated by Hottes & Frison (1931:247)

Siphonophora ambrosiae Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):4. Lectotype ♀ designated by Hottes & Frison (1931:298)

Siphonophora coreopsidis Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):7. Syntypes 1♂, 1♀

Siphonophora euphorbiae Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):6. Syntype 1♀

Siphonophora euphorbicola Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):6. Syntype 1♀

Siphonophora heucherae Thomas 1879 Rep. State Entomol. Ill. 8:66. Syntypes many

Siphonophora minor Forbes 1884 Rep. State Entomol. Ill. 13:101. Lectotype ♀ designated by Frison (1927:156)

Siphonophora salicicola Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):8. Syntype 1♀

Siphonophora setariae Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):5. Lectotype ♀ designated by Hottes & Frison (1931:234)

Siphonophora viticola Thomas 1878 Bull. Ill. State Lab. Nat. Hist. 1(2):5. Lectotype ♀ designated by Hottes & Frison (1931:199)

Symdobius salicicorticis Essig 1912 Pomona Coll. J. Entomol. Zool. 4:731. Syntypes 2♀

Symydobius agrifoliae Essig 1917 Univ. Calif. Publ. Entomol. 1:311. Syntype 1♀

Thomasia crucis Essig 1912 Pomona Coll. J. Entomol. Zool. 4:741. Syntype 1♀

Thoracaphis umbellulariae Essig 1932 Univ. Calif. Publ. Entomol. 6:4. Syntype 1♀

Thripsaphis hottesi Frison & Ross 1933 Can. Entomol. 65:152. Holotype ♀

Tychea brevicornis Hart 1894 Rep. State Entomol. Ill. 18:97. Syntypes 8♀

Tychea erigeronensis Thomas 1879 Rep. State Entomol. Ill. 8:168. Syntypes 3 immatures

Cicadellidae

Dikraneura hamar DeLong & Ross 1950 Ohio J. Sci. 50:87. Holotype ♂

Empoa albopicta Forbes 1884 Rep. State Entomol. Ill. 13:181. Lectotype ♂ designated by Frison (1927:149)

Empoasca alberta Ross 1963 Ann. Entomol. Soc. Am. 56:216. Holotype ♂

Empoasca alceda Ross & Cunningham 1960 Ohio J. Sci. 60:314. Holotype ♂

Empoasca altmani Cunningham & Ross 1965 Ann. Entomol. Soc. Am. 58:836. Holotype ♂

Empoasca ancella Cunningham & Ross 1965 Ann. Entomol. Soc. Am. 58:838. Holotype ♂

Empoasca andresia Ross 1963 Ann. Entomol. Soc. Am. 56:218. Holotype ♂

Empoasca angustifoliae Ross 1963 Ann. Entomol. Soc. Am. 56:220. Holotype ♂

Empoasca anilla Ross 1959 Ann. Entomol. Soc. Am. 52:315. Holotype ♂

Empoasca arizona Ross 1963 Ann. Entomol. Soc. Am. 56:221. Holotype ♂

Empoasca beckeri Ross 1959 Ann. Entomol. Soc. Am. 52:310. Holotype ♂

Empoasca canda Ross & Moore 1957 Ann. Entomol. Soc. Am. 50:120. Holotype ♂

Empoasca canthella Ross & Cunningham 1960 Ohio J. Sci. 60:311. Holotype ♂

Empoasca cascada Ross 1963 Ann. Entomol. Soc. Am. 56:222. Holotype ♂

Empoasca caverna Davidson & DeLong 1938 Ohio J. Sci. 38:93. Holotype ♂

Empoasca chapingo Ross 1963 Ann. Entomol. Soc. Am. 56:222. Holotype ♂

Empoasca cirsia Cunningham & Ross 1965 Ann. Entomol. Soc. Am. 58:838. Holotype ♂

Empoasca clinata Ross 1963 Ann. Entomol. Soc. Am. 56:215. Holotype ♂

Empoasca consecta Ross 1963 Ann. Entomol. Soc. Am. 56:221. Holotype ♂

Empoasca cristella Ross & Cunningham 1960 Ohio J. Sci. 60:311. Holotype ♂

Empoasca crystola Ross 1963 Ann. Entomol. Soc. Am. 56:215. Holotype ♂

Empoasca cunninghami Ross 1959 Ann. Entomol. Soc. Am. 52:314. Holotype ♂

Empoasca deckeri Ross & Cunningham 1960 Ohio J. Sci. 60:312. Holotype ♂

Empoasca eccla Ross & Moore 1957 Ann. Entomol. Soc. Am. 50:120. Holotype ♂

Empoasca exiguae Ross 1963 Ann. Entomol. Soc. Am. 56:220. Holotype ♂

Empoasca fenestra Ross 1959 Ann. Entomol. Soc. Am.52:312. Holotype ♂

Empoasca fontana Ross 1963 Ann. Entomol. Soc. Am. 56:223. Holotype ♂

Empoasca foxi Ross & Cunningham 1960 Ohio J. Sci. 60:312. Holotype ♂

Empoasca foxiella Cunningham & Ross 1965 Ann. Entomol. Soc. Am. 58:836. Holotype ♂

Empoasca gansella Ross 1959 Ann. Entomol. Soc. Am. 52:312. Holotype ♂

Empoasca gibbosa Cunningham & Ross 1965 Ann. Entomol. Soc. Am. 58:840. Holotype ♂

Empoasca gibsoni Ross 1959 Ann. Entomol. Soc. Am. 52:314. Holotype ♂

Empoasca gribisa Ross 1963 Ann. Entomol. Soc. Am. 56:219. Holotype ♂

Empoasca guttiformis Cunningham & Ross 1965 Ann. Entomol. Soc. Am. 58:840. Holotype ♂

Empoasca hastosa Ross & Moore 1957 Ann. Entomol. Soc. Am. 50:119. Holotype ♂

Empoasca humilis Ross 1963 Ann. Entomol. Soc. Am. 56:218. Holotype ♂

Empoasca improcera Ross 1963 Ann. Entomol. Soc. Am. 56:220. Holotype ♂

Empoasca inaequiformis Cunningham & Ross 1965 Ann. Entomol. Soc. Am. 58:840. Holotype ♂

Empoasca incoata Ross 1959 Ann. Entomol. Soc. Am. 52:313. Holotype ♂

Empoasca kraemeri Ross & Moore 1957 Ann. Entomol. Soc. Am. 50:120. Holotype ♂

Empoasca laceiba Ross & Cunningham 1960 Ohio J. Sci. 60:311. Holotype ♂

Empoasca lucidae Ross 1963 Ann. Entomol. Soc. Am. 56:216. Holotype ♂

Empoasca mergata Ross 1959 Ann. Entomol. Soc. Am. 52:312. Holotype ♂

Empoasca mexara Ross & Moore 1957 Ann. Entomol. Soc. Am. 50:121. Holotype ♂

Empoasca millsi Ross 1959 Ann. Entomol. Soc. Am. 52:315. Holotype ♂

Empoasca minetra Cunningham & Ross 1965 Ann. Entomol. Soc. Am. 58:838. Holotype ♂

Empoasca necyla Davidson & DeLong 1939 Ohio J. Sci. 39:110. Holotype ♂

Empoasca nodosa Cunningham & Ross 1965 Ann. Entomol. Soc. Am. 58:842. Holotype ♂

Empoasca occidua Ross 1963 Ann. Entomol. Soc. Am. 56:220. Holotype ♂

Empoasca ophiodera Ross & Cunningham 1960 Ohio J. Sci. 60:316. Holotype ♂

Empoasca orthodens Davidson & DeLong 1938 Ohio J. Sci. 38:91. Holotype ♂

Empoasca ovalis Ross 1963 Ann. Entomol. Soc. Am. 56:217. Holotype ♂

Empoasca panisca Ross & Moore 1957 Ann. Entomol. Soc. Am. 50:120. Holotype ♂

Empoasca petaluma Ross 1963 Ann. Entomol. Soc. Am. 56:222. Holotype ♂

Empoasca petiolaridis Ross 1963 Ann. Entomol. Soc. Am. 56:217. Holotype ♂

Empoasca portola Ross 1963 Ann. Entomol. Soc. Am. 56:215. Holotype ♂

Empoasca reddina Ross 1963 Ann. Entomol. Soc. Am. 56:222. Holotype ♂

Empoasca robacki Ross & Cunningham 1960 Ohio J. Sci. 60:314. Holotype ♂

Empoasca saxosa Cunningham & Ross 1965 Ann. Entomol. Soc. Am. 58:838. Holotype ♂

Empoasca serrula Davidson & DeLong 1940 Ann. Entomol. Soc. Am. 33:608. Holotype ♂

Empoasca sinusina Ross & Cunningham 1960 Ohio J. Sci. 60:315. Holotype ♂

Empoasca spinuloides Cunningham & Ross. 1965 Ann. Entomol. Soc. Am. 58:842. Holotype ♂

Empoasca sprita Ross 1963 Ann. Entomol. Soc. Am. 56:219. Holotype ♂

Empoasca styliformis Cunningham & Ross 1965 Ann. Entomol. Soc. Am. 58:843. Holotype ♂

Empoasca tecpatana Ross & Cunningham 1960 Ohio J. Sci. 60:316. Holotype ♂

Empoasca teneris Ross & Cunningham 1960 Ohio J. Sci. 60:314. Holotype ♂

Empoasca velutina Ross 1963 Ann. Entomol. Soc. Am. 56:221. Holotype ♂

Empoasca verdia Ross & Moore 1957 Ann. Entomol. Soc. Am. 50:121. Holotype ♂

Empoasca zapoides Ross 1959 Ann. Entomol. Soc. Am. 52:310. Holotype ♂

Erythroneura abolla lemnisca McAtee 1926 Bull. Ill. State Nat. Hist. Surv. 16:131. Holotype ♀

Erythroneura acantha Ross & DeLong 1950 Ohio J. Sci. 50:296. Holotype ♂

Erythroneura accicurta Hepner 1966 Fla. Entomol. 49:106. Holotype ♂

Erythroneura acericola Ross & DeLong 1953 Ohio J. Sci. 53:88. Holotype ♂

Erythroneura acutalis Ross & DeLong 1953 Ohio J. Sci. 53:83. Holotype ♂

Erythroneura adae Hepner 1977 J. Ga. Entomol. Soc. 12:363. Holotype ♂

Erythroneura aesculella Ross & DeLong 1953 Ohio J. Sci. 53:82. Holotype ♂

Erythroneura albanyensis Hepner 1976 J. Ga. Entomol. Soc. 11:124. Holotype ♂

Erythroneura albiquera Hepner 1967 Entomol. News 78:62. Holotype ♂

Erythroneura alevra Ross 1956 Entomol. News 67:89. Holotype ♂

Erythroneura alicia Ross 1957 Entomol. News 68:185. Holotype ♂

Erythroneura alloplana Ross 1956 Entomol. News 67:88. Holotype ♂

Erythroneura alveyi Hepner 1972 Fla. Entomol. 55:269. Holotype ♂

Erythroneura amboyensis Hepner 1972 J. Kans. Entomol. Soc. 45:431. Holotype ♂

Erythroneura amethica Ross 1957 Entomol. News 68:186. Holotype ♂

Erythroneura ampaiae Hepner 1976 J. Ga. Entomol. Soc. 11:314. Holotype ♂

Erythroneura ampasa Ross & DeLong 1953 Ohio J. Sci. 53:86. Holotype ♂

Erythroneura andrewsi Hepner 1976 J. Ga. Entomol. Soc. 11:121. Holotype ♂

Erythroneura anseri Hepner 1966 Fla. Entomol. 49:103. Holotype ♂

Erythroneura arenosa Ross & DeLong 1950 Ohio J. Sci. 50:295. Holotype ♂

Erythroneura arneri Hepner 1969 J. Kans. Entomol. Soc. 42:130. Holotype ♂

Erythroneura arpegia Ross 1957 Entomol. News 68:188. Holotype ♂

Erythroneura asymmetra Hepner 1973 J. Kans. Entomol. Soc. 46:186. Holotype ♂

Erythroneura atkinsoni Hepner 1972 Fla. Entomol. 55:270. Holotype ♂

Erythroneura bainteri Hepner 1972 Fla. Entomol. 55:271. Holotype ♂

Erythroneura barbarae Hepner 1978 J. Kans. Entomol. Soc. 51:134. Holotype ♂

Erythroneura barnesae Hepner 1976 J. Ga. Entomol. Soc. 11:313. Holotype ♂

Erythroneura beckiae Hepner 1978 J. Kans. Entomol. Soc. 51:131. Holotype ♂

Erythroneura beeri Hepner 1972 Fla. Entomol. 55:272. Holotype ♂

Erythroneura belindae Hepner 1976 J. Kans. Entomol. Soc. 49:207. Holotype ♂

Erythroneura benedicti Hepner 1976 J. Ga. Entomol. Soc. 11:124. Holotype ♂

Erythroneura bicurvata Hepner 1973 J. Kans. Entomol. Soc. 46:184. Holotype ♂

Erythroneura billi Hepner 1966 J. Kans. Entomol. Soc. 39:88. Holotype ♂

Erythroneura blockeri Hepner 1967 Entomol. News 78:72. Holotype ♂

Erythroneura boniorum Hepner 1976 J. Ga. Entomol. Soc. 11:125. Holotype ♂

Erythroneura bowmanorum Hepner 1977 J. Ga. Entomol. Soc. 12:362. Holotype ♂

Erythroneura brazzeli Hepner 1966 Fla. Entomol. 49:106. Holotype ♂

Erythroneura brendae Hepner 1967 J. Kans. Entomol. Soc. 40:21. Holotype ♂

Erythroneura brooki Hepner 1969 J. Kans. Entomol. Soc. 42:126. Holotype ♂

Erythroneura brucensis Hepner 1975 J. Kans. Entomol. Soc. 48:6. Holotype ♂

Erythroneura brundusoides Hepner 1976 J. Ga. Entomol. Soc. 11:315. Holotype ♂

Erythroneura byersi Hepner 1972 Fla. Entomol. 55:271. Holotype ♂

Erythroneura caddoensis Hepner 1966 Fla. Entomol. 49:100. Holotype ♂

Erythroneura callisoga Ross 1956 Entomol. News 67:86. Holotype ♂

Erythroneura camirei Hepner 1976 J. Ga. Entomol. Soc. 11:119. Holotype ♂

Erythroneura carmiensis Hepner 1976 J. Ga. Entomol. Soc. 11:316. Holotype ♂

Erythroneura caryaglabrae Hepner 1977 J. Kans. Entomol. Soc. 50:250. Holotype ♂

Erythroneura cautoides Hepner 1977 J. Ga. Entomol. Soc. 12:363. Holotype ♂

Erythroneura caverna Hepner 1967 J. Kans. Entomol. Soc. 40:23. Holotype ♂

Erythroneura cavipierra Hepner 1967 Entomol. News 78:64. Holotype ♂

Erythroneura cera Hepner 1966 Fla. Entomol. 49:105. Holotype ♂

Erythroneura chambersi Hepner 1976 J. Kans. Entomol. Soc. 49:208. Holotype ♂

Erythroneura chandleri Hepner 1976 Fla. Entomol. 59:296. Holotype ♂

Erythroneura chehawensis Hepner 1966 Fla. Entomol. 49:100. Holotype ♂

Erythroneura citrosa Ross 1956 Entomol. News 67:86. Holotype ♂

Erythroneura claroides Hepner 1967 J. Kans. Entomol. Soc. 40:17. Holotype ♂

Erythroneura clarysae Hepner 1976 Fla. Entomol. 59:299. Holotype ♂

Erythroneura clavatoides Hepner 1978 J. Kans. Entomol. Soc. 51:131. Holotype ♂

Erythroneura cliffordi Hepner 1976 Fla. Entomol. 59:293. Holotype ♂

Erythroneura cliftoni Hepner 1977 J. Ga. Entomol. Soc. 12:363. Holotype ♂

Erythroneura clydei Hepner 1977 J. Ga. Entomol. Soc. 12:363. Holotype ♂

Erythroneura codyi Hepner 1966 Fla. Entomol. 49:101. Holotype ♂

Erythroneura coleyi Hepner 1977 J. Kans. Entomol. Soc. 50:254. Holotype ♂

Erythroneura collinsi Hepner 1977 J. Ga. Entomol. Soc. 12:364. Holotype ♂

Erythroneura colmeri Hepner 1969 J. Kans. Entomol. Soc. 42:132. Holotype ♂

Erythroneura colvardi Hepner 1966 Fla. Entomol. 49:95. Holotype ♂

Erythroneura combesi Hepner 1972 Fla. Entomol. 55:267. Holotype ♂

Erythroneura comes palimpsesta McAtee 1924 Bull. Ill. State Nat. Hist. Surv. 15:43. Holotype ♂

Erythroneura comes pontifex McAtee 1926 Bull. Ill. State Nat. Hist. Surv. 16:136. Holotype ♀

Erythroneura comes rufomaculata McAtee 1924 Bull. Ill. State Nat. Hist. Surv. 15:43. Holotype ♀

Erythroneura comoides Ross & DeLong 1953 Ohio J. Sci. 53:90. Holotype ♂

Erythroneura cooni Hepner 1976 J. Ga. Entomol. Soc. 11:121. Holotype ♂

Erythroneura coxi Ross & DeLong 1950 Ohio J. Sci. 50:295. Holotype ♂

Erythroneura crossi Hepner 1976 J. Kans. Entomol. Soc. 49:211. Holotype ♂

Erythroneura cuneatoides Hepner 1977 J. Ga. Entomol. Soc. 12:364. Holotype ♂

Erythroneura cunninghami Hepner 1966 J. Ga. Entomol. Soc. 1:3. Holotype ♂

Erythroneura curtaega Hepner 1976 J. Ga. Entomol. Soc. 11:313. Holotype ♂

Erythroneura curtoides Hepner 1972 Fla. Entomol. 55:272. Holotype ♂

Erythroneura custeri Hepner 1966 J. Kans. Entomol. Soc. 39:89. Holotype ♂

Erythroneura daltonorum Hepner 1966 J. Kans. Entomol. Soc. 39:81. Holotype ♂

Erythroneura davichi Hepner 1977 J. Kans. Entomol. Soc. 50:248. Holotype ♂

Erythroneura deformata Hepner 1966 J. Kans. Entomol. Soc. 39:85. Holotype ♂

Erythroneura deklei Hepner 1967 J. Kans. Entomol. Soc. 40:20. Holotype ♂

Erythroneura denmarki Hepner 1967 J. Kans. Entomol. Soc. 40:20. Holotype ♂

Erythroneura dianae Hepner 1976 J. Kans. Entomol. Soc. 49:205. Holotype ♂

Erythroneura doeringae Hepner 1975 J. Kans. Entomol. Soc. 48:7. Holotype ♂

Erythroneura dorisae Hepner 1976 J. Kans. Entomol. Soc. 49:204. Holotype ♂

Erythroneura douglasi Hepner 1967 Entomol. News 78:60. Holotype ♂

Erythroneura dunni Hepner 1976 Fla. Entomol. 59:295. Holotype ♂

Erythroneura econa Ross 1957 Entomol. News 68:184. Holotype ♂

Erythroneura edeni Hepner 1967 J. Kans. Entomol. Soc. 40:20. Holotype ♂

Erythroneura edgari Hepner 1976 Fla. Entomol. 59:300. Holotype ♂

Erythroneura ellisi Hepner 1969 J. Kans. Entomol. Soc. 42:129. Holotype ♂

Erythroneura emquu Ross & DeLong 1953 Ohio J. Sci. 53:88. Holotype ♂

Erythroneura enatoides Hepner 1977 J. Ga. Entomol. Soc. 12:365. Holotype ♂

Erythroneura enfieldensis Hepner 1976 J. Ga. Entomol. Soc. 11:126. Holotype ♂

Erythroneura eversi Ross & DeLong 1953 Ohio J. Sci. 53:88. Holotype ♂

Erythroneura extimoides Hepner 1976 J. Ga. Entomol. Soc. 11:314. Holotype ♂

Erythroneura fagiphylla Hepner 1977 J. Kans. Entomol. Soc. 50:254. Holotype ♂

Erythroneura fagusae Hepner 1967 J. Kans. Entomol. Soc. 40:22. Holotype ♂

Erythroneura fergersoni Hepner 1969 J. Kans. Entomol. Soc. 42:130. Holotype ♂

Erythroneura ferrosa Hepner 1966 J. Kans. Entomol. Soc. 39:83. Holotype ♂

Erythroneura florida Ross & DeLong 1953 Ohio J. Sci. 53:82. Holotype ♂

Erythroneura floridoides Hepner 1978 J. Kans. Entomol. Soc. 51:133. Holotype ♂

Erythroneura frazieri Hepner 1976 J. Kans. Entomol. Soc. 49:210. Holotype ♂

Erythroneura fretoides Hepner 1977 J. Ga. Entomol. Soc. 12:364. Holotype ♂

Erythroneura freytagi Hepner 1966 J. Kans. Entomol. Soc. 39:83. Holotype ♂

Erythroneura frisoni Ross & DeLong 1953 Ohio J. Sci. 53:80. Holotype ♂

Erythroneura fulleri Hepner 1967 J. Kans. Entomol. Soc. 40:19. Holotype ♂

Erythroneura fultonae Hepner 1976 J. Ga. Entomol. Soc. 11:314. Holotype ♂

Erythroneura garretsoni Hepner 1976 Fla. Entomol. 59:295. Holotype ♂

Erythroneura gemoides Ross 1953 Trans. Ill. State Acad. Sci. 46:190. Holotype ♂

Erythroneura gilesi Hepner 1966 Fla. Entomol. 49:97. Holotype ♂

Erythroneura gladysae Hepner 1976 J. Ga. Entomol. Soc. 11:315. Holotype ♂

Erythroneura glicilla Ross 1956 Entomol. News 67:86. Holotype ♂

Erythroneura greeni Hepner 1969 J. Kans. Entomol. Soc. 42:127. Holotype ♂

Erythroneura guicei Hepner 1972 Fla. Entomol. 55:269. Holotype ♂

Erythroneura hamiltonia Hepner 1977 Fla. Entomol. 60:52. Holotype ♂

Erythroneura hamlinorum Hepner 1977 J. Ga. Entomol. Soc. 12:362. Holotype ♂

Erythroneura hamneri Hepner 1969 J. Kans. Entomol. Soc. 42:127. Holotype ♂

Erythroneura harei Hepner 1977 J. Kans. Entomol. Soc. 50:255. Holotype ♂

Erythroneura harnedi Hepner 1966 J. Ga. Entomol. Soc. 1:5. Holotype ♂

Erythroneura harpola Ross 1956 Entomol. News 67:85. Holotype ♂

Erythroneura harrisi Hepner 1976 J. Kans. Entomol. Soc. 49:210. Holotype ♂

Erythroneura haspata Ross & DeLong 1953 Ohio J. Sci. 53:85. Holotype ♂

Erythroneura havana Ross & DeLong 1953 Ohio J. Sci. 53:90. Holotype ♂

Erythroneura haysensis Hepner 1966 J. Kans. Entomol. Soc. 39:79. Holotype ♂

Erythroneura hendersoni Hepner 1967 J. Kans. Entomol. Soc. 40:21. Holotype ♂

Erythroneura herberti Hepner 1976 J. Ga. Entomol. Soc. 11:312. Holotype ♂

Erythroneura hibernia Hepner 1966 J. Kans. Entomol. Soc. 39:83. Holotype ♂

Erythroneura hildae Hepner 1977 J. Ga. Entomol. Soc. 12:362. Holotype ♂

Erythroneura hormchunae Hepner 1976 J. Ga. Entomol. Soc. 11:120. Holotype ♂

Erythroneura hutchinsi Hepner 1966 J. Ga. Entomol. Soc. 1:2. Holotype ♂

Erythroneura igella Ross & DeLong 1950 Ohio J. Sci. 50:295. Holotype ♂

Erythroneura ilexae Hepner 1976 J. Ga. Entomol. Soc. 11:315. Holotype ♂

Erythroneura ilicis Ross 1953 Trans. Ill. State Acad. Sci. 46:189. Holotype ♂

Erythroneura imbricariae Ross & DeLong 1953 Ohio J. Sci. 53:86. Holotype ♂

Erythroneura isei Hepner 1977 Fla. Entomol. 60:54. Holotype ♂

Erythroneura ivae Hepner 1976 Fla. Entomol. 59:297. Holotype ♂

Erythroneura ivani Hepner 1976 J. Ga. Emtomol. Soc. 11:312. Holotype ♂

Erythroneura jeanae Hepner 1976 J. Kans. Entomol. Soc. 49:205. Holotype ♂

Erythroneura joanneae Hepner 1978 J. Kans. Entomol. Soc. 51:133. Holotype ♂

Erythroneura johnsoni Hepner 1972 J. Kans. Entomol. Soc. 45:432. Holotype ♂

Erythroneura jonesi Hepner 1976 Fla. Entomol. 59:294. Holotype ♂

Erythroneura juglandacea Ross & DeLong 1953 Ohio J. Sci. 53:78. Holotype ♂

Erythroneura kanensis Hepner 1976 J. Ga. Entomol. Soc. 11:314. Holotype ♂

Erythroneura kennethi Hepner 1976 Fla. Entomol. 59:298. Holotype ♂

Erythroneura kingstoniensis Hepner 1976 J. Ga. Entomol. Soc. 11:124. Holotype ♂

Erythroneura kirki Hepner 1967 Entomol. News 78:64. Holotype ♂

Erythroneura knullae Ross 1953 Trans. Ill. State Acad. Sci. 46:192. Holotype ♂

Erythroneura krameri Hepner 1967 Entomol. News 78:67. Holotype ♂

Erythroneura kuiterti Hepner 1967 J. Kans. Entomol. Soc. 40:17. Holotype ♂

Erythroneura lamucata Ross & DeLong 1953 Ohio J. Sci. 53:88. Holotype ♂

Erythroneura larryi Hepner 1966 J. Kans. Entomol. Soc. 39:89. Holotype ♂

Erythroneura lasteri Hepner 1977 J. Kans. Entomol. Soc. 50:248. Holotype ♂

Erythroneura lauriphylla Hepner 1978 J. Kans. Entomol. Soc. 51:134. Holotype ♂

Erythroneura leforsorum Hepner 1977 J. Ga. Entomol. Soc. 12:360. Holotype ♂

Erythroneura leucophylla Hepner 1977 Fla. Entomol. 60:55. Holotype ♂

Erythroneura levecki Hepner 1966 Fla. Entomol. 49:99. Holotype ♂

Erythroneura lianae Hepner 1976 J. Ga. Entomol. Soc. 11:125. Holotype ♂

Erythroneura ligata pupillata McAtee 1924 Bull. Ill. State Nat. Hist. Surv. 15:42. Holotype ♂

Erythroneura lillianae Hepner 1966 J. Kans. Entomol. Soc. 39:89. Holotype ♂

Erythroneura lindleyi Hepner 1976 J. Kans. Entomol. Soc. 49:207. Holotype ♂

Erythroneura lloydi Hepner 1977 J. Kans. Entomol. Soc. 50:253. Holotype ♂

Erythroneura loisae Hepner 1978 J. Kans. Entomol. Soc. 51:138. Holotype ♂

Erythroneura longifurca Hepner 1966 J. Ga. Entomol. Soc. 1:3. Holotype ♂

Erythroneura loriae Hepner 1967 Entomol. News 78:70. Holotype ♂

Erythroneura lucileae Hepner 1976 Fla. Entomol. 59:299. Holotype ♂

Erythroneura lucora Hepner 1967 J. Kans. Entomol. Soc. 40:24. Holotype ♂

Erythroneura lucyae Hepner 1966 J. Kans. Entomol. Soc. 39:81. Holotype ♂

Erythroneura lunata McAtee 1924 Bull. Ill. State Nat. Hist. Surv. 15:41. Holotype ♂

Erythroneura lundi Hepner 1967 J. Kans. Entomol. Soc. 40:22. Holotype ♂

Erythroneura lyratae Ross & DeLong 1953 Ohio J. Sci. 53:83. Holotype ♂

Erythroneura lyratiphylla Hepner 1977 Fla. Entomol. 60:55. Holotype ♂

Erythroneura lyriquera Hepner 1967 Entomol. News 78:61. Holotype ♂

Erythroneura mallochi McAtee 1924 Bull. Ill. State Nat. Hist. Surv. 15:41. Holotype ♂

Erythroneura marilandicae Ross 1957 Entomol. News 68:183. Holotype ♂

Erythroneura mariquera Hepner 1973 J. Kans. Entomol. Soc. 46:186. Holotype ♂

Erythroneura martini Hepner 1976 J. Kans. Entomol. Soc. 49:207. Holotype ♂

Erythroneura maryae Hepner 1976 J. Ga. Entomol. Soc. 11:313. Holotype ♂

Erythroneura maxwelli Hepner 1972 J. Ga. Entomol. Soc. 7:218. Holotype ♂

Erythroneura mccomasi Hepner 1978 J. Kans. Entomol. Soc. 51:138. Holotype ♂

Erythroneura meadi Hepner 1966 J. Kans. Entomol. Soc. 39:79. Holotype ♂

Erythroneura meridiana Hepner 1977 Fla. Entomol. 60:53. Holotype ♂

Erythroneura merkli Hepner 1977 J. Kans. Entomol. Soc. 50:253. Holotype ♂

Erythroneura metopia Ross 1957 Entomol. News 68:185. Holotype ♂

Erythroneura micheneri Hepner 1972 Fla. Entomol. 55:271. Holotype ♂

Erythroneura millsi Ross & DeLong 1950 Ohio J. Sci. 50:291. Holotype ♂

Erythroneura mimica Ross 1957 Entomol. News 68:190. Holotype ♂

Erythroneura mitella McAtee 1926 Bull. Ill. State Nat. Hist. Surv. 16:132. Holotype ♂

Erythroneura mitlini Hepner 1977 J. Kans. Entomol. Soc. 50:250. Holotype ♂

Erythroneura morelandi Hepner 1976 J. Ga. Entomol. Soc. 11:316. Holotype ♂

Erythroneura morrisi Hepner 1977 J. Kans. Entomol. Soc. 50:251. Holotype ♂

Erythroneura natchezensis Hepner 1967 Entomol. News 78:70. Holotype ♂

Erythroneura navoides Hepner 1977 Fla. Entomol. 60:50. Holotype ♂

Erythroneura nebekeri Hepner 1976 J. Ga. Entomol. Soc. 11:120. Holotype ♂

Erythroneura neeli Hepner 1976 J. Ga. Entomol. Soc. 11:121 Holotype ♂

Erythroneura newtonensis Hepner 1978 J. Kans. Entomol. Soc. 51:133. Holotype ♂

Erythoneura nielsoni Hepner 1967 Entomol. News 78:62. Holotype ♂

Erythroneura nigriphylla Hepner 1977 Fla. Entomol. 60:54. Holotype ♂

Erythroneura nigriquera Hepner 1967 Entomol. News 78:60. Holotype ♂

Erythroneura noevoides Ross & DeLong 1953 Ohio J. Sci. 53:83. Holotype ♂

Erythroneura norica Ross 1956 Entomol. News 67:88. Holotype ♂

Erythroneura normanti Hepner 1976 J. Ga. Entomol. Soc. 11:120. Holotype ♂

Erythroneura oculata McAtee 1924 Bull. Ill. State Nat. Hist. Surv. 15:39. Holotype ♀

Erythroneura odettae Hepner 1977 J. Ga. Entomol. Soc. 12:362. Holotype ♂

Erythroneura ostryae Hepner 1967 J. Kans. Entomol. Soc. 40:23. Holotype ♂

Erythroneura pagodifoliae Hepner 1977 Fla. Entomol. 60:52. Holotype ♂

Erythroneura paigeae Hepner 1976 J. Kans. Entomol. Soc. 49:208. Holotype ♂

Erythroneura paluloides Ross 1953 Trans. Ill. State Acad. Sci. 46:189. Holotype ♂

Erythroneura pamelae Hepner 1967 Entomol. News. 78:67. Holotype ♂

Erythroneura paramera Hepner 1978 J. Kans. Entomol. Soc. 51:137. Holotype ♂

Erythroneura parisensis Hepner 1972 J. Kans. Entomol. Soc. 45:431. Holotype ♂

Erythroneura parrotti Hepner 1977 J. Kans. Entomol. Soc. 50:251. Holotype ♂

Erythroneura parsonsi Hepner 1976 Fla. Entomol. 59:295. Holotype ♂

Erythroneura patei Hepner 1967 J. Kans. Entomol. Soc. 40:19. Holotype ♂

Erythroneura patriciae Hepner 1966 J. Kans. Entomol. Soc. 39:88. Holotype ♂

Erythroneura patricki Hepner 1976 J. Kans. Entomol. Soc. 49:208. Holotype ♂

Erythroneura patris Ross & DeLong 1953 Ohio J. Sci. 53:89. Holotype ♂

Erythroneura paulae Hepner 1966 J. Kans. Entomol. Soc. 39:81. Holotype ♂

Erythroneura pecanae Hepner 1976 Fla. Entomol. 59:297. Holotype ♂

Erythroneura penetura Hepner 1978 J. Kans. Entomol. Soc. 51:135. Holotype ♂

Erythroneura pfrimmeri Hepner 1977 Fla. Entomol. 60:49. Holotype ♂

Erythroneura phelliphylla Hepner 1977 Fla. Entomol. 60:54. Holotype ♂

Erythroneura phellos Ross & DeLong 1953 Ohio J. Sci. 53:90. Holotype ♂

Erythroneura pietersi Hepner 1978 J. Kans. Entomol. Soc. 51:137. Holotype ♂

Erythroneura pitrei Hepner 1973 J. Kans. Entomol. Soc. 46:184. Holotype ♂

Erythroneura priniquera Hepner 1967 Entomol. News 78:68. Holotype ♂

Erythroneura protuma Ross 1957 Entomol. News 68:188. Holotype ♂

Erythroneura pumicasta Hepner 1967 Entomol. News 78:72. Holotype ♂

Erythroneura quadratoides Hepner 1977 Fla. Entomol. 60:51. Holotype ♂

Erythroneura quercalbae Ross & DeLong 1950 Ohio J. Sci. 50:294. Holotype ♂

Erythroneura rangifer Ross & DeLong 1950 Ohio J. Sci. 50:292. Holotype ♂

Erythroneura ratcliffensis Hepner 1966 J. Kans. Entomol. Soc. 39:85. Holotype ♂

Erythroneura reedi Hepner 1967 Entomol. News 78:61. Holotype ♂

Erythroneura reiteri Hepner 1966 J. Kans. Entomol. Soc. 39:87. Holotype ♂

Erythroneura repetita McAtee 1926 Bull. Ill. State Nat. Hist. Surv. 16:131. Holotype ♀

Erythroneura rhodedendronae Hepner 1978 J. Kans. Entomol. Soc. 51:134. Holotype ♂

Erythroneura richardsi Ross 1953 Trans. Ill. State Acad. Sci. 46:189. Holotype ♂

Erythroneura robinsoni Hepner 1966 J. Kans. Entomol. Soc. 39:89. Holotype ♂

Erythroneura rolandi Hepner 1977 J. Ga. Entomol. Soc. 12:364. Holotype ♂

Erythroneura rosenkranzi Hepner 1977 J. Kans. Entomol. Soc. 50:254. Holotype ♂

Erythroneura rossi Hepner 1966 J. Kans. Entomol. Soc. 39:85. Holotype ♂

Erythroneura rubiphylla Hepner 1977 Fla. Entomol. 60:52. Holotype ♂

Erythroneura rubrarta Hepner 1967 Entomol. News 78:66. Holotype ♂

Erythroneura rubulna Hepner 1972 J. Kans. Entomol. Soc. 45:433. Holotype ♂

Erythroneura rugosae Ross & DeLong 1953 Ohio J. Sci. 53:80. Holotype ♂

Erythroneura sadleri Hepner 1969 J. Kans. Entomol. Soc. 42:132. Holotype ♂

Erythroneura saileri Hepner 1977 J. Kans. Entomol. Soc. 50:253. Holotype ♂

Erythroneura salmoides Ross & DeLong 1953 Ohio J. Sci. 53:83. Holotype ♂

Erythroneura sanctaerosae Hepner 1967 J. Kans. Entomol. Soc. 40:24. Holotype ♂

Erythroneura sandersoni Ross 1956 Entomol. News 67:90. Holotype ♂

Erythroneura schusteri Hepner 1976 J. Ga. Entomol. Soc. 11:120. Holotype ♂

Erythroneura scobyensis Hepner 1966 Fla. Entomol. 49:97. Holotype ♂

Erythroneura scutelleris insolita McAtee 1926 Bull. Ill. State Nat. Hist. Surv. 16:133. Holotype ♀

Erythroneura sebringensis Hepner 1966 Fla. Entomol. 49:97. Holotype ♂

Erythroneura sethi Hepner 1966 Fla. Entomol. 49:100. Holotype. ♂

Erythroneura sexpunctata Malloch 1921 Bull. Brooklyn Entomol. Soc. 16:25. Holotype ♂

Erythroneura shanklandi Hepner 1978 J. Kans. Entomol. Soc. 51:137. Holotype ♂

Erythroneura shumiquera Hepner 1972 J. Kans. Entomol. Soc. 45:431. Holotype ♂

Erythroneura sikorowskii Hepner 1976 J. Kans. Entomol. Soc. 49:210. Holotype ♂

Erythroneura siloamensis Hepner 1967 J. Kans. Entomol. Soc. 40:22. Holotype ♂

Erythroneura similalis Ross & DeLong 1953 Ohio J. Sci. 53:82. Holotype ♂

Erythroneura smithi Ross 1956 Entomol. News 67:90. Holotype ♂

Erythroneura solomoni Hepner 1977 J. Kans. Entomol. Soc. 50:251. Holotype ♂

Erythroneura sorota Hepner 1975 J. Kans. Entomol. Soc. 48:5. Holotype ♂
Erythroneura spala Ross & DeLong 1950 Ohio J. Sci. 50:294. Holotype ♂
Erythroneura spatulata Ross 1956 Entomol. News 67:88. Holotype ♂
Erythroneura spiniterma Hepner 1969 J. Kans. Entomol. Soc. 42:133. Holotype ♂
Erythroneura staffordi Hepner 1966 J. Ga. Entomol. Soc. 1:3. Holotype ♂
Erythroneura stannardi Hepner 1967 Entomol. News 78:66. Holotype ♂
Erythroneura starkvillensis Hepner 1966 Fla. Entomol. 49:103. Holotype ♂
Erythroneura stoveri Ross & DeLong 1950 Ohio J. Sci. 50:296. Holotype ♂
Erythroneura styraxae Hepner 1976 Fla. Entomol. 59:300. Holotype ♂
Erythroneura tammina Ross & DeLong 1953 Ohio J. Sci. 53:86. Holotype ♂
Erythroneura tenilla Ross & DeLong 1950 Ohio J. Sci. 50:294. Holotype ♂
Erythroneura teshi Hepner 1972 Fla. Entomol. 55:269. Holotype ♂
Erythroneura tietzi Ross & DeLong 1953 Ohio J. Sci. 53:85. Holotype ♂
Erythroneura tomaneki Hepner 1977 J. Ga. Entomol. Soc. 12:359. Holotype ♂
Erythroneura tomentosae Hepner 1976 Fla. Entomol. 59:297. Holotype ♂
Erythroneura tridenoides Hepner 1976 J. Ga. Entomol. Soc. 11:312. Holotype ♂
Erythroneura tura Ross & DeLong 1953 Ohio J. Sci. 53:84. Holotype ♂
Erythroneura turoides Hepner 1978 J. Kans. Entomol. Soc. 51:135. Holotype ♂
Erythroneura ulmalatae Ross & DeLong 1953 Ohio J. Sci. 53:80. Holotype ♂
Erythroneura ulmarubrae Hepner 1976 J. Ga. Entomol. Soc. 11:313. Holotype ♂
Erythroneura ulmosa Ross & DeLong 1953 Ohio J. Sci. 53:78. Holotype ♂
Erythroneura uniforma Hepner 1976 J. Ga. Entomol. Soc. 11:315. Holotype ♂
Erythroneura vartyi Hepner 1977 Fla. Entomol. 60:51. Holotype ♂
Erythroneura velox Ross 1953 Trans. Ill. State Acad. Sci. 46:190. Holotype ♂
Erythroneura velutinae Hepner 1977 Fla. Entomol. 60:51. Holotype ♂
Erythroneura verae Hepner 1978 J. Kans. Entomol. Soc. 51:138. Holotype ♂
Erythroneura verdana Ross & DeLong 1953 Ohio J. Sci. 53:81. Holotype ♂
Erythroneura vierii Hepner 1976 J. Ga. Entomol. Soc. 11:125. Holotype ♂
Erythroneura vinsoni Hepner 1969 J. Kans. Entomol. Soc. 42:129. Holotype ♂
Erythroneura vulgaris Hepner 1975 J. Kans. Entomol. Soc. 48:4. Holotype ♂
Erythroneura wandae Hepner 1976 Fla. Entomol. 59:299. Holotype ♂
Erythroneura weemsi Hepner 1967 J. Kans. Entomol. Soc. 40:19. Holotype ♂
Erythroneura whitcombi Hepner 1975 J. Kans. Entomol. Soc. 48:6. Holotype ♂
Erythroneura whitti Hepner 1976 J. Ga. Entomol. Soc. 11:123. Holotype ♂
Erythroneura wilsoni Hepner 1966 Fla. Entomol. 49:106. Holotype ♂
Erythroneura winslowensis Hepner 1966 J. Kans. Entomol. Soc. 39:85. Holotype ♂
Erythroneura wisei Hepner 1966 Fla. Entomol. 49:97. Holotype ♂
Erythroneura wiyguli Hepner 1966 Fla. Entomol. 49:103. Holotype ♂
Erythroneura wolcottensis Hepner 1973 J. Kans. Entomol. Soc. 46:185. Holotype ♂
Erythroneura woodruffi Hepner 1967 J. Kans. Entomol. Soc. 40:23. Holotype ♂
Erythroneura wysongi Ross & DeLong 1953 Ohio J. Sci. 53:84. Holotype ♂
Erythroneura youngi Hepner 1966 J. Kans. Entomol. Soc. 39:87. Holotype ♂
Erythroneura zephyr Ross & DeLong 1953 Ohio J. Sci. 53:84. Holotype ♂
Forcipata ancantha DeLong & Caldwell 1936 Ann. Entomol. Soc. Am. 29:73. Holotype ♂
Ossiannilssonia rossi Christian 1953 Univ. Kans. Sci. Bull. 35:1153. Holotype ♂
Typhlocyba antigone McAtee 1926 Proc. U. S. Natl. Mus. 68(18):35. Holotype ♂

Typhlocyba appendiculata Malloch 1920 Can. Entomol. 52:95. Holotype ♂

Typhlocyba athene McAtee 1926 Proc. U. S. Natl. Mus. 68(18):31. Holotype ♂

Typhlocyba escana Ross & DeLong 1949 Ohio J. Sci. 49:118. Holotype ♂

Typhlocyba nicarete McAtee 1926 Proc. U. S. Natl. Mus. 68(18):36. Holotype ♂

Typhlocyba phryne McAtee 1926 Proc. U. S. Natl. Mus. 68(18):34. Holotype ♀

Typhlocyba piscator McAtee 1926 Proc. U. S. Natl. Mus. 68(18):7. Holotype ♂

Typhlocyba rubriocellata Malloch 1920 Bull. Brooklyn Entomol. Soc. 15:48. Holotype ♀

Typhlocyba rubriocellata clara McAtee 1926 Proc. U. S. Natl. Mus. 68(18):21. Holotype ♀

Typhlocyba sollisa Ross & DeLong 1949 Ohio J. Sci. 49:116. Holotype ♂

Typhlocyba tortosa Ross & DeLong 1949 Ohio J. Sci. 49:115. Holotype ♂

Typhlocyba troza Ross & DeLong 1949 Ohio J. Sci. 49:117. Holotype ♂

Coccidae

Aspidiotus aesculi Johnson 1896 Bull. Ill. State Lab. Nat. Hist. 4:386. Syntypes 5

Aspidiotus comstocki Johnson 1896 Bull. Ill. State Lab. Nat. Hist. 4:383. Lectotype ♀ designated by Frison (1927:157)

Aspidiotus forbesi Johnson 1896 Bull. Ill. State Lab. Nat. Hist. 4:380. Lectotype ♀ designated by Frison (1927:157)

Aspidiotus hartii Cockerell 1895 Psyche 7(Suppl. 1):7. Syntypes 5

Aspidiotus piceus Sanders 1904 Ohio Nat. 4:96. Syntypes many

Aspidiotus ulmi Johnson 1896 Bull. Ill. State Lab. Nat. Hist. 4:388. Lectotype ♀ designated by Frison (1927:158)

Chionaspis americana Johnson 1896 Bull. Ill. State Lab. Nat. Hist. 4:390. Lectotype ♀ designated by Frison (1927:158)

Chionaspis gleditsiae Sanders 1903 Ohio Nat. 3:413. Syntypes many

Coccus sorghiellus Forbes 1885 Rep. State Entomol. Ill. 14:71. Syntypes 12

Coccus trifolii Forbes 1885 Rep. State Entomol. Ill. 14:72. Syntypes 3

Euscellidae

Auridius xanthus Hamilton & Ross 1972 J. Ga. Entomol. Soc. 7:139. Holotype ♂

Chlorotettix brevidus DeLong 1937 Entomol. News 48:52. Holotype ♂

Chlorotettix filamenta DeLong 1937 Entomol. News 48:53. Holotype ♂

Chlorotettix obsenus DeLong 1937 Entomol. News 48:52. Holotype ♂

Chlorotettix serratus DeLong 1937 Entomol. News 48:54. Holotype ♂

Cicadula nigrifrons Forbes 1885 Rep. State Entomol. Ill. 14:67. Lectotype ♂ designated by Frison (1927:149)

Cicadula quadrilineatus Forbes 1885 Rep. State Entomol. Ill. 14:68. Lectotype ♂ designated by Frison (1927:149)

Cloanthanus atratus DeLong 1945 Ohio J. Sci. 45:27. Holotype ♂

Cloanthanus hastus DeLong 1945 Ohio J. Sci. 45:24. Holotype ♂

Cloanthanus triangularis DeLong 1945 Ohio J. Sci. 45:27. Holotype ♂

Cloanthanus varius DeLong 1945 Ohio J. Sci. 45:26. Holotype ♂

Diplocolenus aquilonius Ross & Hamilton 1970 Ann. Entomol. Soc. Am. 63:330. Holotype ♂

Diplocolenus brevior Ross & Hamilton 1970 Ann. Entomol. Soc. Am. 63:330. Holotype ♂

Flexamia delongi Ross & Cooley 1969 Entomol. News 80:246. Holotype ♂

Flexamia prairiana DeLong 1937 Pan-Pac. Entomol. 13:32. Holotype ♂

Flexamia rubranura DeLong 1935 Ann. Entomol. Soc. Am. 28:154. Holotype ♂

Graminella oquaka DeLong 1937 Entomol. News 48:51. Holotype ♂

Hebecephalus beameri Hamilton & Ross 1972 J. Ga. Entomol. Soc. 7:136. Holotype ♂

Hebecephalus circus Hamilton & Ross 1972 J. Ga. Entomol. Soc. 7:133. Holotype ♂

Hebecephalus filamentus Hamilton & Ross 1972 J. Ga. Entomol. Soc. 7:135. Holotype ♂

Laevicephalus harrisi Ross & Hamilton 1972 Ann. Entomol. Soc. Am. 65:939. Holotype ♂

Laevicephalus opalinus Ross & Hamilton 1972 Ann. Entomol. Soc. Am. 65:940. Holotype ♂

Laevicephalus peronatus Ross & Hamilton 1972 Ann. Entomol. Soc. Am. 65:933. Holotype ♂

Laevicephalus pravus DeLong 1937 Pan-Pac. Entomol. 13:34. Holotype ♂

Latalus draculus Ross & Hamilton 1972 Proc. Biol. Soc. Wash. 84:442. Holotype ♂

Latalus intermedius Ross & Hamilton 1972 Proc. Biol. Soc. Wash. 84:439. Holotype ♂

Macrosteles jussiaeae Moore & Ross 1957 Ann. Entomol. Soc. Am. 50:112. Holotype ♂

Macrosteles urticae Moore & Ross 1957 Ann. Entomol. Soc. Am. 50:114. Holotype ♂

Macuellus caprillus Ross & Hamilton 1970 J. Kans. Entomol. Soc. 43:175. Holotype ♂

Macuellus strictus Ross & Hamilton 1970 J. Kans. Entomol. Soc. 43:174. Holotype ♂

Orocastus (Cabrulus) pinnipenis Ross & Hamilton 1972 Proc. Biol. Soc. Wash. 84:443. Holotype ♂

Paraphlepsius brunneus ravus Hamilton 1975 Mem. Entomol. Soc. Can. 96:43. Holotype ♂

Paraphlepsius lupalus Hamilton 1975 Mem. Entomol. Soc. Can. 96:47. Holotype ♂

Paraphlepsius umbellatus Hamilton 1975 Mem. Entomol. Soc. Can. 96:73. Holotype ♂

Polyamia herbida DeLong 1935 Ann. Entomol. Soc. Am. 28:155. Holotype ♂

Polyamia saxosa DeLong 1935 Ann. Entomol. Soc. Am. 28:156. Holotype ♂

Psammotetix viridinervis Ross & Hamilton 1972 Proc. Biol. Soc. Wash. 84:443. Holotype ♂

Scaphoideus chelus DeLong & Berry 1936 Ohio J. Sci. 36:339. Holotype ♂

Scaphoideus curvatus DeLong & Mohr 1936 Am. Midl. Nat. 17:967. Holotype ♂

Scaphoideus nigrellus DeLong & Mohr 1936 Am. Midl. Nat. 17:973. Holotype ♂

Scaphoideus radix DeLong & Mohr 1936 Am. Midl. Nat. 17:969. Holotype ♂

Fulgoridae

Bruchomorpha bicolor Metcalf 1923 J. Elisha Mitchell Sci. Soc. 38:186. Holotype ♂

Bruchomorpha decorata Metcalf 1923 J. Elisha Mitchell Sci. Soc. 38:188. Holotype ♂

Bruchomorpha vittata Metcalf 1923 J. Elisha Mitchell Sci. Soc. 38:185. Holotype ♀

Euklastus harti Metcalf 1923 J. Elisha Mitchell Sci. Soc. 38:195. Holotype ♂

Herpis australis Metcalf 1923 J. Elisha Mitchell Sci. Soc. 38:196. Holotype ♂

Liburnia fulvidorsum Metcalf 1923 J. Elisha Mitchell Sci. Soc. 38:200. Holotype ♂

Megamelanus lautus Metcalf 1923 J. Elisha Mitchell Sci. Soc. 38:200. Holotype ♂

Microledrida flava Metcalf 1923 J. Elisha Mitchell Sci. Soc. 38:183. Holotype ♂

Myndus truncatus Metcalf 1923 J. Elisha Mitchell Sci. Soc. 38:184. Holotype ♂

Oecleus productus Metcalf 1923 J. Elisha Mitchell Sci. Soc. 38:184. Holotype ♂

Oliarus texanus Metcalf 1923 J. Elisha Mitchell Sci. Soc. 38:181. Holotype ♂

Oliarus vittatus Metcalf 1923 J. Elisha Mitchell Sci. Soc. 38:181. Holotype ♂

Otiocerus wolfii nubilus McAtee 1926 Bull. Ill. State Nat. Hist. Surv. 16:128. Holotype ♀

Pissonotus fulvus Metcalf 1923 J. Elisha Mitchell Sci. Soc. 38:206. Holotype ♂

Gyponidae

Gypona albimarginata Woodworth 1887 Bull. Ill. State Lab. Nat. Hist. 3:31. Holotype ♂

Gypona bimaculata Woodworth 1887 Bull. Ill. State Lab. Nat. Hist. 3:32. Holotype ♂

Gypona bipunctulata Woodworth 1887 Bull. Ill. State Lab. Nat. Hist. 3:30. Holotype ♀

Gypona nigra Woodworth 1887 Bull. Ill. State Lab. Nat. Hist. 3:31. Lectotype ♂ designated by Frison (1927:151)

Idioceridae

Idiocerus apache juniperus DeLong & Hershberger 1947 Ohio J. Sci. 47:46. Holotype ♂

Idiocerus hebetus DeLong & Hershberger 1947 Ohio J. Sci. 47:48.Holotype ♂

Idiocerus incomptus DeLong & Hershberger 1947 Ohio J. Sci. 47:45. Holotype ♂

Idiocerus rossi Freytag 1965 Trans. Am. Entomol. Soc. 91:405. Holotype ♂

Idiocerus snowi raphus Freytag 1965 Trans. Am. Entomol. Soc. 91:384. Holotype ♂

Idiocerus telus DeLong & Hershberger 1947 Ohio J. Sci. 47:45. Holotype ♂

Membracidae

Telamona irrorata Goding 1894 Bull. Ill. State Lab. Nat. Hist. 3:418. Syntype 1♂

Psyllidae

Trioza pyrifoliae Forbes 1885 Rep. State Entomol. Ill. 14:98. Lectotype ♂ designated by Frison (1927:154)

Tettigoniellidae

Calophya pallidula McAtee 1926 Bull. Ill. State Nat. Hist. Surv. 16:127. Holotype ♀

Tettigonia hartii Ball 1901 Proc. Iowa Acad. Sci. 8:61. Syntypes 1♂, 1♀

Tettigonia similis Woodworth 1887 Bull. Ill. State Lab. Nat. Hist. 3:25. Holotype ♀

CORRODENTIA

Caeciliidae

Caecilius manteri Sommerman 1943 Proc. Entomol. Soc. Wash. 45:29. Holotype ♀

THYSANOPTERA

See Gerdes 1977.

NEUROPTERA

Coniopterygidae

Coniopteryx (Scotoconiopteryx) cyphodera Johnson 1978 Ann. Entomol. Soc. Am. 71:163. Holotype ♂

Sialidae

Sialis cornuta Ross 1937 Ill. Nat. Hist. Surv. Bull. 21:69. Holotype ♂

Sialis glabella Ross 1937 Ill. Nat. Hist. Surv. Bull. 21:71. Holotype ♂

Sialis hamata Ross 1937 Ill. Nat. Hist. Surv. Bull. 21:70. Holotype ♂

Sialis hasta Ross 1937 Ill. Nat. Hist.Surv. Bull. 21:74. Holotype ♂

Sialis iola Ross 1937 Ill. Nat. Hist. Surv. Bull. 21:68. Holotype ♂

Sialis itasca Ross 1937 Ill. Nat. Hist. Surv. Bull. 21:72. Holotype ♂

Sialis joppa Ross 1937 Ill. Nat. Hist. Surv. Bull. 21:67. Holotype ♂

Sialis mohri Ross 1937 Ill. Nat.Hist. Surv. Bull. 21:74. Holotype ♂

Sialis vagans Ross 1937 Ill. Nat. Hist. Surv. Bull. 21:76. Holotype ♂

Sialis velata Ross 1937 Ill. Nat. Hist. Surv. Bull. 21:71 Holotype ♂

Sisyridae

Climacia tenebra Parfin & Gurney 1956 Proc. U. S. Natl. Mus. 105:501. Holotype ♀

COLEOPTERA

Alleculidae

Lobopoda bicolor Campbell 1966 Ill. Biol. Monogr. 37:28. Holotype ♂

Lobopoda flavifemoralis Campbell 1966 Ill. Biol. Monogr. 37:29. Holotype ♀

Lobopoda haitensis Campbell 1966 Ill. Biol. Monogr. 37:158. Holotype ♀

Cantharidae

Malthinis georgiensis Fender 1966 Pan-Pac. Entomol. 42:219. Holotype ♂

Malthodes frisoni Fender 1946 Pan-Pac. Entomol. 22:142. Holotype ♂

Malthodes sandersoni Fender 1951 Am. Midl. Nat. 46:300. Holotype ♂

Malthodes whittakeri Fender 1951 Am. Midl. Nat. 46:550. Holotype ♂

Trypherus frisoni Fender 1960 Pan-Pac. Entomol. 36:110. Holotype ♂

Trypherus pauperculus Fender 1960 Pan-Pac. Entomol. 36:106. Holotype ♂

Carabidae

Rhadine ozarkensis Sanderson & Miller 1941 Arkansas Acad. Sci. Proc. 1:39. Holotype ♂

Catopidae

Ptomaphagus (Adelops) shapardi Sanderson 1939 J. Kans. Entomol. Soc. 12:121. Holotype ♂

Cerambycidae

Cyrtinus sandersoni H. Howden 1959 Can. Entomol. 91:374. Holotype ♀

Chrysomelidae

Chalepus hebalus Sanderson 1951 Proc. Entomol. Soc. Wash. 53:160. Holotype ♂

Demotispa coeruleata Sanderson 1967 Caribb. J. Sci. 7:137. Holotype ♂

Donacia curticollis Knab 1905 Proc. Entomol. Soc. Wash. 7:122. Lectotype ♀ designated by Frison (1927:160)

Sceloenopla mantecada Sanderson 1967 Caribb. J. Sci. 7:135. Holotype ♂

Xenochalepus mundulus Sanderson 1951 Proc. Entomol. Soc. Wash. 53:162. Holotype ♂

Cicindelidae

Cicindela illinoensis Mares 1921 Entomol. News 32:310. Holotype ♂

Cicindela repanda hoosieri Mares 1921 Entomol. News 32:310. Holotype ♀

Cleridae

Priocera lecontei Wolcott 1910 Field Mus. Nat. Hist. Publ. Zool. Ser. 7:356. Holotype (sex undetermined)

Coccinellidae

Hyperaspis congeminata Watson 1969 Mich. Entomol. 1:368. Holotype ♂

Curculionidae

Apion agraticum Kissinger 1974 Apioninae Occurring in the West Indies p. 28. Holotype ♂

Apion analomum Kissinger 1974 Apioninae Occurring in the West Indies p. 6. Holotype ♂

Apion chermum Kissinger 1974 Apioninae Occurring in the West Indies p. 25. Holotype ♀

Apion chreum Kissinger 1974 Apioninae Occurring in the West Indies p. 16. Holotype ♀

Apion latrum Kissinger 1974 Apioninae Occurring in the West Indies p. 9. Holotype ♂

Apion naulum Kissinger 1974 Apioninae Occurring in the West Indies p. 10. Holotype ♂

Apion nesium Kissinger 1974 Apioninae Occurring in the West Indies p. 11. Holotype ♂

Apion sandersoni Kissinger 1974 Apioninae Occurring in the West Indies p. 26. Holotype ♂

Apion tributum Kissinger 1974 Apioninae Occurring in the West Indies p. 29. Holotype ♀

Apion valentinei Kissinger 1974 Apioninae Occurring in the West Indies p. 23. Holotype ♂

Caecossonus dentipes Gilbert 1955 Pan-Pac. Entomol. 31:195. Holotype ♂

Conotrachelus anaglypticus Say 1831 Descriptions of North American Curculionides p. 18. Neotype ♂ designated by Schoof (1942:123)

Conotrachelus hayesi Schoof 1942 Ill. Biol. Monogr. 19:85. Holotype ♂

Conotrachelus hicoriae Schoof 1942 Ill. Biol. Monogr. 19:69. Holotype ♂

Cosmobaris sionilli Hayes 1936 J. Kans. Entomol. Soc. 9:28. Holotype ♂

Cosmobaris squamiger Hayes 1936 J. Kans. Entomol. Soc. 9:27. Holotype ♂

Lixus albisetiger Chittenden 1930 Proc. U. S. Natl. Mus. 77(18):2. Holotype ♀

Lixus elephantulus Chittenden 1930 Proc. U. S. Natl. Mus. 77(18):24. Holotype ♀

Onychylis secundus Burke 1961 Coleopt. Bull. 15:4. Holotype ♂

Sphenophorus minimus Hart 1890 Rep. State Entomol. Ill. 16:65. Lectotype ♀ designated by Frison (1927:160)

Elateridae

Agriotes sagittus Becker 1956 Can. Entomol. 88 (Suppl. 1):79. Holotype ♂

Ctenicera lanei Becker 1949 Ann. Entomol. Soc. Am. 42:187. Holotype ♂

Denticollis quadrosa Becker 1952 Proc. Entomol. Soc. Wash. 54:108. Holotype ♂

Elmidae

Cylloepus parkeri Sanderson 1953 Coleopt. Bull. 7:38. Holotype ♂

Stenelmis antennalis Sanderson 1938 Univ. Kans. Sci. Bull. 25:695. Holotype ♂

Stenelmis convexula Sanderson 1938 Univ. Kans. Sci. Bull. 25:704. Holotype ♂

Stenelmis knobeli Sanderson 1938 Univ. Kans. Sci. Bull. 25:677. Holotype ♂

Stenelmis parva Sanderson 1938 Univ. Kans. Sci. Bul. 25:688. Holotype ♂

Haliplidae

Haliplus (Haliplus) allisonae Brigham 1977 Proc. Entomol. Soc. Wash. 79:254. Holotype ♂

Haliplus (Liaphlus) tortilipenis Brigham & Sanderson 1972 Trans. Ill. State Acad. Sci. 65:18. Holotype ♂

Haliplus (Paraliaphlus) variomaculatus Brigham & Sanderson 1973 Coleopt. Bull. 27:137. Holotype ♂

Heteroceridae

Neoheterocerus pallidus Say 1823 J. Acad. Nat. Sci. Phila. 3:199. Neotype ♂ designated by Pacheco (1964:65)

Neoheterocerus sandersoni Pacheco 1964 Esc. Nac. Agric. Chapingo Monogr. 1:58. Holotype ♂

Hydrophilidae

Cymbiodyta beckeri picta Smetana 1974 Mem. Entomol. Soc. Can. 93:55. Holotype ♂

Limnichidae

(See also Addendum, page 133.)

Physemus excavatus Wooldridge 1976 Coleopt. Bull. 30:182. Holotype ♂

Meloidae

Linsleya compressicornis neglecta Selander 1955 Am. Mus. Novit. 1730:22. Holotype ♂

Nemognatha selloa Selander 1957 Coleopt. Bull. 11:25. Holotype ♂

Mordellidae

Mordella longipalpis Ray 1946 Pan-Pac. Entomol. 22:121. Holotype (sex undetermined)

Mordellistena bifasciata Ray 1936 Can. Entomol. 68:125. Holotype ♂

Mordellistena lateralis Ray 1946 Pan-Pac. Entomol. 22:95. Holotype ♀

Mordellistena mixta Ray 1946 Pan-Pac. Entomol. 22:97. Holotype ♀

Pselaphidae

Actium concavum Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:416. Holotype ♂

Apharus punctatus Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:459. Holotype ♂

Arianops sandersoni Barr 1971 Bull. Am. Mus. Nat. Hist. 154:21. Holotype ♀

Arthmius corradus Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:456. Holotype ♂

Arthmius torcerus Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:455. Holotype ♂

Batrisodes cartwrighti Sanderson 1940 Entomol. News 51:169. Holotype ♂

Batrisodes curvatus Sanderson 1940 Entomol. News 51:170. Holotype ♂

Batrisodes rossi Park 1947 Bull. Chic. Acad. Sci. 8:100. Holotype ♂

Batrisodes sandersoni Park 1947 Bull. Chic. Acad. Sci. 8:97. Holotype ♀

Bythinoplectus carenado Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:408. Holotype ♂

Bythinoplectus emargo Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:410. Holotype ♂

Bythinoplectus trapezodis Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:406. Holotype ♂

Cercoceroides grandis Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:460. Holotype ♀

Decarthron aguanensis Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:446. Holotype ♂

Decarthron armatum Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:453. Holotype ♂

Decarthron castaneum Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:450. Holotype ♂

Decarthron confrente Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:442. Holotype ♂

Decarthron cristatum Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:452. Holotype ♂

Decarthron truncatum Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:452. Holotype ♂

Decarthron yaguale Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:448. Holotype ♂

Eupsenius angulosus Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:418. Holotype ♂

Pycnoplectus parki Wagner 1975 Entomol. Am. 49:168. Holotype ♂

Reichenbachia blandura Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:426. Holotype ♂

Reichenbachia parki Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:423. Holotype ♂

Rhinoscepsis bonita Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:412. Holotype ♂

Scalenarthrus depressus Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:428. Holotype ♂

Scalenarthrus femoralis Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:429. Holotype ♂

Scalenarthrus olanchitus Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:429. Holotype ♂

Scalenarthrus torrus Becker & Sanderson 1953 Ann. Entomol. Soc. Am. 46:431. Holotype ♂

Scarabaeidae

Phyllophaga blanda Sanderson 1958 J. Kans. Entomol. Soc. 31:169. Holotype ♂

Phyllophaga epulara Sanderson 1958 J. Kans. Entomol. Soc. 31:169. Holotype ♂

Phyllophaga falta Sanderson 1950 J. Kans. Entomol. Soc. 23:92. Holotype ♂

Phyllophaga foxii Davis 1920 Bull. Ill. State Nat. Hist. Surv. 13:334. Holotype ♂

Phyllophaga fraterna mississippiensis Davis 1920 Bull. Ill. State Nat. Hist. Surv. 13:330. Holotype ♂

Phyllophaga hirticula comosa Davis 1920 Bull. Ill. State Nat. Hist. Surv. 13:337. Holotype ♂

Phyllophaga impar Davis 1920 Bull. Ill. State Nat. Hist. Surv. 13:335. Holotype ♂

Phyllophaga jonesi Sanderson 1939 J. Kans. Entomol. Soc. 12:5. Holotype ♂

Phyllophaga lodingi Sanderson 1939 J. Kans. Entomol. Soc. 12:4. Holotype ♂

Phyllophaga parvidens hysteropyga Davis 1920 Bull. Ill. State Nat. Hist. Surv. 13:336. Holotype ♂

Phyllophaga pearliae Davis 1920 Bull. Ill. State Nat. Hist. Surv. 13:332. Holotype ♂

Phyllophaga perlonga Davis 1920 Bull. Ill. State Nat. Hist. Surv. 13:329. Holotype ♂

Phyllophaga saylori Sanderson 1965 Proc. Calif. Acad. Sci. 31:560. Holotype ♂

Phyllophaga soror Davis 1920 Bull. Ill. State Nat. Hist. Surv. 13:333. Holotype ♂

Phyllophaga sylvatica Sanderson 1942 J. Kans. Entomol. Soc. 15:49. Holotype ♂

Serica arkansana Dawson 1947 J. N. Y. Entomol. Soc. 55:223. Holotype ♂

Scydmaenidae

Eubaeocera charybda Cornell 1967 Coleopt. Bull. 21:9. Holotype ♂

Staphylinidae

Ancylophorus sandersoni Smetana 1971 Mem. Entomol. Soc. Can. 79:258. Holotype ♂

Beyeria pulex Sanderson 1943 J. Kans. Entomol. Soc. 16:137. Holotype ♂

Lathrotropis caseyi Blaisdell 1906 Entomol. News 17:71. Syntype 1♂

Lithocharis ardenus Sanderson 1945 Proc. Entomol. Soc. Wash. 47:94. Holotype ♂

Paederus zayasi Sanderson 1967 Coleopt. Bull. 21:61. Holotype ♂

Rimulincola divalis Sanderson 1946 J. Kans. Entomol. Soc. 19:131. Holotype ♂

Stenus rossi Sanderson 1957 Trans. Ill. State Acad. Sci. 50:283. Holotype ♂

Stenus vista Sanderson 1946 Ann. Entomol. Soc. Am. 39:430. Holotype ♂

Tenebrionidae

Eleodes acuta pernigra Blaisdell 1937 Trans. Am. Entomol. Soc. 63:128. Holotype ♀

MECOPTERA

Bittacidae

Bittacus taraiensis Penny 1969 Orient. Insects 3:161. Holotype ♂

Panorpidae

Neopanorpa byersi Webb & Penny 1979 Pac. Insects 20:63. Holotype ♂

Panorpa setifera Webb 1974 Entomol. News 5-6:171. Holotype ♂

Panorpa sigmoides Carpenter 1931 Bull. Mus. Comp. Zool. 72:250. Holotype ♂

DIPTERA

Acroceridae

Ogcodes porteri Schlinger 1953 Wasmann J. Biol. 11:319. Holotype ♂

Agromyzidae

Agromyza albidohalterata Malloch 1916 Psyche 23:52. Holotype ♂

Agromyza angulicornis Malloch 1918 Can. Entomol. 50:79. Holotype ♂

Agromyza aprilina Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 11:359. Lectotype ♀ designated by Frison (1927:192)

Agromyza aristata Malloch 1915 Can. Entomol. 47:13. Holotype ♀

Agromyza assimilis Malloch 1918 Can. Entomol. 50:80. Holotype ♂

Agromyza deceptiva Malloch 1918 Can. Entomol. 50:78. Holotype ♀

Agromyza destructor Malloch 1916 Proc. Entomol. Soc. Wash. 18:93. Lectotype ♀ designated by Frison (1927:193)

Agromyza fumicosta Malloch 1914 Entomol. News 25:310. Holotype ♀

Agromyza indecora Malloch 1918 Can. Entomol. 50:132. Lectotype ♂ designated by Frison (1927:193)

Agromyza infumata Malloch 1915 Can. Entomol. 47:15. Holotype ♂

Agromyza nigrisquama Malloch 1916 Psyche 23:53. Holotype ♀

Agromyza pleuralis Malloch 1914 Entomol. News 25:311. Holotype ♀

Agromyza riparia Malloch 1916 Proc. U. S. Natl. Mus. 49:105. Lectotype ♂ designated by Frison (1927:194)

Agromyza similata Malloch 1918 Can. Entomol. 50:178. Holotype ♂

Agromyza subangulata Malloch 1916 Psyche 23:51. Holotype ♂

Agromyza subvirens Malloch 1916 Proc. U. S. Natl. Mus. 49:105. Lectotype ♀ designated by Frison (1927:194)

Cerodontha illinoensis Malloch 1934 Diptera of Patagonia and South Chile 6:484. Neotype ♀ designated by Frick (1952:153)

Limnoagromyza diantherae Malloch 1920 Bull. Brooklyn Entomol. Soc. 15:147. Holotype ♀

Anthomyidae

Anthomyia dorsimaculata Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:336. Syntype 1♂

Emmesomyia apicalis Malloch 1917 Bull. Brooklyn Entomol. Soc. 12:115. Holotype ♀

Emmesomyia unica Malloch 1917 Bull. Brooklyn Entomol. Soc. 12:114. Holotype ♀

Eremomyioides fuscipes Malloch 1920 Trans. Am. Entomol. Soc. 46:182. Holotype ♂

Eremomyioides parkeri Malloch 1918 Proc. Biol. Soc. Wash. 31:67. Syntypes 3♀

Eremomyioides similis Malloch 1920 Trans. Am. Entomol. Soc. 46:183. Holotype ♀

Gimnomera atrifrons Malloch 1920 Proc. Entomol. Soc. Wash. 22:37. Holotype ♂

Gimnomera fasciventris Malloch 1920 Proc. Entomol. Soc. Wash. 22:38. Holotype ♂

Gimnomera incisurata Malloch 1920 Proc. Entomol. Soc. Wash. 22:37. Holotype ♂

Hydrophoria collaris Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:333. Syntype 1♂

Hydrophoria flavipalpis Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:334. Syntype 1♂

Hydrophoria polita Malloch 1920 Trans. Am. Entomol. Soc. 46:170. Holotype ♂

Hydrophoria transversalis Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:334. Syntypes 1♂, 1♀

Hydrophoria uniformis Malloch 1918 Trans. Am. Entomol. Soc. 44:297. Holotype ♂

Hylemyia attenuata Malloch 1920 Trans. Am. Entomol. Soc. 46:188. Holotype ♂

Hylemyia bicaudata Malloch 1920 Trans. Am. Entomol. Soc. 46:193. Holotype ♂

Hylemyia bicruciata Malloch 1920 Trans. Am. Entomol. Soc. 46:190. Holotype ♂

Hylemyia cilifera Malloch 1918 Trans. Am. Entomol. Soc. 44:311. Holotype ♂

Hylemyia curvipes Malloch 1918 Trans. Am. Entomol. Soc. 44:316. Holotype ♂

Hylemyia extremitata Malloch 1919 Proc. Calif. Acad. Sci. 9:309. Holotype ♂

Hylemyia gracilipes Malloch 1920 Trans. Am. Entomol. Soc. 46:187. Holotype ♂

Hylemyia inaequalis Malloch 1920 Trans. Am. Entomol. Soc. 46:190. Holotype ♂

Hylemyia innocua Malloch 1920 Trans. Am. Entomol. Soc. 46:186. Holotype ♂

Hylemyia marginella Malloch 1918 Trans. Am. Entomol. Soc. 44:311. Holotype ♂

Hylemyia normalis Malloch 1919 Proc. Calif. Acad. Sci. 9:309. Holotype ♂

Hylemyia occidentalis Malloch 1920 Trans. Am. Entomol. Soc. 46:191. Holotype ♂

Hylemyia piloseta Malloch 1918 Trans. Am. Entomol. Soc. 44:313. Holotype ♂

Hylemyia pluvialis Malloch 1918 Can. Entomol. 50:310. Holotype ♂

Hylemyia spinilamellata Malloch 1918 Trans. Am. Entomol. Soc. 44:312. Holotype ♂

Hylemyia substriatella Malloch 1918 Trans. Am. Entomol. Soc. 44:309. Holotype ♂

Macrophorbia houghi Malloch 1920 Trans. Am. Entomol. Soc. 46:173. Holotype ♀

Neochirosia setiger Malloch 1917 Bull. Brooklyn Entomol. Soc. 12:36. Lectotype ♂ designated by Frison (1927:205)

Neohylemyia proboscidalis Malloch 1917 Bull. Brooklyn Entomol. Soc. 12:38. Holotype ♂

Orthachaeta dissimilis Malloch 1924 Psyche 31:194. Holotype ♀

Pegomyia emmesia Malloch 1920 Trans. Am. Entomol. Soc.46:179. Holotype ♂

Pegomyia labradorensis Malloch 1920 Trans. Am. Entomol. Soc. 46:176. Holotype ♂

Pegomyia quadrispinosa Malloch 1920 Trans. Am. Entomol. Soc. 46:181. Holotype ♂

Pegomyia spinigerellus Malloch 1920 Trans. Am. Entomol. Soc. 46:178. Holotype ♂

Pegomyia subgrisea Malloch 1920 Trans. Am. Entomol. Soc. 46:180. Holotype ♂

Phorbia prisca Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:340. Syntype 1♀

Scatophaga grisea Malloch 1920 Proc. Entomol. Soc. Wash. 22:34. Holotype ♂

Bombyliidae

Anthrax anna Coquillett 1887 Trans. Am. Entomol. Soc. 14:169. Syntypes 2♂, 2♀

Anthrax inauratus Coquillett 1887 Trans. Am. Entomol. Soc. 14:170. Syntypes 1♂ 1♀

Cecidomyiidae

Forbesomyia atra Malloch 1914 Bull. Ill. State Lab. Nat. Hist. 10:235. Holotype ♀

Lasioptera muhlenbergiae Marten 1893 Ohio Agric. Exp. Stn. Tech. Ser. 1:155. Syntypes many

Monardia illinoensis Felt 1935 J. N. Y. Entomol. Soc. 43:47. Syntypes 2♂, 44♀

Zygoneura fenestrata Malloch 1914 Bull. Ill. State Lab. Nat. Hist. 10:233. Lectotype ♂ designated by Frison (1927:180)

Ceratopogonidae

Bezzia albidorsata Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:349. Holotype ♀

Bezzia apicata Malloch 1914 J. N. Y. Entomol. Soc. 22:284. Holotype ♂

Bezzia cockerelli Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:346. Holotype ♀

Bezzia dentata Malloch 1914 J. N. Y. Entomol. Soc. 22:284. Lectotype ♀ designated by Frison (1927:163)

Bezzia flavitarsis Malloch 1914 J. N. Y. Entomol. Soc. 22:283. Holotype ♀

Ceratopogon fusinervis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:308. Lectotype ♂ designated by Frison (1927:169)

Culicoides crepuscularis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:303. Holotype ♂

Culicoides haematopotus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:302. Lectotype ♂ designated by Frison (1927:170)

Culicoides multipunctatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:296. Lectotype ♀ designated by Frison (1927:170)

Euforcipomyia hirtipennis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 11:313. Lectotype ♀ designated by Frison (1927:170)

Euforcipomyia longitarsis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 11:314. Holotype ♀

Forcipomyia aurea Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:318. Lectotype ♀ designated by Frison (1927:171)

Forcipomyia elegantula Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 11:311. Lectotype ♀ designated by Frison (1927:171)

Forcipomyia pergandei concolor Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:319. Lectotype ♀ designated by Frison (1927:171)

Hartomyia lutea Malloch 1918 Bull. Brooklyn Entomol. Soc. 13:18. Holotype ♀

Hartomyia pallidiventris Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:344. Lectotype ♀ designated by Frison (1927:171)

Heteromyia aldrichi Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:326. Holotype ♀

Heteromyia hirta Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:330. Lectotype ♀ designated by Frison (1927:171)

Heteromyia opacithorax Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:329. Holotype ♀

Heteromyia tenuicornis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:328. Holotype ♀

Johanseniella flavidula Malloch 1914 Bull. Ill. State Lab. Nat. Hist. 10:230. Lectotype ♀ designated by Frison (1927:172)

Johannsenomyia aequalis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:336. Holotype ♂

Johannsenomyia albibasis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 11:315. Lectotype ♀ designated by Frison (1927:172)

Johannsenomyia annulicornis Malloch 1918 Entomol. News 29:230. Holotype ♀

Johannsenomyia halteralis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:338. Lectotype ♂ designated by Frison (1927:173)

Johannsenomyia macroneura Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:337. Holotype ♀

Palpomyia illinoensis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:219. Holotype ♀

Palpomyia nebulosa Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:322. Holotype ♀

Parabezzia petiolata Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:359. Lectotype ♂ designated by Frison (1927:175)

Probezzia fulvithorax Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:354. Lectotype ♀ designated by Frison (1927:175)

Probezzia incerta Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:358. Lectotype ♀ designated by Frison (1927:175)

Probezzia infuscata Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 11:316. Lectotype ♀ designated by Frison (1927:176)

Probezzia obscura Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:355. Holotype ♀

Probezzia pallida Malloch 1914 Proc. Biol. Soc. Wash. 27:138. Holotype ♀

Pseudoculicoides johannseni Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:311. Lectotype ♂ designated by Frison (1927:176)

Pseudoculicoides major Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:311. Holotype ♂

Serromyia crassifemorata Malloch 1914 Bull. Ill. State Lab. Nat. Hist. 10:218. Lectotype ♀ designated by Frison (1927:177)

Chamaemyiidae

Leucopis americana Malloch 1921 Bull. Ill. State Nat. Hist. Surv. 13:354. Holotype ♂

Leucopis major Malloch 1921 Bull. Ill. State Nat. Hist. Surv. 13:352. Holotype ♀

Leucopis minor Malloch 1921 Bull. Ill. State Nat. Hist. Surv. 13:354. Holotype ♂

Leucopis orbitalis Malloch 1921 Bull. Ill. State Nat. Hist. Surv. 13:352. Holotype ♀

Leucopis parallela Malloch 1921 Bull. Ill. State Nat. Hist. Surv. 13:353. Holotype ♀

Leucopis pemphigae Malloch 1921 Bull. Ill. State Nat. Hist. Surv. 13:350. Holotype ♂

Leucopis piniperda Malloch 1921 Bull. Ill. State Nat. Hist. Surv. 13:351. Holotype ♂

Neoleucopis pinicola Malloch 1921 Bull. Ill. State Nat. Hist. Surv. 13:357. Holotype ♂

Plunomia elegans Curran 1934 The Families and Genera of North American Diptera p. 365. Lectotype ♂ (Illinois, Champaign, 25-VII-1889, J. S. Terrill) here designated by J. F. McAlpine

Pseudodinia polita Malloch 1915 Proc. U. S. Natl. Mus. 49:152. Lectotype ♀ designated by Frison (1927:196)

Chironomidae

Camptocladius flavens Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:511. Lectotype ♂ designated by Frison (1927:163)

Camptocladius flavibasis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:511. Holotype ♀

Camptocladius lasiophthalmus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:509. Lectotype ♀ designated by Frison (1927:163)

Camptocladius lasiops Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:508. Lectotype ♂ designated by Frison (1927:164)

Camptocladius subaterrimus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:512. Holotype ♂

Chironomus abbreviatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:451. Lectotype ♂ designated by Frison (1927:164)

Chironomus abortivus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:465. Lectotype ♂ designated by Frison (1927:164)

Chironomus alboviridis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:482. Holotype ♀

Chironomus basalis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:441. Lectotype ♂ designated by Frison (1927:164)

Chironomus claripennis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:439. Lectotype ♂ designated by Frison (1927:164)

Chironomus crassicaudatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:453. Holotype ♂

Chironomus cucini Webb 1969 J. Kans. Entomol. Soc. 42:105. Holotype ♂

Chironomus curtilamellatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:474. Holotype ♂

Chironomus digitatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:483. Lectotype ♀ designated by Frison (1927:165)

Chironomus dimorphus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:464. Lectotype ♂ designated by Frison (1927:165)

Chironomus dorneri Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:471. Holotype ♀

Chironomus fasciventris Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:438. Lectotype ♂ designated by Frison (1927:165)

Chironomus fuscicornis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:466. Holotype ♂

Chironomus fusciventris Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:465. Holotype ♂

Chironomus griseopunctatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:428. Holotype ♀

Chironomus griseus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:468. Lectotype ♂ designated by Frison (1927:166)

Chironomus harti Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:457. Holotype ♀

Chironomus illinoensis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:471. Lectotype ♂ designated by Frison (1927:166)

Chironomus illinoensis decoloratus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:472. Lectotype ♂ designated by Frison (1927:167)

Chironomus incognitus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:480. Holotype ♂

Chironomus indistinctus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:477. Lectotype ♂ designated by Frison (1927:167)

Chironomus neomodestus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:475. Lectotype ♂ designated by Frison (1927:167)

Chironomus nigrohalteralis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:440. Lectotype ♂ designated by Frison (1927:167)

Chironomus nigrovittatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:456. Lectotype ♂ designated by Frison (1927:167)

Chironomus obscuratus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:479. Lectotype ♂ designated by Frison (1927:168)

Chironomus parvilamellatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:479. Lectotype ♂ designated by Frison (1927:168)

Chironomus pseudoviridis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:450. Lectotype ♂ designated by Frison (1927:168)

Chironomus quadripunctatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:437. Holotype ♂

Chironomus serus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:481. Lectotype ♂ designated by Frison (1927:168)

Chironomus subaequalis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:440. Lectotype ♂ designated by Frison (1927:169)

Chironomus tentans pallidivittatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:445. Lectotype ♂ designated by Frison (1927:169)

Chironomus tenuicaudatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:475. Lectotype ♂ designated by Frison (1927:169)

Corynoneura similis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:413. Holotype ♀

Cricotopus flavibasis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:506. Lectotype ♂ designated by Frison (1927:170)

Cricotopus slossonae Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:502. Holotype ♀

Metriocnemus annuliventris Malloch 1915 Proc. Biol. Soc. Wash. 28:46. Lectotype ♂ designated by Frison (1927:173)

Metriocnemus brachyneura Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:498. Holotype ♂

Orthocladius albidohalteralis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:528. Holotype ♀

Orthocladius bifasciatus Malloch 1918 Bull. Brooklyn Entomol. Soc. 13:42. Lectotype ♀ designated by Frison (1927:173)

Orthocladius brevinervis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:526. Holotype ♂

Orthocladius distinctus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:518. Lectotype ♂ designated by Frison (1927:174)

Orthocladius distinctus basalaris Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:519. Lectotype ♂ designated by Frison (1927:174)

Orthocladius distinctus bicolor Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:519. Lectotype ♂ designated by Frison (1927:174)

Orthocladius flavoscutellatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:523. Holotype ♂

Orthocladius infuscatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:517. Holotype ♂

Orthocladius lacteipennis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:524. Holotype ♂

Orthocladius nitidellus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:515. Holotype ♂

Orthocladius nitidus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:515. Holotype ♂

Orthocladius obseptus Webb 1969 J. Kans. Entomol. Soc. 42:91. Holotype ♂

Orthocladius pilipes Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:522. Lectotype ♂ designated by Frison (1927:174)

Orthocladius pleuralis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:527. Holotype ♂

Orthocladius striatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:517. Holotype ♂

Orthocladius subparallelus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:522. Lectotype ♂ designated by Frison (1927:174)

Paralauterborniella ostansa Webb 1969 J. Kans. Entomol. Soc. 42:102. Holotype ♂

Protenthes claripennis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:387. Lectotype ♂ designated by Frison (1927:176)

Protenthes riparius Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:389. Holotype ♂

Psectrocladius vernalis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:520. Holotype ♂

Pseudochironomus rex Hauber 1947 Am. Midl. Nat. 38:458. Holotype ♂

Pseudochironomus richardsoni Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:500. Lectotype ♂ designated by Frison (1927:176)

Stempellina leptocelloides Webb 1969 J. Kans. Entomol. Soc. 42:94. Holotype ♂

Stempellina ranota Webb 1969 J. Kans. Entomol. Soc. 42:96. Holotype ♂

Stempellina rodesta Webb 1969 J. Kans. Entomol. Soc. 42:95. Holotype ♂

Tanypus decoloratus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:370. Lectotype ♂ designated by Frison (1927:177)

Tanypus illinoensis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:376. Lectotype ♂ designated by Frison (1927:177)

Tanypus inconspicuus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:371. Lectotype ♂ designated by Frison (1927:177)

Tanypus marginellus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:374. Lectotype ♂ designated by Frison (1927:178)

Tanypus neopunctipennis Sublette 1964 Proc. U. S. Natl. Mus. 115:118. Holotype ♂

Tanytarsus confusus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:490. Lectotype ♂ designated by Frison (1927:178)

Tanytarsus dubius Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:496. Lectotype ♂ designated by Frison (1927:178)

Tanytarsus flavicauda Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:493. Lectotype ♂ designated by Frison (1927:178)

Tanytarsus neoflavellus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:489. Lectotype ♂ designated by Frison (1927:178)

Tanytarsus politus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:493. Lectotype ♂ designated by Frison (1927:179)

Tanytarsus similatus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:494. Lectotype ♂ designated by Frison (1927:179)

Tanytarsus tibialis Webb 1969 J. Kans. Entomol. Soc. 42:100. Holotype ♂

Tanytarsus trilobus Webb 1969 J. Kans. Entomol. Soc. 42:99. Holotype ♂

Tanytarsus viridiventris Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 10:491. Lectotype ♂ designated by Frison (1927:179)

Thienemanniella mallochi Sublette 1970 J. Kans. Entomol. Soc. 43:88. Holotype ♀

Chloropidae

Anthracophaga distichliae Malloch 1918 J. Econ. Entomol. 11:386. Syntype 1♀

Botanobia bispina Malloch 1918 Bull. Brooklyn Entomol. Soc. 13:109. Holotype ♂

Botanobia hinkleyi Malloch 1915 Can. Entomol. 47:12. Holotype ♀

Botanobia spiniger Malloch 1918 Bull. Brooklyn Entomol. Soc. 13:109. Holotype ♀

Chloropisca glabra clypeata Malloch 1914 Can. Entomol. 46:119. Lectotype ♀ designated by Frison (1927:190)

Chloropisca obtusa Malloch 1914 Can. Entomol. 46:118. Holotype ♂

Chloropisca parviceps Malloch 1915 Proc. Entomol. Soc. Wash. 17:158. Holotype ♀

Dasyopa pleuralis Malloch 1918 Bull. Brooklyn Entomol. Soc. 13:20. Lectotype ♂ designated by Frison (1927:190)

Gaurax apicalis Malloch 1915 Proc. Entomol. Soc. Wash. 17:160. Holotype ♀

Gaurax flavidulus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 11:361. Holotype ♂

Gaurax interruptus Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 11:363. Holotype ♀

Gaurax pallidipes Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 11:362. Holotype ♂

Gaurax splendidus Malloch 1915 Proc. Entomol. Soc. Wash. 17:161. Holotype ♂

Madiza setulosa Malloch 1918 Bull. Brooklyn Entomol. Soc. 13:110. Holotype ♀

Meromyza flavipalpis Malloch 1914 Can. Entomol. 46:117. Lectotype ♂ designated by Frison (1927:191)

Neogaurax fumipennis Malloch 1915 Entomol. News 26:108. Holotype ♀

Oscinoides arpidia Malloch 1916 Bull. Brooklyn Entomol. Soc. 11:87. Holotype ♀

Oscinoides arpidia atra Malloch 1918 Bull. Brooklyn Entomol. Soc. 13:19. Holotype ♀

Oscinoides arpidia elegans Malloch 1918 Bull. Brooklyn Entomol. Soc. 13:19. Holotype. ♂

Oscinoides arpidia humeralis Malloch 1918 Bull. Brooklyn Entomol. Soc. 13:19. Holotype ♀

Chyromyidae

Aphaniosoma quadrivittatum Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 11:357. Holotype ♀

Chyromya concolor Malloch 1914 Proc. Entomol. Soc. Wash. 16:181. Lectotype ♂ designated by Frison (1927:192)

Chyromya nigrimana Malloch 1914 Proc. Entomol. Soc. Wash. 16:181. Lectotype ♂ designated by Frison (1927:192)

Clusiidae

Clusia occidentalis Malloch 1918 Proc. Entomol. Soc. Wash. 20:4. Holotype ♂

Conopidae

Zodion palpalis Robertson 1901 Can. Entomol. 33:284. Holotype ♂

Dolichopodidae

Argyra similis Harmston & Knowlton 1940 J. Kans. Entomol. Soc. 13:58. Holotype ♂

Chrysotus anomalus Malloch 1914 Bull. Ill. State Lab. Nat. Hist. 10:238. Holotype ♂

Chrysotus ciliatus Malloch 1914 Bull. Ill. State Lab. Nat. Hist. 10:236. Holotype ♂

Chrysotus flavisetus Malloch 1914 Bull. Ill. State Lab. Nat. Hist. 10:239. Lectotype ♂ designated by Frison (1927:183)

Chrysotus spinifer Malloch 1914 Bull. Ill. State Lab. Nat. Hist. 10:238. Holotype ♂

Hydrophorus pilitarsis Malloch 1919 Report of the Canadian Arctic Expedition 3:51c. Syntypes 1♂, 1♀

Hygroceleuthus idahoensis Aldrich 1894 Kans. Univ. Q. 2:154. Syntype 1♂

Medeterus caerulescens Malloch 1919 Entomol. News 30:8. Holotype ♂

Rhaphium rossi Harmston & Knowlton 1940 J. Kans. Entomol. Soc. 13:60. Holotype ♂

Drosophilidae

Amiota setigera Malloch 1924 Bull. Brooklyn Entomol. Soc. 19:51. Holotype ♂

Phortica minor Malloch 1921 Entomol. News 32:312. Holotype ♂

Empididae

Tachydromia harti Malloch 1919 Can. Entomol. 51:248. Holotype ♂

Heleomyzidae

Anarostomoides petersoni Malloch 1916 Bull. Brooklyn Entomol. Soc. 11:15. Holotype ♂

Hilarimorphidae

Hilarimorpha lantha Webb 1974 J. Kans. Entomol. Soc. 47:203. Holotype ♂

Hilarimorpha mikii Williston 1888 Psyche 5:100. Holotype ♂

Hilarimorpha modesta Webb 1974 J. Kans. Entomol. Soc. 47:215. Holotype ♂

Hilarimorpha robertsoni Webb 1974 J. Kans. Entomol. Soc. 47:206. Holotype ♂

Hilarimorpha sidora Webb 1974 J. Kans. Entomol. Soc. 47:199. Holotype ♂

Lauxaniidae

Sapromyza aequalis Malloch 1914 Proc. Biol. Soc. Wash. 27:36. Holotype ♂

Sapromyza cilifera Malloch 1914 Proc. Biol. Soc. Wash. 27:33. Holotype ♂

Sapromyza citreifrons Malloch 1920 Can. Entomol. 52:127. Holotype ♂

Sapromyza fuscibasis Malloch 1920 Can. Entomol. 52:126. Holotype ♂

Sapromyza harti Malloch 1914 Proc. Biol. Soc. Wash. 27:32. Lectotype ♂ designated by Frison (1927:188)

Sapromyza inaequalis Malloch 1914 Proc. Biol. Soc. Wash. 27:35. Holotype ♂

Sapromyza littoralis Malloch 1915 Proc. Biol. Soc. Wash. 28:47. Lectotype ♂ designated by Frison (1927:188)

Sapromyza nubilifera Malloch 1920 Can. Entomol. 52:126. Holotype ♂

Sapromyza pernotata Malloch 1920 Can. Entomol. 52:128. Holotype ♂

Sapromyza seticauda Malloch 1914 Proc. Biol. Soc. Wash. 27:34. Holotype ♂

Sapromyza similata Malloch 1914 Proc. Biol. Soc. Wash. 27:30. Holotype ♀

Lonchaeidae

Lonchaea aberrans Malloch 1920 Can. Entomol. 52:131. Holotype ♀

Lonchaea ruficornis Malloch 1920 Can. Entomol. 52:130. Holotype ♀

Lonchaea vibrissata Malloch 1914 Proc. Biol. Soc. Wash. 27:37. Holotype ♀

Milichiidae

Meoneura nigrifrons Malloch 1915 Proc. Biol. Soc. Wash. 28:47. Holotype ♂

Muscidae

Allognota semivitta Malloch 1918 Trans. Am. Entomol. Soc. 44:282. Holotype ♂

Ariciella flavicornis Malloch 1918 Proc. Biol. Soc. Wash. 31:66. Holotype ♂

Charadrella macrosoma Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:341. Syntypes 1♂, 1♀

Clinoptera hieroglyphica Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:307. Syntype 1♂

Coenosia aliena Malloch 1921 Entomol. News 32:134. Holotype ♀

Coenosia anthracina Malloch 1921 Entomol. News 32:134. Holotype ♀

Coenosia denticornis Malloch 1920 Trans. Am. Entomol. Soc. 46:164. Holotype ♀

Coenosia femoralis Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:345. Syntype 1♀

Coenosia frisoni Malloch 1920 Trans. Am. Entomol. Soc. 46:165. Holotype ♂

Coenosia laricata Malloch 1920 Trans. Am. Entomol. Soc. 46:166. Holotype ♀

Coenosia macrocera Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:344. Syntype 1♀

Coenosia punctulata Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:343. Syntype 1♀

Eulimnophora cilifera Malloch 1920 Trans. Am. Entomol. Soc. 46:145. Holotype ♂

Eulimnophora dorsovittata Malloch 1920 Trans. Am. Entomol. Soc. 46:146. Holotype ♀

Fannia canadensis Malloch 1924 Ann. Mag. Nat. Hist. 13:423. Holotype ♂

Fannia lasiops Malloch 1920 Trans. Am. Entomol. Soc. 46:168. Holotype ♂

Fannia latifrons Malloch 1914 Bull. Ill. State Lab. Nat. Hist. 10:240. Holotype ♂

Fannia spathiophora Malloch 1918 Trans. Am. Entomol. Soc. 44:294. Holotype ♀

Helina algonquina Malloch 1922 Bull. Brooklyn Entomol. Soc. 17:96. Holotype ♂

Helina bispinosa Malloch 1920 Trans. Am. Entomol. Soc. 46:142. Holotype ♂

Helina consimilata Malloch 1920 Trans. Am. Entomol. Soc. 46:144. Holotype ♂

Helina linearis Malloch 1920 Trans. Am. Entomol. Soc. 46:139. Holotype ♂

Helina nasoni Malloch 1920 Trans. Am. Entomol. Soc. 46:138. Holotype ♂

Helina nigribasis Malloch 1920 Trans. Am. Entomol. Soc. 46:143. Holotype ♂

Helina nigrita Malloch 1920 Trans. Am. Entomol. Soc. 46:139. Holotype ♂

Helina spinilamellata Malloch 1920 Trans. Am. Entomol. Soc. 46:140. Holotype ♂

Helina tuberculata Malloch 1919 Can. Entomol. 51:277. Holotype ♂

Hydrotaea cristata Malloch 1918 Bull. Brooklyn Entomol. Soc. 13:93. Holotype ♂

Hydrotaea houghi Malloch 1916 Bull. Brooklyn Entomol. Soc. 11:110. Lectotype ♂ designated by Frison (1927: 201)

Leucomelina deleta Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:329. Syntype 1♂

Leucomelina minuscula Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:330. Syntype 1♀

Limnophora clivicola Malloch 1920 Trans. Am. Entomol. Soc. 46:155. Holotype ♂

Limnophora socia Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:326. Syntype 1♀

Limnophora tetrachaeta Malloch 1920 Trans. Am. Entomol. Soc. 46:153. Holotype ♂

Melanochelia angulata Malloch 1921 Can. Entomol. 53:63. Lectotype ♂ designated by Frison (1927:204)

Melanochelia imitatrix Malloch 1921 Can. Entomol. 53:64. Holotype ♂

Muscina tripunctata Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:305. Syntype 1♂

Mydaea armata Malloch 1920 Trans. Am. Entomol. Soc. 46:135. Holotype ♀

Mydaea brevipilosa Malloch 1920 Trans. Am. Entomol. Soc. 46:135. Holotype ♂

Mydaea concinna Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:317. Syntype 1♀

Mydaea discimana Malloch 1920 Trans. Am. Entomol. Soc. 46:136. Holotype ♀

Mydaea neglecta Malloch 1920 Trans. Am. Entomol. Soc. 46:136. Holotype ♂

Mydaea obscura Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:317. Syntype 1♂

Mydaea persimilis Malloch 1920 Trans. Am. Entomol. Soc. 46:134. Holotype ♀

Phaonia basiseta Malloch 1920 Trans. Am. Entomol. Soc. 46:133. Holotype ♀

Phaonia brevispina Malloch 1923 Trans. Am. Entomol. Soc. 48:269. Holotype ♂

Phaonia harti Malloch 1923 Trans. Am. Entomol. Soc. 48:266. Holotype ♂

Phaonia laticornis Malloch 1923 Trans. Am. Entomol. Soc. 48:279. Holotype ♂

Phaonia subfusca Malloch 1923 Trans. Am. Entomol. Soc. 48:273. Holotype ♂

Phaonia texensis Malloch 1923 Trans. Am. Entomol. Soc. 48:271. Holotype ♂

Phorbia fuscisquama Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:340. Syntype 1♂

Phyllogaster littoralis Malloch 1917 Can. Entomol. 49:228. Holotype ♂

Pogonomyia aldrichi Malloch 1918 Trans. Am. Entomol. Soc. 44:281. Holotype ♂

Pogonomyia aterrima Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:335. Syntype 1♂

Pogonomyia flavinervis Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 11:356. Lectotype ♂ designated by Frison (1927:207)

Pogonomyia latifrons Malloch 1918 Trans. Am. Entomol. Soc. 44:281. Holotype ♀

Schoenomyza aurifrons Malloch 1918 Trans. Am. Entomol. Soc. 44:288. Holotype ♂

Spilogaster copiosa Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:321. Syntypes 1♂, 1♀

Spilogaster parvula Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:321. Syntype 1♀

Spilogaster rubripalpis Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:320. Syntype 1♀

Spilogaster signatipennis Wulp 1903 Biol. Cent-Am., Insecta-Diptera 2:322. Syntypes 1♂, 1♀

Tetramerinx brevicornis Malloch 1917 Can. Entomol. 49:226. Holotype ♀

Xenomydaea buccata Malloch 1920 Trans. Am. Entomol. Soc. 46:144. Holotype ♂

Mycetophilidae

Fungivora comata Laffoon 1956 Iowa State J. Sci. 31:196. Holotype ♂

Zygomyia interrupta Malloch 1914 Bull. Ill. State Lab. Nat. Hist. 10:234. Holotype ♂

Periscelididae

Phorticoides flinti Malloch 1915 Bull. Brooklyn Entomol. Soc. 10:87. Lectotype ♂ designated by Frison (1927:187)

Phoridae

Aphiochaeta aristalis Malloch 1914 Bull. Brooklyn Entomol. Soc. 9:57. Holotype ♂

Aphiochaeta bisetulata Malloch 1915 Bull. Brooklyn Entomol. Soc. 10:65. Holotype ♀

Aphiochaeta nasoni Malloch 1914 Bull. Brooklyn Entomol. Soc. 9:58. Holotype ♂

Aphiochaeta pallidiventris Malloch 1919 Bull. Brooklyn Entomol. Soc. 14:47. Holotype ♀

Aphiochaeta plebeia Malloch 1914 Bull. Brooklyn Entomol. Soc. 9:59. Holotype ♂

Aphiochaeta quadripunctata Malloch 1918 Entomol. News 29:147. Holotype ♂

Apocephalus pictus Malloch 1918 Entomol. News 29:146. Holotype ♂

Beckerina luteola Malloch 1919 Can. Entomol. 51:256. Holotype ♀

Platyphora flavofemorata Malloch 1915 Bull. Ill. State Lab. Nat. Hist. 11:353. Holotype ♂

Rhagionidae

Chrysopilus kincaidi Hardy 1949 Am. Midl. Nat. 41:156. Holotype ♂

Chrysopilus pilosus Leonard 1930 Mem. Am. Entomol. Soc. 7:152. Holotype ♂

Sarcophagidae

Sarcophaga piva Roback 1952 J. Wash. Acad. Sci. 42:45. Holotype ♂

Scatopsidae

Aspistes harti Malloch 1920 Entomol. News 31:275. Holotype ♂

Scenopinidae

Scenopinus nubilipes Say 1829 J. Acad. Nat. Sci. Phila. 6:170. Neotype ♂ designated by Kelsey (1969:145)

Simuliidae

Simulium forbesi Malloch 1914 U. S. Bur. Entomol. Bull. 26:63. Holotype ♀

Simulium johannseni Hart 1912 Rep. State Entomol. Ill. 27:32. Lectotype ♀ designated by Frison (1927:181)

Simulium venustoides Hart 1912 Rep. State Entomol. Ill. 27:42. Lectotype ♂ designated by Frison (1927:181)

Sphaeroceridae

Borborus scriptus Malloch 1915 Bull. Brooklyn Entomol. Soc. 10:64. Holotype ♂

Stratiomyidae

Eupachygaster henshawi Malloch 1917 Bull. Ill. State Lab. Nat. Hist. 12:338. Holotype ♀

Eupachygaster punctifer Malloch 1915 Ann. Entomol. Soc. Am. 8:316. Holotype ♀

Nemotelus bellulus Melander 1903 Psyche 10:183. Syntype 1♀

Nemotelus bruesii Melander 1903 Psyche 10:179. Syntypes 1♂, 1♀

Nemotelus trinotatus Melander 1903 Psyche 10:180. Syntypes 2♂, 1♀

Nemotelus wheeleri Melander 1903 Psyche 10:182. Syntype 1♀

Odontomyia snowi Hart 1896 Bull. Ill. State Lab. Nat. Hist. 4:256. Holotype ♂

Oxycera albovittata Malloch 1917 Bull. Ill. State Lab. Nat. Hist. 12:330. Holotype ♀

Oxycera aldrichi Malloch 1917 Bull. Ill. State Lab. Nat. Hist. 12:329. Holotype ♂

Oxycera approximata Malloch 1917 Bull. Ill. State Lab. Nat. Hist. 12:326. Holotype ♀

Syrphidae

Callicera johnsoni auripila Metcalf 1916 J. Elisha Mitchell Sci. Soc. 32:112. Holotype ♀

Cnemedon trochateratus Malloch 1918 Proc. Entomol. Soc. Wash. 20:127. Holotype ♂

Mallota illinoensis Robertson 1901 Can. Entomol. 33:284. Holotype ♀

Metasyrphus metcalfi Fluke 1933 Trans. Wis. Acad. Sci. Arts Lett. 28:119. Holotype ♀

Platycheirus scamboides Curran 1927 Am. Mus. Novit. 247:6. Holotype ♂

Sphaerophoria cranbrookensis Curran 1921 Can. Entomol. 53:173. Holotype ♂

Sphegina campanulata Robertson 1901 Can. Entomol. 33:284. Holotype ♂

Syrphus canadensis Curran 1926 Can. Entomol. 58:172. Syntypes 1♂, 1♀

Syrphus oronoensis Metcalf 1917 Maine Agric. Exp. Stn. Tech. Bull. 263:162. Holotype ♀

Temnostoma trifasciata Robertson 1901 Can. Entomol. 33:285. Holotype ♂

Tabanidae

Chrysops sequax tau Philip 1955 Rev. Bras. Entomol. 3:113. Holotype ♀

Tachinidae

Cryptomeigenia flavibasis Curran 1927 Bull. Brooklyn Entomol. Soc. 22:145. Holotype ♀

Epigrimyia illinoensis Robertson 1901 Can. Entomol. 33:286. Holotype ♂

Eutheresia interrupta Curran 1929 Can. Entomol. 61:33. Holotype ♀

Hyalomya pruinosa Robertson 1901 Can. Entomol. 33:284. Holotype ♂

Phorantha humeralis Robertson 1901 Can. Entomol. 33:286. Holotype ♂

Phorantha pruinosa Robertson 1901 Can. Entomol. 33:285. Holotype ♂

Winthemia illinoensis Robertson 1901 Can. Entomol. 33:286. Holotype ♂

Winthemia imitator Reinhard 1931 Proc. U. S. Natl. Mus. 79:39. Holotype ♂

Tipulidae

Dicranota iowa Alexander 1920 Can. Entomol. 52:78. Holotype ♀

Elliptera illini Alexander 1920 Pomona Coll. J. Entomol. Zool. 12:86. Holotype ♀

Limnophila imbecilla illinoiensis Alexander 1920 Can. Entomol. 52:226. Holotype ♂

Nephrotoma sphagnicola Alexander 1920 Can. Entomol. 52:110. Holotype ♀

Ormosia frisoni Alexander 1920 Can. Entomol. 52:224. Holotype ♂

Tipula mallochi Alexander 1920 Pomona Coll. J. Entomol. Zool. 12:91. Holotype ♂

Xylomyidae

Xylomyia pallidifemur Malloch 1917 Bull. Ill. State Lab. Nat. Hist. 12:343. Lectotype ♂ designated by Frison (1927:182)

Xylophagidae

Glutops rossi Pechuman 1945 Can. Entomol. 77:134. Holotype ♀

TRICHOPTERA

Beraeidae

Beraea gorteba Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:208. Holotype ♂

Brachycentridae

Brachycentrus aspilus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:178. Holotype ♂

Brachycentrus chelatus Ross 1947 Trans. Am. Entomol. Soc. 73:164. Holotype ♂

Brachycentrus dimicki Milne 1936 Studies in North American Trichoptera 3:113. Holotype ♂

Brachycentrus lateralis Say 1823 West. Q. Rep. 2:161. Neotype ♂ designated by Ross (1944:265)

Brachycentrus numerosus Say 1823 West. Q. Rep. 2:160. Neotype ♂ designated by Ross (1944:264)

Brachycentrus spinae Ross 1948 Proc. Entomol. Soc. Wash. 50:153. Holotype ♂

Micrasema bactro Ross 1938 Proc. Entomol. Soc. Wash. 40:122. Holotype ♂

Micrasema bennetti Ross 1947 Trans. Am. Entomol. Soc. 73:160. Holotype ♂

Micrasema burksi Ross & Unzicker 1965 Proc. Biol. Soc. Wash. 78:255. Holotype ♂

Micrasema diteris Ross 1947 Trans. Am. Entomol. Soc. 73:161. Holotype ♂

Micrasema onisca Ross 1947 Trans. Am. Entomol. Soc. 73:160. Holotype ♂

Micrasema ozarkana Ross & Unzicker 1965 Proc. Biol. Soc. Wash. 78:254. Holotype ♂

Micrasema rickeri Ross & Unzicker 1965 Proc. Biol. Soc. Wash. 78:256. Holotype ♂

Micrasema scotti Ross 1947 Trans. Am. Entomol. Soc. 73:159. Holotype ♂

Micrasema sprulesi Ross 1941 Trans. Am. Entomol. Soc. 67:115. Holotype ♂

Micrasema wataga Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:178. Holotype ♂

Oligoplectrum echo Ross 1947 Trans. Am. Entomol. Soc. 73:164. Holotype ♂

Calamoceratidae

Heteroplectron amerus Ross 1939 Proc. Entomol. Soc. Wash. 41:68. Holotype ♂

Heteroplectron gameta Ross 1939 Proc. Entomol. Soc. Wash. 41:69. Holotype ♂

Glossosomatidae

Agapetus artesus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:106. Holotype ♂

Agapetus crasmus Ross 1939 Proc. Entomol. Soc. Wash. 41:66. Holotype ♂

Agapetus debilis Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:108. Holotype ♂

Agapetus gelbae Ross 1947 Trans. Am. Entomol. Soc. 73:132. Holotype ♂

Agapetus illini Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:106. Holotype ♂

Agapetus iridis Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:269. Holotype ♂

Agapetus jafiwi Ross 1951 J. Wash. Acad. Sci. 41:354. Holotype ♂

Agapetus latosus Ross 1951 J. Wash. Acad. Sci. 41:354. Holotype ♂

Agapetus marlo Milne 1936 Studies in North American Trichoptera 3:108. Holotype ♂

Agapetus medicus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:107. Holotype ♂

Agapetus ophionis Ross 1947 Trans. Am. Entomol. Soc. 73:133. Holotype ♂

Agapetus pinatus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:107. Holotype ♂

Agapetus taho Ross 1947 Trans. Am. Entomol. Soc. 73:133. Holotype ♂

Agapetus tomus Ross 1941 Trans. Am. Entomol. Soc. 67:44. Holotype ♂

Agapetus ulmeri Ross 1951 J. Wash. Acad. Sci. 41:353. Holotype ♂

Agapetus vireo Ross 1941 Trans. Am. Entomol. Soc. 67:43. Holotype ♂

Anagapetus bernea Ross 1947 Trans. Am. Entomol. Soc. 73:131. Holotype ♂

Anagapetus hoodi Ross 1951 Pan-Pac. Entomol. 27:143. Holotype ♂

Electragapetus tsudai Ross 1951 J. Wash. Acad. Sci. 41:353. Holotype ♂

Glossosoma excita Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:109. Holotype ♂

Glossosoma idaho Ross 1941 Trans. Am. Entomol. Soc. 67:41. Holotype ♂

Glossosoma montana Ross 1941 Trans. Am. Entomol. Soc. 67:42. Holotype ♂

Glossosoma pterna Ross 1947 Trans. Am. Entomol. Soc. 73:130. Holotype ♂

Glossosoma pyroxum Ross 1941 Trans. Am. Entomol. Soc. 67:42. Holotype ♂

Glossosoma schuhi Ross 1947 Trans. Am. Entomol. Soc. 73:130. Holotype ♂

Glossosoma velona Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:109. Holotype ♂

Glossosoma verdona Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:110. Holotype ♂

Glossosoma wenatchee Ross & Spencer 1952 Proc. Entomol. Soc. B. C. 48:45. Holotype ♂

Paragapetus celsus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:111. Holotype ♂

Protoptila alexanderi Ross 1941 Trans. Am. Entomol. Soc. 67:48. Holotype ♂

Protoptila balmorhea Ross 1941 Trans. Am. Entomol. Soc. 67:45. Holotype ♂

Protoptila cantha Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:113. Holotype ♂

Protoptila coloma Ross 1941 Trans. Am. Entomol. Soc. 67:45. Holotype ♂

Protoptila erotica Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:113. Holotype ♂

Protoptila jeanae Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:112. Holotype ♂

Protoptila lega Ross 1941 Trans. Am. Entomol. Soc. 67:48. Holotype ♂

Protoptila palina Ross 1941 Trans. Am. Entomol. Soc. 67:46. Holotype ♂

Protoptila thoracica Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:114. Holotype ♂

Goeridae

Goera archaon Ross 1947 Trans. Am. Entomol. Soc. 73:156. Holotype ♂

Goera stylata Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:172. Holotype ♂

Goerita betteni Ross 1962 Entomol. News 73:132. Holotype ♂

Goerita genota Ross 1941 Trans. Am. Entomol. Soc. 67:116. Holotype ♂

Goerita semata Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:172. Holotype ♂

Helicopsychidae

Helicopsyche comosa Kingsolver 1964 Proc. Entomol. Soc. Wash. 66:259. Holotype ♂

Helicopsyche cubana Kingsolver 1964 Proc. Entomol. Soc. Wash. 66:259. Holotype ♂

Helicopsyche dampfi Ross 1956 J. Wash. Acad. Sci. 46:398. Holotype ♂

Helicopsyche extensa Ross 1956 J. Wash. Acad. Sci. 46:397. Holotype ♂

Helicopsyche incisa Ross 1956 J. Wash. Acad. Sci. 46:398. Holotype ♂

Helicopsyche limnella Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:179. Holotype ♂

Helicopsyche piroa Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:298. Holotype ♂

Helicopsyche planata Ross 1956 J. Wash. Acad. Sci. 46:400. Holotype ♂

Helicopsyche quadrosa Ross 1956 J. Wash. Acad. Sci. 46:400. Holotype ♂

Helicopsyche selanderi Ross 1956 J. Wash. Acad. Sci. 46:400. Holotype ♂

Helicopsyche truncata Ross 1956 J. Wash. Acad. Sci. 46:398. Holotype ♂
Helicopsyche vergelana Ross 1956 J. Wash. Acad. Sci. 46:400. Holotype ♂
Helicopsyche woytkowskii Ross 1956 J. Wash. Acad. Sci. 46:398. Holotype ♂

Hydropsychidae

Aphropsyche aprilis Ross 1941 Trans. Am. Entomol. Soc. 67:78. Holotype ♂
Cheumatopsyche aphanta Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:151. Holotype ♂
Cheumatopsyche burksi Ross 1941 Trans. Am. Entomol. Soc. 67:83. Holotype ♂
Cheumatopsyche campyla Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:152. Holotype ♂
Cheumatopsyche enonis Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:153. Holotype ♂
Cheumatopsyche etrona Ross 1941 Trans. Am. Entomol. Soc. 67:80. Holotype ♂
Cheumatopsyche gyra Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:154. Holotype ♂
Cheumatopsyche helma Ross 1939 Proc. Entomol. Soc. Wash. 41:68. Holotype ♂
Cheumatopsyche lasia Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:154. Holotype ♂
Cheumatopsyche mollala Ross 1941 Trans. Am. Entomol. Soc. 67:81. Holotype ♂
Cheumatopsyche oxa Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:155. Holotype ♂
Cheumatopsyche pasella Ross 1941 Trans. Am. Entomol. Soc. 67:84. Holotype ♂
Cheumatopsyche pinaca Ross 1941 Trans. Am. Entomol. Soc. 67:82. Holotype ♂
Cheumatopsyche wrighti Ross 1947 Trans. Am. Entomol. Soc. 73:140. Holotype ♂
Cheumatopsyche zion Ross 1947 Trans. Am. Entomol. Soc. 73:141. Holotype ♂
Homoplectra alseae Ross 1938 Proc. Entomol. Soc. Wash. 40:120. Holotype ♂
Hydropsyche aerata Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:144. Holotype ♂
Hydropsyche alhedra Ross 1939 Proc. Entomol. Soc. Wash. 41:67. Holotype ♂
Hydropsyche amblis Ross 1938 Proc. Entomol. Soc. Wash. 40:120. Holotype ♂
Hydropsyche antilles Ross & Palmer 1946 Proc. Entomol. Soc. Wash. 48:184. Holotype ♂
Hydropsyche arinale Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:143. Holotype ♂
Hydropsyche betteni Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:146. Holotype ♂
Hydropsyche bidens Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:142. Holotype ♂
Hydropsyche bronta Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:149. Holotype ♂
Hydropsyche catawba Ross 1939 Proc. Entomol. Soc. Wash. 41:67. Holotype ♂
Hydropsyche centra Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:150. Holotype ♂
Hydropsyche cheilonis Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:149. Holotype ♂
Hydropsyche cornuta Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:141. Holotype ♂
Hydropsyche cuanis Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:147. Holotype ♂
Hydropsyche decalda Ross 1947 Trans. Am. Entomol. Soc. 73:138. Holotype ♂
Hydropsyche delrio Ross 1941 Trans. Am. Entomol. Soc. 67:86. Holotype ♂
Hydropsyche demora Ross 1941 Trans. Am. Entomol. Soc. 67:86. Holotype ♂
Hydropsyche dicantha Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:146. Holotype ♂
Hydropsyche elissoma Ross 1947 Trans. Am. Entomol. Soc. 73:137. Holotype ♂
Hydropsyche fattigi Ross 1941 Trans. Am. Entomol. Soc. 67:88. Holotype ♂
Hydropsyche frisoni Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:142. Holotype ♂
Hydropsyche hoffmani Ross 1962 Entomol. News 73:129. Holotype ♂
Hydropsyche leonardi Ross 1938 Ill. Nat Hist. Surv. Bull. 21:145. Holotype ♂

Hydropsyche orris Ross 1938 Proc. Entomol. Soc. Wash. 40:121. Holotype ♂

Hydropsyche philo Ross 1941 Trans. Am. Entomol. Soc. 67:90. Holotype ♂

Hydropsyche piatrix Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:148. Holotype ♂

Hydropsyche placoda Ross 1941 Trans. Am. Entomol. Soc. 67:83. Holotype ♂

Hydropsyche protis Ross 1938 Proc. Entomol. Soc. Wash. 40:120. Holotype ♂

Hydropsyche rotosa Ross 1947 Trans. Am. Entomol. Soc. 73:139. Holotype ♂

Hydropsyche simulans Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:139. Holotype ♂

Hydropsyche solex Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:271. Holotype ♂

Hydropsyche sparna Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:150. Holotype ♂

Hydropsyche tana Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:151. Holotype ♂

Hydropsyche valanis Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:144. Holotype ♂

Hydropsyche venada Ross 1941 Trans. Am. Entomol. Soc. 67:91. Holotype ♂

Hydropsyche ventura Ross 1941 Trans. Am. Entomol. Soc. 67:92. Holotype ♂

Hydropsyche vexa Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:148. Holotype ♂

Oropsyche howellae Ross 1941 Trans. Am. Entomol. Soc. 67:79. Holotype ♂

Parapsyche almota Ross 1938 Proc. Entomol. Soc. Wash. 40:119. Holotype ♂

Parapsyche cardis Ross 1938 Proc. Entomol. Soc. Wash. 40:119. Holotype ♂

Parapsyche elsis Milne 1936 Studies in North American Trichoptera 3:66. Holotype ♂

Plectropsyche hoogstraali Ross 1947 Trans. Am. Entomol. Soc. 73:142. Holotype ♂

Smicridea caldwelli Ross 1947 Trans. Am. Entomol. Soc. 73:145. Holotype ♂

Smicridea utico Ross 1947 Trans. Am. Entomol. Soc. 73:144. Holotype ♂

Hydroptilidae

Agraylea costello Ross 1941 Can. Entomol. 73:15. Holotype ♂

Agraylea saltesea Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:114. Holotype ♂

Dibusa angata Ross 1939 Proc. Entomol. Soc. Wash. 41:67. Holotype ♂

Hydroptila acadia Ross 1941 Trans. Am. Entomol. Soc. 67:63. Holotype ♂

Hydroptila ajax Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:127. Holotype ♂

Hydroptila amoena Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:124. Holotype ♂

Hydroptila ampoda Ross 1941 Can. Entomol. 73:16. Holotype ♂

Hydroptila angusta Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:130. Holotype ♂

Hydroptila arctia Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:129. Holotype ♂

Hydroptila argosa Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:131. Holotype ♂

Hydroptila armata Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:123. Holotype ♂

Hydroptila berneri Ross 1941 Trans. Am. Entomol. Soc. 67:67. Holotype ♂

Hydroptila broweri Blickle 1963 Bull. Brooklyn Entomol. Soc. 58:18. Holotype ♂

Hydroptila dentata Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:126. Holotype ♂

Hydroptila grandiosa Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:126. Holotype ♂

Hydroptila denza Ross 1948 J. Wash. Acad. Sci. 38:204. Holotype ♂

Hydroptila fiskei Blickle 1963 Bull. Brooklyn Entomol. Soc. 58:19. Holotype ♂

Hydroptila jackmanni Blickle 1963 Bull. Brooklyn Entomol. Soc. 58:17. Holotype ♂

Hydroptila latosa Ross 1947 Trans. Am. Entomol. Soc. 73:148. Holotype ♂

Hydroptila lloganae Blickle 1961 Bull. Brooklyn Entomol. Soc. 56:131. Holotype ♂

Hydroptila lonchera Blickle & Morse 1954 Bull. Brooklyn Entomol. Soc. 49:123. Holotype ♂

Hydroptila melia Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:128. Holotype ♂

Hydroptila metoeca Blickle & Morse 1954 Bull. Brooklyn Entomol. Soc. 49:127. Holotype ♂

Hydroptila molsonae Blickle 1961 Bull. Brooklyn Entomol. Soc. 56:132. Holotype ♂

Hydroptila nicoli Ross 1941 Trans. Am. Entomol. Soc. 67:69. Holotype ♂

Hydroptila novicola Blickle & Morse 1954 Bull. Brooklyn Entomol. Soc. 49:124. Holotype ♂

Hydroptila pecos Ross 1941 Trans. Am. Entomol. Soc. 67:64. Holotype ♂

Hydroptila protera Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:131. Holotype ♂

Hydroptila quinola Ross 1947 Trans. Am. Entomol. Soc. 73:147. Holotype ♂

Hydroptila remita Blickle & Morse 1954 Bull. Brooklyn Entomol. Soc. 49:124. Holotype ♂

Hydroptila rono Ross 1941 Trans. Am. Entomol. Soc. 67:66. Holotype ♂

Hydroptila salmo Ross 1941 Trans. Am. Entomol. Soc. 67:66. Holotype ♂

Hydroptila scolops Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:128. Holotype ♂

Hydroptila spinata Blickle & Morse 1954 Bull. Brooklyn Entomol. Soc. 49:123. Holotype ♂

Hydroptila strepha Ross 1941 Trans. Am. Entomol. Soc. 67:68. Holotype ♂

Hydroptila tortosa Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:125. Holotype ♂

Hydroptila tusculum Ross 1947 Trans. Am. Entomol. Soc. 73:148. Holotype ♂

Hydroptila vala Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:123. Holotype ♂

Hydroptila virgata Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:125. Holotype ♂

Hydroptila waskesia Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:276. Holotype ♂

Hydroptila xella Ross 1941 Trans. Am. Entomol. Soc. 67:65. Holotype ♂

Hydroptila xera Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:132. Holotype ♂

Hydroptila xoncla Ross 1941 Can. Entomol. 73:16. Holotype ♂

Ithytrichia mazon Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:124. Holotype ♂

Leucotrichia limpia Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:273. Holotype ♂

Leucotrichia notosa Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:271. Holotype ♂

Leucotrichia sarita Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:274. Holotype ♂

Loxotrichia glasa Ross 1941 Trans. Am. Entomol. Soc. 67:70. Holotype ♂

Mayatrichia acuna Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:279. Holotype ♂

Mayatrichia ponta Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:278. Holotype ♂

Neotrichia edalis Ross 1941 Trans. Am. Entomol. Soc. 67:62. Holotype ♂

Neotrichia elerobi Blickle 1961 Bull. Brooklyn Entomol. Soc. 56:132. Holotype ♂

Neotrichia falca Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:119. Holotype ♂

Neotrichia kitae Ross 1941 Trans. Am. Entomol. Soc. 67:60. Holotype ♂

Neotrichia numii Ross 1948 J. Wash. Acad. Sci. 38:205. Holotype ♂

Neotrichia okopa Ross 1939 Ann. Entomol. Soc. Am. 32:629. Holotype ♂

Neotrichia osmena Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:278. Holotype ♂

Neotrichia riegeli Ross 1941 Trans. Am. Entomol. Soc. 67:61. Holotype ♂

Neotrichia sonora Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:277. Holotype ♂

Neotrichia vibrans Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:119. Holotype ♂

Ochrotrichia capitana Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:275. Holotype ♂

Ochrotrichia felipe Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:275. Holotype ♂

Ochrotrichia phenosa Ross 1947 Trans. Am. Entomol. Soc. 73:147. Holotype ♂

Ochrotrichia riesi Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:132. Holotype ♂

Ochrotrichia trapoiza Ross 1947 Trans. Am. Entomol. Soc. 73:146. Holotype ♂

Ochrotrichia weddleae Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:274. Holotype ♂

Ochrotrichia wojcickyi Blickle 1963 Bull. Brooklyn Entomol. Soc. 58:20. Holotype ♂

Orthotrichia baldufi Kingsolver & Ross 1961 Trans. Ill. State Acad. Sci. 54:32. Holotype ♂

Orthotrichia curta Kingsolver & Ross 1961 Trans. Ill. State Acad. Sci. 54:33. Holotype ♂

Orthotrichia dentata Kingsolver & Ross 1961 Trans. Ill. State Acad. Sci. 54:33. Holotype ♂

Oxyethira aculea Ross 1941 Trans. Am. Entomol. Soc. 67:53. Holotype ♂

Oxyethira aeola Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:117. Holotype ♂

Oxyethira allagashensis Blickle 1963 Bull. Brooklyn Entomol. Soc. 58:20. Holotype ♂

Oxyethira anobola Blickle 1966 Entomol. News 77:185. Holotype ♂

Oxyethira araya Ross 1941 Can. Entomol. 73:15. Holotype ♂

Oxyethira arizona Ross 1948 J. Wash. Acad. Sci. 38:202. Holotype

Oxyethira lumosa Ross 1948 J. Wash. Acad. Sci. 38:204. Holotype ♂

Oxyethira novasota Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:138. Holotype ♂

Oxyethira rivicola Blickle & Morse 1954 Bull. Brooklyn Entomol. Soc. 49:121. Holotype ♂

Oxyethira rossi Blickle & Morse 1957 Bull. Brooklyn Entomol. Soc. 52:48. Holotype ♂

Oxyethira serrata Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:117. Holotype ♂

Oxyethira sida Blickle & Morse 1954 Bull. Brooklyn Entomol. Soc. 49:122. Holotype ♂

Oxyethira sodalis Ross & Spencer 1952 Proc. Entomol. Soc. B. C. 48:46. Holotype ♂

Oxyethira verna Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:118. Holotype ♂

Oxyethira zeronia Ross 1941 Can. Entomol. 73:15. Holotype ♂

Polytrichia anisca Ross 1941 Trans. Am. Entomol. Soc. 67:58. Holotype ♂

Polytrichia arva Ross 1941 Trans. Am. Entomol Soc. 67:58. Holotype ♂

Polytrichia contorta Ross 1941 Trans. Am. Entomol. Soc. 67:60. Holotype ♂

Polytrichia eliaga Ross 1941 Trans. Am. Entomol. Soc. 67:57. Holotype ♂

Polytrichia logana Ross 1941 Trans. Am. Entomol. Soc. 67:54. Holotype ♂

Polytrichia lometa Ross 1941 Trans. Am. Entomol. Soc. 67:55. Holotype ♂

Polytrichia mono Ross 1941 Trans. Am. Entomol. Soc. 67:55. Holotype ♂

Polytrichia oregona Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:121. Holotype ♂

Polytrichia shawnee Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:120. Holotype ♂

Polytrichia spinosa Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:121. Holotype ♂

Polytrichia stylata Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:120. Holotype ♂

Polytrichia unio Ross 1941 Trans. Am. Entomol. Soc. 67:56. Holotype ♂

Polytrichia xena Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:122. Holotype ♂

Stactobia brustia Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:115. Holotype ♂

Stactobia delira Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:115. Holotype ♂

Stactobia palmata Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:116. Holotype ♂

Lepidostomatidae

Jenortha cascadensis Milne 1936 Studies in North American Trichoptera 3:119. Holotype ♂

Lepidostoma cantha Ross 1941 Trans. Am. Entomol. Soc. 67:118. Holotype ♂

Lepidostoma delongi Ross 1946 Ann. Entomol. Soc. Am. 39:283. Holotype ♂

Lepidostoma hoodi Ross 1948 Proc. Entomol. Soc. Wash. 50:152. Holotype ♂

Lepidostoma jewetti Ross 1946 Ann. Entomol. Soc. Am. 39:285. Holotype ♂

Lepidostoma knowltoni Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:75. Holotype ♂

Lepidostoma knulli Ross 1946 Ann. Entomol. Soc. Am. 39:280. Holotype ♂

Lepidostoma liba Ross 1941 Trans. Am. Entomol. Soc. 67:120. Holotype ♂

Lepidostoma lotor Ross 1946 Ann. Entomol. Soc. Am. 39:275. Holotype ♂

Lepidostoma lydia Ross 1939 Proc. Entomol. Soc. Wash. 41:70. Holotype ♂

Lepidostoma ontario Ross 1941 Trans. Am. Entomol. Soc. 67:119. Holotype ♂

Lepidostoma ormea Ross 1946 Ann. Entomol. Soc. Am. 39:275. Holotype ♂

Lepidostoma pleca Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:175. Holotype ♂

Lepidostoma quercina Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:176. Holotype ♂

Lepidostoma rayneri Ross 1941 Trans. Am. Entomol. Soc. 67:117. Holotype ♂

Lepidostoma rhino Ross 1946 Ann. Entomol. Soc. Am. 39:276. Holotype ♂

Lepidostoma sommermanae Ross 1946 Ann. Entomol. Soc. Am. 39:286. Holotype ♂

Lepidostoma strophis Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:177. Holotype ♂

Lepidostoma swannanoa Ross 1939 Proc. Entomol. Soc. Wash. 41:69. Holotype ♂

Lepidostoma veroda Ross 1948 Proc. Entomol. Soc. Wash. 50:151. Holotype ♂

Theliopsyche corona Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:174. Holotype ♂

Theliopsyche epilone Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:173. Holotype ♂

Leptoceridae

Athripsodes alagmus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:155. Holotype ♂

Athripsodes alces Ross 1941 Trans. Am. Entomol. Soc. 67:95. Holotype ♂

Athripsodes brevis Etnier 1968 Entomol. News 79:188. Holotype ♂

Athripsodes cophus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:156. Holotype ♂

Athripsodes erraticus Milne 1936 Studies in North American Trichoptera 3:58. Holotype ♂

Athripsodes erullus Ross 1938 Ann. Entomol. Soc. Am. 31:90. Holotype ♂

Athripsodes miscus Ross 1941 Trans. Am. Entomol. Soc. 67:93. Holotype ♂

Athripsodes nephus Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:230. Holotype ♂

Athripsodes ophioderus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:157. Holotype ♂

Athripsodes saccus Ross 1938 Ann. Entomol. Soc. Am. 31:89. Holotype ♂

Athripsodes uvalo Ross 1938 Ann. Entomol. Soc. Am. 31:89. Holotype ♂

Athripsodes wetzeli Ross 1941 Trans. Am. Entomol. Soc. 67:94. Holotype ♂

Leptocella diarina Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:218. Holotype ♂

Leptocella spiloma Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:219. Holotype ♂

Leptocella tavara Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:287. Holotype ♂

Leptocerus oligius Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:160. Holotype ♂

Leptocerus oxapius Ross 1938 Ann. Entomol. Soc. Am. 31:88. Holotype ♂

Leptocerus stehri Ross 1941 Trans. Am. Entomol. Soc. 67:99. Holotype ♂

Mystacides sandersoni Yamamoto & Ross 1966 Can. Entomol. 98:630. Holotype ♂

Oecetis daytona Ross 1947 Trans. Am. Entomol. Soc. 73:153. Holotype ♂

Oecetis ditissa Ross 1966 Trans. Ill. State Acad. Sci. 59:13. Holotype ♂

Oecetis eddlestoni Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:160. Holotype ♂

Oecetis georgia Ross 1941 Trans. Am. Entomol. Soc. 67:98. Holotype ♂

Oecetis nocturna Ross 1966 Trans. Ill. State Acad. Sci. 59:11. Holotype ♂

Oecetis porteri Ross 1947 Trans. Am. Entomol. Soc. 73:154. Holotype ♂

Oecetis sphyra Ross 1941 Trans. Am. Entomol. Soc. 67:99. Holotype ♂

Triaenodes aba Milne 1935 Studies in North American Trichoptera 2:20. Holotype ♂

Triaenodes baris Ross 1938 Ann. Entomol. Soc. Am. 31:88. Holotype ♂

Triaenodes connata Ross 1959 Entomol. News 70:44. Holotype ♂

Triaenodes dipsia Ross 1938 Ann. Entomol. Soc. Am. 31:89. Holotype ♂

Triaenodes florida Ross 1941 Trans. Am. Entomol. Soc. 67:96. Holotype ♂

Triaenodes furcella Ross 1959 Entomol. News 70:44. Holotype ♂

Triaenodes melaca Ross 1947 Trans. Am.. Entomol. Soc. 73:155. Holotype ♂

Triaenodes nox Ross 1941 Trans. Am. Entomol. Soc. 67:96. Holotype ♂

Triaenodes perna Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:159. Holotype ♂

Triaenodes phalacris Ross 1938 Ann. Entomol. Soc. Am. 31:88. Holotype ♂

Triaenodes smithi Ross 1959 Entomol. News 70:40. Holotype ♂

Triaenodes taenia Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:157. Holotype ♂

Triaenodes tridonta Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:158. Holotype ♂

Limnephilidae

Apatelia aenicta Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:162. Holotype ♂

Arctoecia ozburni Milne 1935 Studies in North American Trichoptera 2:39. Holotype ♂

Banksiola selina Betten 1944 Ill. Nat. Hist. Surv. Bull. 23:169. Holotype ♂

Caborius kaskaskia Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:198. Holotype ♀

Carborius lyratus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:163. Holotype ♂

Chyranda cordon Ross 1949 Pan-Pac. Entomol. 25:122. Holotype ♂

Colpotaulius rhaeus Milne 1935 Studies in North American Trichoptera 2:42. Holotype ♂

Dicosmoecus aureoventris Davis 1949 Ann. Entomol. Soc. Am. 42:449. Holotype ♂

Dicosmoecus canax Ross 1947 Trans. Am. Entomol. Soc. 73:149. Holotype ♂

Ecclisomyia scylla Milne 1935 Studies in North American Trichoptera 2:37. Holotype ♂

Farula malkini Ross 1950 Am. Midl. Nat. 43:421. Holotype ♂

Farula ranieri Milne 1936 Studies in North American Trichoptera 3:116. Holotype ♂

Glyphopsyche avigo Ross 1941 Trans. Am. Entomol. Soc. 67:113. Holotype ♂

Glyphopsyche missouri Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:200. Holotype ♂

Glyphopsyche ormiae Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:163. Holotype ♂

Homophylax andax Ross 1941 Trans. Am. Entomol. Soc. 67:112. Holotype ♂

Imania acanthis Ross 1950 Am. Midl. Nat. 43:419. Holotype ♂

Imania bifosa Ross 1950 Am. Midl. Nat. 43:415. Holotype ♂

Imania cascadis Ross 1950 Am. Midl. Nat. 43:415. Holotype ♂

Imania gnathos Ross 1950 Am. Midl. Nat. 43:413. Holotype ♂

Lepania cascada Ross 1941 Trans. Am. Entomol. Soc. 67:102. Holotype ♂

Limnephilus acnestus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:164. Holotype ♂

Limnephilus acula Ross & Merkley 1952 Am. Midl. Nat. 47:454. Holotype ♂

Limnephilus adapus Ross 1950 Am. Midl. Nat. 43:429. Holotype ♂

Limnephilus ademus Ross 1941 Can. Entomol. 73:18. Holotype ♂

Limnephilus alconura Ross & Merkley 1952 Am. Midl. Nat. 47:453. Holotype ♂

Limnephilus aldinus Ross 1941 Can. Entomol. 73:19. Holotype ♂

Limnephilus aretto Ross 1938 Proc. Entomol. Soc. Wash. 40:121. Holotype ♂

Limnephilus arizona Ross 1941 Trans. Am. Entomol. Soc. 67:108. Holotype ♂

Limnephilus castor Ross & Merkley 1952 Am. Midl. Nat. 47:451. Holotype ♂

Limnephilus cerus Ross & Spencer 1952 Proc. Entomol. Soc. B. C. 48:48. Holotype ♂

Limnephilus circopa Ross & Merkley 1952 Am. Midl. Nat. 47:452. Holotype ♂

Limnephilus conerus Ross 1950 Am. Midl. Nat. 43:426. Holotype ♂

Limnephilus ectus Ross 1941 Trans. Am. Entomol. Soc. 67:105. Holotype ♂

Limnephilus fagus Ross 1941 Can. Entomol. 73:18. Holotype ♂

Limnephilus frijole Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:282. Holotype ♂

Limnephilus keratus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:165. Holotype ♂

Limnephilus labus Ross 1941 Trans. Am. Entomol. Soc. 67:105. Holotype ♂

Limnephilus lopho Ross 1949 Pan-Pac. Entomol. 25:119. Holotype ♂

Limnephilus lunonus Ross 1941 Trans. Am. Entomol. Soc. 67:107. Holotype ♂

Limnephilus merinthus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:166. Holotype ♂

Limnephilus nogus Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:281. Holotype ♂

Limnephilus oreus Milne 1935 Studies in North American Trichoptera 2:46. Holotype ♂

Limnephilus santanus Ross 1949 Pan-Pac. Entomol. 25:120. Holotype ♂

Limnephilus sericeus Say 1824 From the Narrative of the Expedition to the Source of the St. Peter's River, etc., Under the Command of Stephen H. Long, Major U. S. T. E. 2:309. Neotype ♀ designated by Ross (1944: 192)

Limnephilus taloga Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:166. Holotype ♂

Limnephilus thorus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:167. Holotype ♂

Neophylax aniqua Ross 1947 Trans. Am. Entomol. Soc. 73:153. Holotype ♂

Neophylax atlanta Ross 1947 Trans. Am. Entomol. Soc. 73:152. Holotype ♂

Neophylax ayanus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:168. Holotype ♂

Neophylax oligius Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:168. Holotype ♂

Neophylax rickeri Milne 1935 Studies in North American Trichoptera 2:22. Holotype ♂

Neophylax stolus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:169. Holotype ♂

Neothremma didactyla Ross 1949 J. Wash. Acad. Sci. 39:92. Holotype ♂

Oligophlebodes ardis Ross 1941 Trans. Am. Entomol. Soc. 67:103. Holotype ♂

Oligophlebodes ruthae Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:285. Holotype ♂

Oligophlebodes sierra Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:284. Holotype ♂

Pedomoecus sierra Ross 1947 Trans. Am. Entomol. Soc. 73:151. Holotype ♂

Philocasca demita Ross 1941 Trans. Am. Entomol. Soc. 67:111. Holotype ♂

Philocasca oron Ross 1949 Pan-Pac. Entomol. 25:124. Holotype ♂

Platycentropus plectrus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:169. Holotype ♂

Platycentropus radiatus Say 1824 From the Narrative of the Expedition to the Source of the St. Peter's River, etc., Under the Command of Stephen H. Long, Major U. S. T. E. 2:308. Neotype ♂ designated by Ross (1944:182)

Psychoglypha avigo Ross 1941 Trans. Am. Entomol. Soc. 67:113. Holotype ♂

Psychoglypha rossi Schmid 1952 Arch. Hydrobiol. 47:126. Holotype ♂

Pycnopsyche aglonus Ross 1941 Can. Entomol. 73:18. Holotype ♂

Pycnopsyche rossi Betten 1950 Ann. Entomol. Soc. Am. 43:520. Holotype ♂

Pycnopsyche subfasciata Say 1828 American Entomology, or Descriptions of the Insects of North America 3:pl. 44. Neotype ♂ designated by Ross (1944:195)

Radema sorex Ross 1941 Trans. Am. Entomol. Soc. 67:101. Holotype ♂

Stenophylax indiana Ross 1938 Proc. Entomol. Soc. Wash. 40:121. Holotype ♂

Molannidae

Molannodes bergi Ross 1952 Entomol. News 63:86. Holotype ♂

Odontoceridae

Marilia nobsca Milne 1936 Studies in North American Trichoptera 3:79. Holotype ♀

Psilotreta labida Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:287. Holotype ♂

Philopotamidae

Chimarra acuta Ross 1959 Entomol. News 70:171. Holotype ♂

Chimarra boneti Ross 1959 Entomol. News 70:171. Holotype ♂

Chimarra brustia Ross 1959 Entomol. News 70:176. Holotype ♂

Chimarra calva Ross 1959 Entomol. News 70:174. Holotype ♂

Chimarra centralis Ross 1959 Entomol. News 70:178. Holotype ♂

Chimarra cornuta Ross 1959 Entomol. News 70:175. Holotype ♂

Chimarra curfmani Ross 1959 Entomol. News 70:174. Holotype ♂

Chimarra dentosa Ross 1948 Ann. Entomol. Soc. Am. 41:25. Holotype ♂

Chimarra elia Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:269. Holotype ♂

Chimarra embia Ross 1959 Entomol. News 70:170. Holotype ♂

Chimarra emima Ross 1959 Entomol. News 70:172. Holotype ♂

Chimarra feria Ross 1941 Trans. Am. Entomol. Soc. 67:51. Holotype ♂

Chimarra florida Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:270. Holotype ♂

Chimarra hoogstraali Ross 1956 Evolution and Classification of the Mountain Caddisflies p. 70. Holotype ♂

Chimarra ovalis Ross 1959 Entomol. News 70:170. Holotype ♂

Chimarra patosa Ross 1956 Evolution and Classification of the Mountain Caddisflies p. 71. Holotype ♂

Chimarra perigua Ross 1948 Ann. Entomol. Soc. Am. 41:24. Holotype ♂

Chimarra schiza Ross 1959 Entomol. News 70:172. Holotype ♂

Chimarra setosa Ross 1959 Entomol. News 70:175. Holotype ♂

Chimarra spatulata Ross 1959 Entomol. News 70:176. Holotype ♂

Chimarra tsudai Ross 1956 Evolution and Classification of the Mountain Caddisflies p. 71. Holotype ♂

Chimarra utahensis Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:134. Holotype ♂

Chimarra volenta Ross 1959 Entomol. News 70:170. Holotype ♂

Dolophilus anillus Ross 1941 Trans. Am. Entomol. Soc. 67:50. Holotype ♂

Dolophilus occideus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:134. Holotype ♂

Dolophilus shawnee Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:133. Holotype ♂

Dolophilus strotus Ross 1938 Proc. Entomol. Soc. Wash. 40:118. Holotype ♂

Gatlinia mohri Ross 1948 Ann. Entomol. Soc. Am. 41:23. Holotype ♂

Paulianodes tsaratanae Ross 1956 Evolution and Classification of the Mountain Caddisflies p. 54. Holotype ♂

Philopotamus dorcus Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:132. Holotype ♂

Protarrha peruviana Ross 1956 Evolution and Classification of the Mountain Caddisflies p. 68. Holotype ♂

Wormaldia dampfi Ross & King *in* Ross 1956 Evolution and Classification of the Mountain Caddisflies p. 62. Holotype ♂

Wormaldia dorsata Ross & King *in* Ross 1956 Evolution and Classification of the Mountain Caddisflies p. 62. Holotype ♂

Wormaldia endonima Ross & King *in* Ross 1956 Evolution and Classification of the Mountain Caddisflies p. 62. Holotype ♂

Wormaldia esperonis Ross & King *in* Ross 1956 Evolution and Classification of the Mountain Caddisflies p. 63. Holotype ♂

Wormaldia planae Ross & King *in* Ross 1956 Evolution and Classification of the Mountain Caddisflies p. 64. Holotype ♂

Wormaldia sisko Ross 1949 Proc. Entomol. Soc. Wash. 51:157. Holotype ♂

Phryganeidae

Agrypnia dextra Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:161. Holotype ♂

Ptilostomis semifasciata Say 1828 American Entomology, or Descriptions of the Insects of North America 3:pl. 44. Neotype ♂ designated by Ross (1944:173)

Polycentropodidae

Cernotina astera Ross 1941 Trans. Am. Entomol. Soc. 67:76. Holotype ♂

Cernotina calcea Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:137. Holotype ♂

Cernotina laticula Ross 1951 Rev. Entomol. 22:348. Holotype ♂

Cernotina ohio Ross 1939 Ann. Entomol. Soc. Am. 32:628. Holotype ♂

Cernotina oklahoma Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:137. Holotype ♂

Cernotina sinosa Ross 1951 Rev. Entomol. 22:346. Holotype ♂

Cernotina spicata Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:138. Holotype ♂

Cernotina stannardi Ross 1951 Rev. Entomol. 22:343. Holotype ♂

Cernotina taeniata Ross 1951 Rev. Entomol. 22:344. Holotype ♂

Cernotina truncona Ross 1947 Trans. Am. Entomol. Soc. 73:137. Holotype ♂

Cernotina uncifera Ross 1951 Rev. Entomol. 22:348. Holotype ♂

Cernotina zanclana Ross 1951 Rev. Entomol. 22:344. Holotype ♂

Holocentropus glacialis Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:135. Holotype ♂

Holocentropus melanae Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:136. Holotype ♂

Neureclipsis melco Ross 1947 Trans. Am. Entomol. Soc. 73:134. Holotype ♂

Nyctiophylas uncus Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:70. Holotype ♂

Phylocentropus rabilis Milne 1936 Studies in North American Trichoptera 3:84. Holotype ♂

Plectrocnemia clinei Milne 1936 Studies in North American Trichoptera 3:87. Holotype ♂

Polycentropus alleni Yamamoto 1967 J. Kans. Entomol. Soc. 40:127. Holotype ♂

Polycentropus altmani Yamamoto 1967 J. Kans. Entomol. Soc. 40:130. Holotype ♂

Polycentropus barri Ross & Yamamoto 1965 Proc. Biol. Soc. Wash. 78:241. Holotype ♂

Polycentropus blickei Ross & Yamamoto 1965 Proc. Biol. Soc. Wash. 78:243. Holotype ♂

Polycentropus charlesi Ross 1941 Trans. Am. Entomol. Soc. 67:74. Holotype ♂

Polycentropus chelatus Ross & Yamamoto 1965 Proc. Biol. Soc. Wash. 78:243. Holotype ♂

Polycentropus chenoides Ross & Yamamoto 1965 Proc. Biol. Soc. Wash. 78:243. Holotype ♂

Polycentropus chilensis Yamamoto 1966 Can. Entomol. 98:911. Holotype ♂

Polycentropus clinei Milne 1936 Studies in North American Trichoptera 3:87. Holotype ♂

Polycentropus colei Ross 1941 Trans. Am. Entomol. Soc. 67:76. Holotype ♂

Polycentropus deltoides Yamamoto 1967 J. Kans. Entomol. Soc. 40:130. Holotype ♂

Polycentropus dentoides Yamamoto 1967 J. Kans. Entomol. Soc. 40:132. Holotype ♂

Polycentropus digitus Yamamoto 1967 J. Kans. Entomol. Soc. 40:131. Holotype ♂

Polycentropus elarus Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:65. Holotype ♂

Polycentropus elongatus Yamamoto 1966 Can. Entomol. 98:909. Holotype ♂

Polycentropus iculus Ross 1941 Trans. Am. Entomol. Soc. 67:74. Holotype ♂

Polycentropus laminatus Yamamoto 1966 Can. Entomol. 98:909. Holotype ♂

Polycentropus milaca Etnier 1968 Entomol. News 79:189. Holotype ♂

Polycentropus nascotius Ross 1941 Trans. Am. Entomol. Soc. 67:73. Holotype ♂

Polycentropus neiswanderi Ross 1947 Trans. Am. Entomol. Soc. 73:135. Holotype ♂

Polycentropus pentus Ross 1941 Trans. Am. Entomol. Soc. 67:71. Holotype ♂

Polycentropus picana Ross 1947 Trans Am. Entomol. Soc. 73:136. Holotype ♂

Polycentropus pixi Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:66. Holotype ♂

Polycentropus recurvatus Yamamoto 1966 Can. Entomol. 98:912. Holotype ♂

Polycentropus rickeri Yamamoto 1966 J. Kans. Entomol. Soc. 39:688. Holotype ♂

Polycentropus robacki Yamamoto 1966 Can. Entomol. 98:911. Holotype ♂

Polycentropus rosarius Kingsolver 1964 Proc. Entomol. Soc. Wash. 66:257. Holotype ♂

Polycentropus santiago Ross 1947 Trans. Am. Entomol. Soc. 73:136. Holotype ♂

Polycentropus spicatus Yamamoto 1967

J. Kans. Entomol. Soc. 40:131. Holotype ♂

Polycentropus weedi Blickle & Morse 1955 Bull. Brooklyn Entomol. Soc. 50:95. Holotype ♂

Psychomyiella lumina Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:139. Holotype ♂

Psychomyiella nomada Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:138. Holotype ♂

Tinodes multispinosa Schmid 1972 Nat. Can. 99:169. Holotype ♂

Tinodes provo Ross & Merkley 1950 J. Kans. Entomol. Soc. 23:66. Holotype ♂

Tinodes sigodana Ross & Merkley 1950 J. Kans. Entomol. Soc. 23:67. Holotype ♂

Psychomyiidae

Xiphocentron mexico Ross 1949 Entomol. News 60:4. Holotype ♂

Rhyacophilidae

Atopsyche alconura Ross 1953 J. Wash. Acad. Sci. 43:292. Holotype ♂

Atopsyche aplita Ross & King 1952 Ann. Entomol. Soc. Am. 45:192. Holotype ♂

Atopsyche boneti Ross & King 1952 Ann. Entomol. Soc. Am. 45:194. Holotype ♂

Atopsyche calopta Ross & King 1952 Ann. Entomol. Soc. Am. 45:188. Holotype ♂

Atopsyche dampfi Ross & King 1952 Ann. Entomol. Soc. Am. 45:194. Holotype ♂

Atopsyche erigia Ross 1947 Trans. Am. Entomol Soc. 73:129. Holotype ♂

Atopsyche espala Ross & King 1952 Ann. Entomol. Soc. Am. 45:190. Holotype ♂

Atopsyche explanata Ross 1953 J. Wash. Acad. Sci. 43:288. Holotype ♂

Atopsyche japoda Ross & Kin 1952 Ann. Entomol. Soc. Am. 45:202. Holotype ♂

Atopsyche kamesa Ross & King 1952 Ann. Entomol. Soc. Am. 45:196. Holotype ♂

Atopsyche kingi Ross 1953 J. Wash Acad. Sci. 43:289. Holotype ♂

Atopsyche majada Ross 1947 Trans. Am. Entomol. Soc. 73:129. Holotype ♂

Atopsyche ulmeri Ross 1953 J. Wash. Acad. Sci. 43:288. Holotype ♂

Atopsyche vatucra Ross 1953 J. Wash. Acad. Sci. 43:290. Holotype ♂

Rhyacophila amicis Ross 1956 Evolution and Classification of the Mountain Caddisflies p. 120. Holotype ♂

Rhyacophila banksi Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:268. Holotype ♂

Rhyacophila belona Ross 1948 Ann. Entomol. Soc. Am. 41:19. Holotype ♂

Rhyacophila blarina Ross 1941 Trans. Am. Entomol. Soc. 67:36. Holotype ♂

Rhyacophila bruesi Milne & Milne 1940 Bull. Brooklyn Entomol. Soc. 35:154. Holotype ♂

Rhyacophila ecosa Ross 1941 Trans. Am. Entomol. Soc. 67:37. Holotype ♂

Rhyacophila fenderi Ross 1948 Ann. Entomol. Soc. Am. 41:18. Holotype ♂

Rhyacophila fenestra Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:102. Holotype ♂

Rhyacophila gemona Ross 1938 Proc. Entomol. Soc. Wash. 40:117. Holotype ♂

Rhyacophila harmstoni Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:268. Holotype ♂

Rhyacophila inculta Ross & Spencer 1952 Proc. Entomol. Soc. B. C. 48:43. Holotype ♂

Rhyacophila iranda Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:103. Holotype ♂

Rhyacophila jigme Schmid 1970 Mem. Entomol. Soc. Can. 66:145. Holotype ♂

Rhyacophila kiamichi Ross 1944 Ill. Nat. Hist. Surv. Bull. 23:37. Holotype ♂

Rhyacophila latitergum Davis 1949 Ann. Entomol. Soc. Am. 42:448. Holotype ♂

Rhyacophila ledra Ross 1939 Proc. Entomol. Soc. Wash. 41:65. Holotype ♂

Rhyacophila malkini Ross 1947 Trans. Am. Entomol. Soc. 73:126. Holotype ♂

Rhyacophila manistee Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:104. Holotype ♂

Rhyacophila melita Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:104. Holotype ♂

Rhyacophila milnei Ross 1950 J. Wash. Acad. Sci. 40:264. Holotype ♂

Rhyacophila mycta Ross 1941 Trans. Am. Entomol. Soc. 67:38. Holotype ♂

Rhyacophila norcuta Ross 1938 Proc. Entomol. Soc. Wash. 40:117. Holotype ♂

Rhyacophila ophrys Ross 1948 Ann. Entomol. Soc. Am. 41:19. Holotype ♂

Rhyacophila oreia Ross 1947 Trans. Am. Entomol. Soc. 73:126. Holotype ♂

Rhyacophila oreta Ross 1941 Trans. Am. Entomol. Soc. 67:39. Holotype ♂

Rhyacophila parantra Ross 1948 Ann. Entomol. Soc. Am. 41:17. Holotype ♂

Rhyacophila pellisa Ross 1938 Proc. Entomol. Soc. Wash. 40:118. Holotype ♂

Rhyacophila perda Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:105. Holotype ♂

Rhyacophila perplana Ross & Spencer 1952 Proc. Entomol. Soc. B. C. 48:44. Holotype ♂

Rhyacophila phryganea Ross 1941 Trans. Am. Entomol. Soc. 67:40. Holotype ♂

Rhyacophila rayneri Ross 1951 Proc. Calif. Acad. Sci. 27:66. Holotype ♂

Rhyacophila rickeri Ross 1956 Evolution and Classification of the Mountain Caddisflies p. 120. Holotype ♂

Rhyacophila teddyi Ross 1939 Ann. Entomol. Soc. Am. 32:628. Holotype ♂

Rhyacophila tucula Ross 1950 J. Wash. Acad. Sci. 40:261. Holotype ♂

Rhyacophila vaccua Milne 1936 Studies in North American Trichoptera 3:94. Holotype ♂

Rhyacophila vaefes Milne 1936 Studies in North American Trichoptera 3:96. Holotype ♂

Rhyacophila vagrita Milne 1936 Studies in North American Trichoptera 3:91. Holotype ♂

Rhyacophila valuma Milne 1936 Studies in North American Trichoptera 3:100. Holotype ♂

Rhyacophila vao Milne 1936 Studies in North American Trichoptera 3:93. Holotype ♂

Rhyacophila vedra Milne 1936 Studies in North American Trichoptera 3:97. Holotype ♂

Rhyacophila vemna Milne 1936 Studies in North American Trichoptera 3:92. Holotype ♂

Rhyacophila vepulsa Milne 1936 Studies in North American Trichoptera 3:96. Holotype ♂

Rhyacophila verrula Milne 1936 Studies in North American Trichoptera 3:90. Holotype ♂

Rhyacophila vetina Milne 1936 Studies in North American Trichoptera 3:91. Holotype ♂

Rhyacophila vibox Milne 1936 Studies in North American Trichoptera 3:101. Holotype ♂

Rhyacophila viquaea Milne 1936 Studies in North American Trichoptera 3:92. Holotype ♂

Rhyacophila visor Milne 1936 Studies in North American Trichoptera 3:91. Holotype ♂

Rhyacophila vobara Milne 1936 Studies in North American Trichoptera 3:94. Holotype ♂

Rhyacophila vocala Milne 1936 Studies in North American Trichoptera 3:100. Holotype ♂

Rhyacophila vofixa Milne 1936 Studies in North American Trichoptera 3:95. Holotype ♂

Rhyacophila vohrna Milne 1936 Studies in North American Trichoptera 3:94. Holotype ♂

Rhyacophila vu Milne 1936 Studies in North American Trichoptera 3:93. Holotype ♂

Rhyacophila vujuna Milne 1936 Studies in North American Trichoptera 3:99. Holotype ♂

Rhyacophila vuphipes Milne 1936 Studies in North American Trichoptera 3:99. Holotype ♂

Rhyacophila vuzana Milne 1936 Studies in North American Trichoptera 3:97. Holotype ♂

Rhyacophila willametta Ross 1950 J. Wash. Acad. Sci. 40:261. Holotype ♂

Sericostomatidae

Notidobia pele Ross 1938 Ill. Nat. Hist. Surv. Bull. 21:170. Holotype ♂

Sericostoma stannardi Ross 1962 Entomol. News 73:130. Holotype ♂

Sericostoma tetron Ross 1948 Proc. Entomol. Soc. Wash. 50:154. Holotype ♂

LEPIDOPTERA

Acrolophidae

Acrolophus sinclairi nelsoni Hasbrouck 1964 Proc. U. S. Natl. Mus. 114:653. Holotype ♂

Arctiidae

Euchaetes bolteri Stretch 1885 Entomol. Am. 1:106. Holotype ♀

Halisidota significans Hy. Edwards 1888 Entomol. Am. 3:182. Holotype ♂

Geometridae

Aspilates behrensaria Hulst 1887 Entomol. Am. 2:210. Syntype 1♀

Biston ypsilon Forbes 1885 Rep. State Entomol. Ill. 14:95. Holotype ♂

Coenocalpe polygrammata Hulst 1896 Trans. Am. Entomol. Soc. 23:288. Syntype 1♀ (?) see Frison (1927:161)

Diastictis floridensis Hulst 1898 Can. Entomol. 30:164. Syntype 1♂ (?) see Frison (1927:161)

Diastictis speciosa Hulst 1896 Trans. Am. Entomol. Soc. 23:332. Syntype 1♀

Hydriomena neomexicana Hulst 1896 Trans. Am. Entomol. Soc. 23:285. Syntype 1♀

Plemyria georgii Hulst 1896 Trans. Am. Entomol. Soc. 23:280. Syntype 1♂

Selidosema albescens Hulst 1896 Trans. Am. Entomol. Soc. 23:355. Holotype ♂

Sympherta julia Hulst 1896 Trans. Am. Entomol. Soc. 23:338. Syntype 1♂ (?) see Frison (1927:233)

Hepialidae

Hepialus confusus Hy. Edwards 1884 Papilio 4:122. Holotype ♀

Hesperiidae

Poanes viator Edwards 1865 Proc. Entomol. Soc. Phila. 4:202. Neotype ♂ designated by Shapiro (1971:110)

Noctuidae

Heliolonche indiana Smith 1908 Entomol. News 19:423. Syntype 1♀

Pallachira hartii French 1894 Bull. Ill. State Lab. Nat. Hist. 4:9. Lectotype ♂ designated by Frison (1927:161)

Pseudaglossa forbesii French 1894 Bull. Ill. State Lab. Nat. Hist. 4:8. Lectotype ♀ designated by Frison (1927:162)

Pseudalypia crotchii atrata Hy. Edwards 1884 Papilio 4:121. Holotype ♀

Notodontidae

Heterocampa superba Hy. Edwards 1884 Papilio 4:121. Holotype ♀

Macrurocampa dorothea Dyar 1896 Can. Entomol. 28:176. Holotype ♀

Phaloniidae

Hysterosia merrickana Kearfott 1907 Can. Entomol. 39:59. Syntypes 2♀

Prodoxidae

Thia extranea Hy. Edwards 1888 Entomol. Am. 3:181. Lectotype ♂ designated by Davis (1967:44)

Pterophoridae

Oidaematophorus glenni Cashatt 1972 J. Lepid. Soc. 26:11. Holotype ♂

Pyralidae

Pyrausta caffreii Flint & Malloch 1920 Bull. Ill. State Nat. Hist. Surv. 13:304. Holotype ♂

Zophodia epischnioides Hulst 1900 Can. Entomol. 32:173. Syntype 1♂

Satyridae

Erebia rhodia Edwards 1871 Trans. Am. Entomol. Soc. 3:273. Syntype 1♂

HYMENOPTERA

Andrenidae

Andrena aliciae Robertson 1891 Trans. Am. Entomol. Soc. 18:57. Holotype ♀

Andrena arabis Robertson 1897 Trans. Acad. Sci. St. Louis 7:334. Lectotype ♀ designated by Ribble (1974:117)

Andrena asteris Robertson 1891 Trans. Am. Entomol. Soc. 18:56. Lectotype ♀ designated by LaBerge (1967:150)

Andrena banksi Malloch 1917 Bull. Brooklyn Entomol. Soc. 12:89. Holotype ♀

Andrena (Melandrena) barbara Bouseman & LaBerge 1979 Trans. Am. Entomol. Soc. 104:297. Holotype ♀

Andrena claytoniae Robertson 1891 Trans. Am. Entomol. Soc. 18:59. Lectotype ♀ designated by LaBerge (1971:455)

Andrena corni Robertson 1900 Trans. Acad. Sci. St. Louis 10:50. Holotype ♀

Andrena crataegi Robertson 1893 Trans. Am. Entomol. Soc. 20:273. Lectotype ♀ designated by LaBerge (1969:8)

Andrena cressonii Robertson 1891 Trans. Am. Entomol. Soc. 18:56. Lectotype ♀ (Illinois, Carlinville, 7-IV-1890, C. A. Robertson, No. 9067) here designated by W.E. LaBerge

Andrena (Nemandrena) crudeni LaBerge 1971 Pan-Pac. Entomol. 47:54. Holotype ♀

Andrena dubia Robertson 1902 Can. Entomol. 34:48. Lectotype ♂ (Illinois, Carlinville, 17-IV-1888, C. A. Robertson, No. 7165) here designated by W. E. LaBerge

Andrena erigeniae Robertson 1891 Trans. Am. Entomol. Soc. 18:52. Lectotype ♀ (Illinois, Carlinville, 4-V-1886, C. A. Robertson, No. 1052) here designated by W. E. LaBerge

Andrena erythronii Robertson 1891 Trans. Am. Entomol. Soc. 18:53. Lectotype ♀ (Illinois, Carlinville, 11-IV-1888, C. A. Robertson, No. 7102) here designated by W. E. LaBerge

Andrena flexa Malloch 1917 Bull. Brooklyn Entomol. Soc. 12:92. Holotype ♀

Andrena forbesii Robertson 1891 Trans. Am. Entomol. Soc. 18:59. Lectotype ♀ designated by LaBerge (1973:263)

Andrena geranii Robertson 1891 Trans. Am. Entomol. Soc. 18:54. Lectotype ♀ designated by LaBerge (1977:116)

Andrena g. maculati Robertson 1897 Trans. Acad. Sci. St. Louis 7:333. Lectotype ♀ (Illinois Carlinville, 11–IV-1886, C. A. Robertson, No. 1101) here desginated by W. E. LaBerge.

Andrena helianthi Robertson 1891 Trans. Am. Entomol. Soc. 18:55. Lectotype ♀ designated by LaBerge (1967:99)

Andrena heraclei Robertson 1897 Trans. Acad. Sci. St. Louis 7:336. Lectotype ♀ designated by LaBerge (1973:345)

Andrena hippotes Robertson 1895 Trans. Am. Entomol. Soc. 22:120. Lectotype ♀ designated by LaBerge (1973:295)

Andrena (Melandrena) illini Bouseman & LaBerge 1979 Trans. Am. Entomol. Soc. 104:355. Holotype ♀

Andrena illinoiensis Robertson 1891 Trans. Am. Entomol. Soc. 18:54. Lectotype ♂ designated by Ribble (1968:305)

Andrena illinoiensis bicolor Robertson 1898 Trans. Acad. Sci. St. Louis 8:46. Lectotype ♀ designated by Ribble (1968:316)

Andrena krigiana Robertson 1901 Can. Entomol. 33:229. Lectotype ♀ designated by LaBerge (1967:160)

Andrena lauracea Robertson 1897 Trans. Acad. Sci. St. Louis 7:331. Holotype ♀

Andrena (Thysandrena) livida LaBerge 1977 Trans. Am. Entomol. Soc. 103:45. Holotype ♀

Andrena macoupinensis Robertson 1900 Trans. Acad. Sci. St. Louis 10:48. Lectotype ♀ (Illinois, Carlinville, 17-V-1897, C. A. Robertson, No. 19427) here designated by W. E. LaBerge

Andrena mandibularis Robertson 1892 Am. Nat. 26:272. Lectotype ♂ (Illinois, Carlinville, 17-IV-1888, C. A. Robertson, No. 7208) here designated by W. E. LaBerge

Andrena mariae Robertson 1891 Trans. Am. Entomol. Soc. 18:58. Lectotype ♀ designated by LaBerge (1973:303)

Andrena mariae concolor Robertson 1898 Trans. Acad. Sci. St. Louis 8:46. Lectotype ♂ designated by LaBerge (1973:303)

Andrena nasonii Robertson 1895 Trans. Am. Entomol. Soc. 22:120. Lectotype ♀ (Illinois, Carlinville, 1-V-1894, C. A. Robertson, No. 16323) here designated by W. E. LaBerge

Andrena nigrae Robertson 1905 Can. Entomol. 37:237. Lectotype ♀ designated by Ribble (1968:316)

Andrena nothoscordi Robertson 1897 Trans. Acad. Sci. St. Louis 7:331. Lectotype ♀ (Illinois, Carlinville, 29-IV-1895, C. A. Robertson, No. 17109) here designated by W. E. LaBerge

Andrena nuda Robertson 1891 Trans. Am. Entomol. Soc. 18:57. Lectotype ♀ designated by LaBerge (1973:335)

Andrena perezi Robertson 1891 Trans. Am. Entomol. Soc. 18:51. Lectotype ♀ designated by LaBerge & Bouseman (1970:554)

Andrena personata Robertson 1897 Trans. Acad. Sci. St. Louis 7:336. Lectotype ♀ designated by Ribble (1968:257)

Andrena platyparia Robertson 1895 Trans. Am. Entomol. Soc. 22:119. Lectotype ♀ designated by LaBerge & Ribble (1972:290)

Andrena polemonii Robertson 1891 Trans. Am. Entomol. Soc. 18:54. Lectotype ♀ designated by LaBerge (1977:134)

Andrena pruni Robertson 1891 Trans. Am. Entomol. Soc. 18:51. Lectotype ♀ designated by Bouseman & LaBerge (1979:307)

Andrena pulchella Robertson 1891 Trans. Am. Entomol. Soc. 18:57. Lectotype ♀ designated by LaBerge (1967:66)

Andrena quintilis Robertson 1898 Trans. Acad. Sci. St. Louis 8:46. Lectotype ♀ designated by LaBerge (1973:283)

Andrena rudbeckiae Robertson 1891 Trans. Am. Entomol. Soc. 18:56. Lectotype ♂ designated by LaBerge (1967:93)

Andrena rugosa Robertson 1891 Trans. Am. Entomol. Soc. 18:58. Lectotype ♀ designated by LaBerge (1973:331)

Andrena salicacea Robertson 1900 Trans. Acad. Sci. St. Louis 10:48. Lectotype ♀ (Illinois, Carlinville, 18-IV-1899, C. A. Robertson, No. 21578) here designated by W. E. LaBerge

Andrena salicis Robertson 1891 Trans. Am. Entomol. Soc. 18:53. Lectotype ♀ (Illinois, Carlinville, 18-IV-1886, C. A. Robertson, No. 835) here designated by W. E. LaBerge

Andrena salictaria Robertson 1905 Can. Entomol. 37:236. Holotype ♀

Andrena sayi Robertson 1891 Trans. Am. Entomol. Soc. 18:52. Lectotype ♀ designated by Bouseman & LaBerge (1979:311)

Andrena scutellaris Robertson 1893 Trans. Am. Entomol. Soc. 20:148. Lectotype ♀ designated by Ribble (1967:36)

Andrena serotina Robertson 1893 Trans. Am. Entomol. Soc. 20:148. Lectotype ♀ designated by LaBerge (1977:100)

Andrena solidaginis Robertson 1891 Trans. Am. Entomol. Soc. 18:55. Lectotype ♀ designated by LaBerge (1967:140)

Andrena spiraeana Robertson 1895 Trans. Am. Entomol. Soc. 22:120. Lectotype ♀ designated by LaBerge (1973:341)

Andrena torulosa LaBerge 1971 Pan-Pac. Entomol. 47:49. Holotype ♀

Andrena tridens Robertson 1902 Trans. Am. Entomol. Soc. 28:192. Lectotype ♂ (Illinois, Carlinville, 21-III-1894, C. A. Robertson, No. 16244) here designated by W. E. LaBerge

Andrena trimaculata LaBerge 1967 Bull. Univ. Nebr. State Mus. 7:68. Holotype♀ (on permanent loan to the Illinois Natural History Survey from the University of Arizona, Tucson)

Andrena viciniformis Robertson 1900 Trans. Acad. Sci. St. Louis 10:47. Lectotype ♀ designated by Bouseman & LaBerge (1979:304)

Andrena violae Robertson 1891 Trans. Am. Entomol. Soc. 18:53. Lectotype ♀ (Illinois, Carlinville, 20-IV-1886, C. A. Robertson, No. 884) here designated by W. E. LaBerge

Andrena ziziae Robertson 1891 Trans. Am. Entomol. Soc. 18:55. Lectotype ♀ designated by Ribble (1968:269)

Anthemurgus passiflorae Robertson 1902 Can. Entomol. 34:321. Lectotype ♂ (Illinois, Carlinville, 31-VII-1902, C. A. Robertson, No. 23355) here designated by W. E. LaBerge

Calliopsis asteris Robertson 1895 Trans. Am. Entomol. Soc. 22:121. Lectotype ♀ (Illinois, Carlinville, 20-IX-1893, C. A. Robertson, No. 15686) here designated by W. E. LaBerge

Calliopsis compositarum Robertson 1893 Trans. Am. Entomol. Soc. 20:274. Lectotype ♀ (Illinois, Carlinville, 20-IX-1888, C. A. Robertson, No. 8654) here designated by W. E. LaBerge

Calliopsis labrosus Robertson 1895 Trans. Am. Entomol. Soc. 22:122. Lectotype ♀ (Illinois, Carlinville, 24-VIII-1893, C. A. Robertson, No. 15264) here designated by W. E. LaBerge

Calliopsis parvus Robertson 1892 Am. Nat. 26:273. Lectotype ♀ (Illinois, Carlinville, 28-V-1891, C. A. Robertson, No. 11153) here designated by W. E. LaBerge

Calliopsis rudbeckiae Robertson 1895 Trans. Am. Entomol. Soc. 22:122. Lectotype ♀ (Illinois) here designated by W. E. LaBerge

Calliopsis rugosus Robertson 1895 Trans. Am. Entomol. Soc. 22:121. Lectotype ♀ (Illinois, Carlinville, 22-VII-1893, C. A. Robertson, No. 15235) here designated by W. E. LaBerge

Calliopsis solidaginis Robertson 1893 Trans. Am. Entomol. Soc. 22:274. Holotype ♀

Panurginus labrosiformis Robertson 1898 Trans. Acad. Sci. St. Louis 8:49. Lectotype ♀ (Illinois, Carlinville, 24-VIII-1893, C. A. Robertson, No. 15277) here designated by W. E. LaBerge

Panurgus autumnalis Robertson 1895 Trans. Am. Entomol. Soc. 22:121. Lectotype ♀ (Illinois, Carlinville, 28-IX-1893, C. A. Robertson, No. 15874) here designated by W. E. LaBerge

Panurgus novae-angliae Robertson 1897 Trans. Acad. Sci. St. Louis 7:339. Lectotype ♂ (Massachusetts, Winchendon, 5-VII-1892) here designated by W. E. LaBerge

Parandrena andrenoides bicolor Robertson 1898 Trans. Acad. Sci. St. Louis 8:47.Lectotype ♀ designated by LaBerge & Ribble (1972:318)

Parandrena wellesleyana Robertson 1897 Trans. Acad. Sci. St. Louis 7:337. Lectotype ♀ designated by LaBerge & Ribble (1972:328)

Perdita fraterna Timberlake 1929 J. N. Y. Entomol. Soc. 37:123. Holotype ♂

Perdita gerhardi arenicola Timberlake 1929 J. N. Y. Entomol. Soc. 37:119. Holotype ♂

Perdita lasiogaster Timberlake 1929 J. N. Y. Entomol. Soc. 37:115. Holotype ♂

Perdita maculipennis bilineata Timberlake 1929 J. N. Y. Entomol. Soc. 37:121. Holotype ♀

Perditella boltoniae Robertson 1902 Can. Entomol. 34:321. Lectotype ♀ (Illinois, Carlinville, 3-IX-1902, C. A. Robertson, No. 23451) here designated by W. E. LaBerge

Trachandrena obscura Robertson 1902 Trans. Am. Entomol. Soc. 28:189. Holotype ♀

Apidae

Ceratina calcarata Robertson 1900 Trans. Acad. Sci. St. Louis 10:54. Lectotype ♂ designated by Daly (1973:43)

Epeolus autumnalis Robertson 1902 Entomol. News 13:81. Lectotype ♀ (Illinois, Carlinville, 20-IX-1890, C. A. Robertson, No. 9528) here designated by W. E. LaBerge

Epeolus cressonii Robertson 1897 Trans. Acad. Sci. St. Louis 7:344. Lectotype ♀ (No. 3282a) here designated by W. E. LaBerge

Epeolus helianthi Robertson 1897 Trans. Acad. Sci. St. Louis 7:344. Lectotype ♀ (Illinois, Carlinville, 18-IX-1890, C. A. Robertson, No. 9496) here designated by W. E. LaBerge

Epeolus interruptus Robertson 1900 Trans. Acad. Sci. St. Louis 10:55. Holotype ♀

Epeolus lectoides Robertson 1901 Can. Entomol. 33:231. Holotype ♀

Epeolus lunatus concolor Robertson 1898 Trans. Acad. Sci. St. Louis 8:51. Lectotype ♀ (Illinois, Carlinville, 24-VII-1888, C. A. Robertson, No. 8174) here designated by W. E. LaBerge

Epeolus pectoralis Robertson 1897 Trans. Acad. Sci. St. Louis 7:345. Lectotype ♀ (Illinois, Carlinville, 18-IX-1893, C. A. Robertson, No. 15626) here designated by W. E. LaBerge

Gnathias cuneatus Robertson 1903 Can. Entomol. 35:175. Lectotype ♀ (Illinois, Carlinville, 19-IV-1890, C. A. Robertson, No. 9119) here designated by W. E. LaBerge

Gnathias cuneatus decemnotatus Robertson 1903 Can. Entomol. 35:175. Type specimens lost

Gnathias cuneatus octonotatus Robertson 1903 Can. Entomol. 35:175. Lectotype ♀ (Illinois, Carlinville, 19-IV-1890, C. A. Robertson, No. 9119) here designated by W. E. LaBerge

Gnathias cuneatus quadrisignatus Robertson 1903 Can. Entomol. 35:176. Lectotype ♀ (Illinois, Carlinville, 17-IV-1888, C.A. Robertson, No. 7355) here designated by W. E. LaBerge

Gnathias cuneatus sexnotatus Robertson 1903 Can. Entomol. 35:176. Holotype ♀

Gnathias ovatus Robertson 1903 Can. Entomol. 35:175. Lectotype ♀ (Illinois, Carlinville, 17-IV-1888, C. A. Robertson, No. 7347) here designated by W. E. LaBerge

Gnathias ovatus binotatus Robertson 1903 Can. Entomol. 35:175. Lectotype ♀ (Illinois, Carlinville, 17-IV-1888, C. A. Robertson, No. 7350) here designated by W. E. LaBerge

Gnathias ovatus octomaculatus Robertson 1903 Can. Entomol. 35:175. Lectotype ♀ (Illinois, Carlinville, 17-IV-1888, C. A. Robertson, No. 7349) here designated by W. E. LaBerge

Gnathias ovatus plenus Robertson 1903 Can. Entomol. 35:175. Lectotype ♀ (Illinois, Carlinville, 17-IV-1888, C. A. Robertson, No. 7347) here designated by W. E. LaBerge

Gnathias ovatus quadrimaculatus Robertson 1903 Can. Entomol. 35:175. Lectotype ♀ (Illinois, Carlinville, 21-IV-1897, C. A. Robertson, No. 19091) here designated by W. E. LaBerge

Gnathias ovatus sexmaculatus Robertson 1903 Can. Entomol. 35:175. Lectotype ♀ (Illinois, Carlinville, 18-V-1898, C. A. Robertson, No. 20903) here designated by W. E. LaBerge

Gnathias ovatus unicolor Robertson 1903 Can. Entomol. 35:175. Lectotype ♀ (Illinois, Carlinville, 28-IV-1900, C. A. Robertson, No. 22307) here designated by W. E. LaBerge

Melissodes asteris Robertson 1914 Entomol. News 25:373. Lectotype ♀ designated by LaBerge (1961:552)

Melissodes autumnalis Robertson 1905 Trans. Am. Entomol. Soc. 31:369. Lectotype ♀ designated by LaBerge (1961:406)

Melissodes boltoniae Robertson 1905 Trans. Am. Entomol. Soc. 31:368. Lectotype ♀ designated by LaBerge (1961:485)

Melissodes cnici Robertson 1901 Can. Entomol. 33:230. Lectotype ♀ designated by LaBerge (1956*b*:566)

Melissodes comptoides Robertson 1898 Trans. Acad. Sci. St. Louis 8:52. Lectotype ♀ designated by LaBerge (1956*a*:1092)

Melissodes coreopsis Robertson 1905 Trans. Am. Entomol. Soc. 31:368. Lectotype ♀ designated by LaBerge (1961:452)

Melissodes illinoensis Robertson 1895 Trans. Am. Entomol. Soc. 22:126. Lectotype ♀designated by LaBerge (1956*a*:1014)

Melissodes nivea Robertson 1895 Trans. Am. Entomol. Soc. 22:127. Lectotype ♀ designated by LaBerge (1961:457)

Melissodes pallida Robertson 1895 Trans. Am. Entomol. Soc. 22:127. Holotype ♀

Melissodes petalostemonis Robertson 1900 Trans. Acad. Sci. St. Louis 10:53. Lectotype ♀ designated by LaBerge (1956*a*: 1135)

Melissodes simillima Robertson 1897 Trans. Acad. Sci. St. Louis 7:355. Lectotype ♀ designated by LaBerge (1961:552)

Melissodes trinodis Robertson 1901 Can. Entomol. 33:231. Lectotype ♀ designated by LaBerge (1961:397)

Melissodes variabilis Robertson 1905 Trans. Am. Entomol. Soc. 31:368. Lectotype ♀ designated by LaBerge (1956*a*:1056)

Melissodes vernoniae Robertson 1902 Can. Entomol. 34:323. Lectotype ♀ designated by LaBerge (1961:519)

Melissodes vernoniana Robertson 1905 Trans. Am. Entomol. Soc. 31:368. Lectotype ♀ designated by LaBerge (1961:515)

Nomada cressonii Robertson 1893 Trans. Am. Entomol. Soc. 20:275. Lectotype ♀ (Illinois, Carlinville, 5-IV-1892, C. A. Robertson, No. 13158) here designated by W. E. LaBerge

Nomada denticulata Robertson 1902 Can. Entomol. 34:49. Lectotype ♂ (Illinois, Carlinville, 17-IV-1888, C. A. Robertson, No. 7346) here designated by W. E. LaBerge

Nomada erigeronis Robertson 1897 Trans. Acad Sci. St. Louis 7:341. Holotype ♀

Nomada illinoisensis Robertson 1900 Can. Entomol. 32:294. Lectotype ♀ (Illinois, Carlinville, 17-IV-1888, C. A. Robertson, No. 7353) here designated by W. E. LaBerge

Nomada integra Robertson 1893 Trans. Am. Entomol. Soc. 20:276. Lectotype ♂ (Illinois, Carlinville, 17-IV-1888, C. A. Robertson, No. 7294) here designated by W. E. LaBerge

Nomada luteoloides Robertson 1895 Trans. Am. Entomol. Soc. 22:124. Lectotype ♀ (Illinois, Carlinville, 3-V-1888, C. A. Robertson, No. 7511) here designated by W. E. LaBerge

Nomada parva Robertson 1900 Can. Entomol. 32:294. Lectotype ♀ (Illinois, Carlinville, 14-V-1892, C. A. Robertson, No. 13242) here designated by W. E. LaBerge

Nomada salicis Robertson 1900 Trans. Acad. Sci. St. Louis 10:52. Holotype ♂

Nomada sayi Robertson 1893 Trans. Am. Entomol. Soc. 20:276. Lectotype ♀ (Illinois,Carlinville, 28-IV-1887, C. A. Robertson, No. 3665) here designated by W. E. LaBerge

Nomada simplex Robertson 1902 Entomol. News 13:80. Lectotype ♀ (Illinois, Carlinville, 10-IV-1896, C. A. Robertson, No. 17800) here designated by W. E. LaBerge

Nomada viburni Robertson 1897 Trans. Acad. Sci. St. Louis 7:341. Type specimens lost

Phileremus illinoiensis Robertson 1891 Trans. Am. Entomol. Soc. 18:64. Lectotype ♀ (Illinois, Carlinville, 14-VII-1888, C. A. Robertson, No. 8462) here designated by W. E. LaBerge

Synhalonia atriventris fuscipes Robertson 1900 Trans. Acad. Sci. St. Louis 10:54. Holotype ♀

Synhalonia illinoensis Robertson 1902 Can. Entomol. 34:49. Holotype ♂

Synhalonia rosae Robertson 1900 Trans. Acad. Sci. St. Louis 10:54. Lectotype ♀ (Illinois, Carlinville, 11-VI-1888, C. A. Robertson, No. 7813) here designated by W. E. LaBerge

Triepeolus micropygius Robertson 1903 Can. Entomol. 35:286. Lectotype ♀ (Illinois, Carlinville, 29-IX-1902, C. A. Robertson, No. 23531) here designated by W. E. LaBerge

Triepeolus minimus Robertson 1902 Entomol. News 13:81. Holotype ♀

Triepeolus simplex Robertson 1903 Can. Entomol. 35:285. Lectotype ♀ (Illinois, Carlinville, 14-VIII-1896, C. A. Robertson, No. 18665) here designated by W. E. LaBerge

Xanthidium dentariae Robertson 1903 Can. Entomol. 35:178. Lectotype ♂ (Illinois, Carlinville, 12-IV-1887, C. A. Robertson, No. 3600) here designated by W. E. LaBerge

Xenoglossa ipomoeae Robertson 1891 Trans. Am. Entomol. Soc. 18:65. Lectotype ♀ (no data) here designated by W. E. LaBerge

Argidae

Hylotoma onerosa MacGillivray 1923 Psyche 30:80. Holotype ♀

Hylotoma sparta MacGillivray 1923 Bull. Univ. Ill. 20:18. Holotype ♀

Hylotoma spiculata MacGillivray 1907 Can. Entomol. 39:308. Holotype ♀

Schizocerus johnsoni MacGillivray 1909 Can. Entomol. 41:403. Holotype ♀

Sterictiphora apios Ross 1933 Proc. Entomol. Soc. Wash. 35:13. Holotype ♀

Sterictiphora apios atrescens Ross 1933 Proc. Entomol. Soc. Wash. 35:14. Holotype ♀

Bethylidae

Apenesia discomphaloides Evans 1963 Bull. Mus. Comp. Zool. 130:297. Holotype ♂

Apenesia exilis Evans 1963 Bull. Mus. Comp. Zool. 130:293. Holotype ♂

Apenesia insolita Evans 1963 Bull. Mus. Comp. Zool. 130:350. Holotype ♀

Dissomphalus singularis Evans 1962 Proc. Entomol. Soc. Wash. 64:77. Holotype ♀

Pseudisobrachium pusillum Evans 1961 Bull. Mus. Comp. Zool. 126:297. Holotype ♂

Bombidae

Bombias auricomus Robertson 1903 Trans. Am. Entomol. Soc. 29:177. Lectotype ♀ designated by Milliron (1971:78)

Bombus alboanalis Franklin 1913 Trans. Am. Entomol. Soc 39:385. Syntypes 2♀

Bombus impatiens deayi Chandler 1956 Proc. Indiana Acad. Sci. 65:116. Holotype ♀ (queen)

Bombus imuganensis Hedicke 1926 Dtsch. Entomol. Z. p. 422. Holotype ♂

Bombus incarum Franklin 1913 Trans. Am. Entomol. Soc. 39:131. Syntypes 2 workers

Bombus laticinctus Franklin 1913 Trans. Am. Entomol. Soc. 39:85. Syntype 1 worker

Bombus mexicensis Franklin 1911 Trans. Am. Entomol. Soc. 37:163. Syntype 1♀

Bombus mormonorum Franklin 1911 Trans. Am. Entomol. Soc. 37:161. Syntypes 3 workers

Bombus nevadensis aztecus Cockerell 1899 Ann. Mag. Nat. Hist. 4:389. Syntype ♀

Bremus atratus alternans Frison 1925 Trans. Am. Entomol. Soc. 51:143. Holotype ♂

Bremus caliginosus Frison 1927 Proc. Calif. Acad. Sci. 16:376. Holotype ♂

Bremus centralis fucatus Frison 1929 Trans. Am. Entomol. Soc. 55:107. Holotype ♀

Bremus centralis stolidus Frison 1929 Trans. Am. Entomol. Soc. 55:107. Holotype ♀

Bremus edwardsii russulus Frison 1927 Proc. Calif. Acad. Sci. 16:374. Holotype worker

Bremus formosellus Frison 1934 Trans. Nat. Hist. Soc. Formosa 24:163. Holotype ♂

Bremus formosellus derivatus Frison 1934 Trans. Nat. Hist. Soc. Formosa 24:166. Holotype worker

Bremus formosellus gradatus Frison 1934 Trans. Nat. Hist. Soc. Formosa 24:167. Holotype ♂

Bremus franklini Frison 1921 Entomol. News 32:147. Holotype ♀

Bremus kirbyellus alexanderi Frison 1923 Trans. Am. Entomol. Soc. 48:308. Holotype ♀

Bremus kirbyellus arizonensis Frison 1923 Trans. Am. Entomol. Soc. 48:309. Holotype ♀

Bremus mearnsi deflectus Frison 1934 Trans. Nat. Hist. Soc. Formosa 24:173. Holotype worker

Bremus mearnsi dilutus Frison 1934 Trans. Nat. Hist. Soc. Formosa 24:174. Holotype worker

Bremus melanopygus washingtonensis Frison 1926 Trans. Am. Entomol. Soc. 52:138. Holotype ♀

Bremus neotropicus Frison 1928 Bull. Brooklyn Entomol. Soc. 23:151. Holotype ♂

Bremus niger signatus Frison 1925 Trans. Am. Entomol. Soc. 51:143. Holotype ♀

Bremus pleuralis clarus Frison 1926 Trans. Am. Entomol. Soc. 52:139. Holotype ♂

Bremus robustus curiosus Frison 1925 Trans. Am. Entomol. Soc. 51:139. Holotype ♂

Bremus rufocinctus sladeni Frison 1926 Trans. Am. Entomol. Soc. 52:138. Holotype ♂

Bremus sonani Frison 1934 Trans. Nat. Hist. Soc. Formosa 24:175. Holotype ♂

Bremus sylvicola lutzi Frison 1923 Trans. Am. Entomol. Soc. 48:309. Holotype ♀

Bremus sylvicola sculleni Frison 1929 Trans. Am. Entomol. Soc. 55:108. Holotype ♀

Bremus terricola severini Frison 1926 Trans. Am. Entomol. Soc. 52:139. Holotype ♀

Bremus vagans helenae Frison 1929 Trans. Am. Entomol. Soc. 55:110. Holotype ♂

Braconidae

Adialytus maidaphidis Garman 1885 Rep. State Entomol. Ill. 14:31. Lectotype ♀ designated by Frison (1927:210)

Apanteles canarsiae Ashmead 1897 Proc. Entomol. Soc. Wash. 4:127. Syntypes 3 ♂, 2♀

Apanteles crambi Weed 1887 Bull. Ill. State Lab. Nat. Hist. 3:8. Lectotype ♀ designated by Frison (1927:211)

Apanteles ornigis Weed 1887 Bull. Ill. State Lab. Nat. Hist. 3:6. Lectotype ♀ designated by Frison (1927:211)

Apanteles orobenae Forbes 1883 Rep. State Entomol. Ill. 12:104. Lectotype ♀ designated by Frison (1927:211)

Apanteles sarrothripae Weed 1887 Bull. Ill. State Lab. Nat. Hist. 3:6. Lectotype ♀ designated by Frison (1927:211)

Bracon crassifemur Muesebeck 1927 Proc. U. S. Natl. Mus. 69:9. Holotype ♂

Clinocentrus americanus Weed 1887 Bull. Ill. State Lab. Nat.Hist. 3:43. Lectotype ♀ designated by Frison (1927:211)

Clinocentrus niger Ashmead 1895 Bull. Ill. State Lab. Nat. Hist. 4:276. Syntypes 6♂

Coelinius meromyzae Forbes 1884 Rep. State Entomol. Ill. 13:26. Lectotype ♀ designated by Frison (1927:212)

Microplitis hyphantriae Ashmead 1897 Proc. Entomol. Soc. Wash. 4:164. Syntypes 8♀

Microplitis mamestrae Weed 1887 Bull. Ill. State Lab. Nat. Hist. 3:2. Lectotype ♀ designated by Frison (1927:212)

Protomicroplitis garmani Ashmead 1900 Proc. U. S. Natl. Mus. 23(1206):132. Syntypes 3♀

Chalcididae

Chalcis megalomis Burks 1940 Proc. U. S. Natl. Mus. 88(3082):250. Holotype ♀

Dirhinus paoli Burks 1947 Proc. Entomol. Soc. Wash. 49:137. Holotype ♂

Dirhinus perideus Burks 1947 Proc. Entomol. Soc. Wash. 49:138. Holotype ♂

Spilochalcis melana Burks 1940 Proc. U. S. Natl. Mus. 88(3082):316. Holotype ♀

Cimbicidae

Cimbex americana nortoni MacGillivray 1916 Conn. State Geol. Nat. Hist. Surv. Bull. 22:104. Holotype ♀

Crabo americana rubrosa Ross 1932 Can. Entomol. 64:250. Holotype ♂

Trichiosoma confundum MacGillivray 1923 Can. Entomol. 55:161. Holotype ♀

Trichiosoma confusum MacGillivray 1916 Conn. State Geol. Nat. Hist. Surv. Bull. 22:103. Holotype ♂

Trichiosoma spicatum MacGillivray 1916 Conn. State Geol. Nat. Hist. Surv. Bull. 22:103. Holotype ♂

Colletidae

Colletes brevicornis Robertson 1897 Trans. Acad. Sci. St. Louis 7:315. Holotype ♂

Colletes eulophi Robertson 1891 Trans. Am. Entomol. Soc. 18:61. Lectotype ♀ designated by Stephen (1954:269)

Colletes heucherae Robertson 1891 Trans. Am. Entomol. Soc. 18:61. Lectotype ♀ designated by Stephen (1954:283)

Colletes illinoiensis Robertson 1891 Trans. Am. Entomol. Soc. 18:62. Holotype ♀

Colletes latitarsis Robertson 1891 Trans. Am. Entomol. Soc. 18:60. Lectotype ♀ designated by Stephen (1954:232)

Colletes nudus Robertson 1898 Trans. Acad. Sci. St. Louis 8:43. Lectotype ♀ designated by Stephen (1954:302)

Colletes producta Robertson 1891 Trans. Am. Entomol. Soc. 18:62. Holotype ♂

Colletes punctata Robertson 1891 Trans. Am. Entomol. Soc. 18:62. Holotype ♂

Colletes similis Robertson 1904 Can. Entomol. 36:276. Type specimen(s) lost

Colletes speciosa Robertson 1891 Trans. Am. Entomol. Soc. 18:62. Holotype ♀

Colletes spinosa Robertson 1891 Trans. Am. Entomol. Soc. 18:60. Lectotype ♀ designated by Stephen (1954:241)

Colletes willistoni Robertson 1891 Trans. Am. Entomol. Soc. 18:60. Holotype ♀

Prosopis eulophi Robertson 1905 Can. Entomol. 37:236. Lectotype ♀ (Illinois, Carlinville, 13-VI-1904, C. A. Robertson, No. 23904) here designated by W. E. LaBerge

Prosopis flammipes Robertson 1893 Trans. Am. Entomol. Soc. 20:273. Holotype ♀

Prosopis floridanus Robertson 1893 Trans. Am. Entomol. Soc. 20:273. Lectotype ♂ (Florida, Inverness, 24-III-1891, C. A. Robertson, No. 10607) here designated by W. E. LaBerge

Prosopis illinoisensis Robertson 1896 Can. Entomol. 28:138. Lectotype ♂ (Illinois, Carlinville, 7-VI-1886, C. A. Robertson, No. 1547) here designated by W. E. LaBerge

Prosopis nelumbonis Robertson 1890 Trans. Am. Entomol. Soc. 17:318. Lectotype ♀ (Illinois, Carlinville, 12-VIII-1889, C. A. Robertson, No. 8997) here designated by W. E. LaBerge

Prosopis saniculae Robertson 1896 Can. Entomol. 28:137. Lectotype ♂ (Illinois, Carlinville, 16-V-1889, C. A. Robertson, No. 8944) here designated by W. E. LaBerge

Prosopis sayi Robertson 1904 Can. Entomol. 36:274. Lectotype ♀ (Illinois, Carlinville, 4-VI-1888, C. A. Robertson, No. 7664) here designated by W. E. LaBerge

Prosopis thaspii Robertson 1898 Trans. Acad. Sci. St. Louis 8:43. Lectotype ♀ (Illinois, Carlinville, 9-VI-1897, No. 19494) here designated by W.E. LaBerge

Prosopis ziziae Robertson 1904 Can. Entomol. 36:274. Lectotype ♀ (Illinois, Carlinville, 18-V-1887, C. A. Robertson, No. 4029) here designated by W. E. LaBerge

Cynipidae

Acraspis compressus Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:197. Type-gall 1

Andricus decidua Beutenmueller 1913 Insecutor Inscit. Menstr. 1:131. Type-galls 4

Andricus lustrans Beutenmueller 1913 Trans. Am. Entomol. Soc. 39:244. Type-galls 23

Andricus pisiformis Beutenmueller 1911 Entomol. News 22:70. Type-galls 2

Andricus rileyi Ashmead 1896 Proc. U. S. Natl. Mus. 19:121. Syntype gall 1

Andricus rugulosus Beutenmueller 1911 Can. Entomol. 43:211. Type-galls 11

Antistrophus bicolor Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:197. Holotype ♀

Antistrophus laciniatus Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:194. Lectotype ♀ designated by Frison (1927:214)

Antistrophus minor Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:196. Lectotype ♀ designated by Frison (1927:214)

Antistrophus rufus Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:195. Lectotype ♀ designated by Frison (1927:214)

Antistrophus silphii Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:192. Lectotype ♀ designated by Frison (1927:215)

Aulacidea solidaginis Girault 1903 Entomol. News. 14:323. Syntypes 1♂ 1♀

Aulax bicolor Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:201. Lectotype ♀ designated by Frison (1927:215)

Belonocnema kinseyi Weld 1921 Proc. U. S. Natl. Mus. 59:241. Syntypes 2♀

Callirhytis ellipsoida Weld 1921 Proc. U. S. Natl. Mus. 59:227. Syntypes 2♀

Callirhytis fulva Weld 1921 Proc. U. S. Natl. Mus. 59:226. Syntype 1♀

Callirhytis marginata Weld 1921 Proc. U. S. Natl. Mus. 59:225. Syntype 1♀

Callirhytis maxima Weld 1921 Proc. U. S. Natl. Mus. 59:217. Syntypes 2♀

Callirhytis middletoni Weld 1922 Proc. U. S. Natl. Mus. 61(2440):25. Syntype 1♀

Coptereucoila marginata Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:203. Lectotype ♀ designated by Frison (1927:216)

Cynips floccosa Bassett 1881 Can. Entomol. 13:111. Type-galls many

Cynips ignota Bassett 1881 Can. Entomol. 13:106. Type-gall 1

Cynips quercus futilis Osten Sacken 1861 Proc. Entomol. Soc. Phila. 1:64. Type-galls 3

Cynips quercus majalis Bassett 1864 Proc. Entomol. Soc. Phila. 3:683. Type-galls 3

Cynips quercus mammula Bassett 1881 Can. Entomol. 13:76. Syntypes 8

Cynips quercus punctata Bassett 1863 Proc. Entomol. Soc. Phila. 2:324. Holotype ♀

Cynips quercus singularis Bassett 1863 Proc. Entomol. Soc. Phila. 2:326. Type-galls 4

Cynips vesicula Bassett 1881 Can. Entomol. 13:97. Type-galls 2

Diastrophus scutellaris Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:191. Holotype ♀

Disholcaspis acetabula Weld 1921 Proc. U. S. Natl. Mus. 59:194. Syntypes 2♀

Disholcaspis globosa Weld 1921 Proc. U. S. Natl. Mus. 59:196. Syntypes 2♀

Disholcaspis lacuna Weld 1921 Proc. U. S. Natl. Mus. 59:195. Syntype 1♀

Dryophanta lanata Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:198. Lectotype ♀ designated by Frison (1927:216)

Eucoila septemspinosa Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:204. Holotype ♀

Eucoilidea rufipes Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:205. Holotype ♀

Neuroterus exiguissimus Bassett 1900 Trans. Am. Entomol. Soc. 26:332. Type-galls 2

Synergus magnus Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:202. Holotype ♀

Synergus villosus Gillette 1891 Bull. Ill. State Lab. Nat. Hist. 3:202. Lectotype ♀ designated by Frison (1927:216)

Diprionidae

Monoctenus juniperinus MacGillivray 1894 Can. Entomol. 26:328. Holotype ♀

Neodiprion warreni Ross 1961 Ann. Entomol. Soc. Am. 54:451. Holotype ♀

Neodiprion werneri Ross 1955 For. Sci. 1:205. Holotype ♀

Encyrtidae

Aenasioidea latiscapus Girault 1911 Can. Entomol. 43:173. Lectotype ♀ designated by Frison (1927:217)

Anagyrus nubilipennis Girault 1909 Psyche 16:76. Lectotype ♀ designated by Frison (1927:217)

Aphycus stomachosus Girault 1909 Psyche 16:77. Lectotype ♀ designated by Frison (1927:217)

Cristatithorax pulcher Girault 1911 Can. Entomol. 43:170. Lectotype ♀ designated by Frison (1927:218)

Microterys speciosissimus Girault 1911 Can. Entomol. 43:175. Lectotype ♀ designated by Frison (1927:218)

Signiphora fax Girault 1913 Proc. U. S. Natl. Mus. 45:223. Syntypes 3 ♀

Eulophidae

Aphelinus varicornis Girault 1909 Psyche 16:29. Lectotype ♀ designated by Frison (1927:221)

Astichus bimaculatipennis Girault 1912 Can. Entomol. 44:8. Holotype ♀

Coccophagus cinguliventris Girault 1909 Psyche 16:79. Lectotype ♀ designated by Frison (1927:222)

Encarsia versicolor Girault 1908 Psyche 15:53. Lectotype ♀ designated by Frison (1927:222)

Mestocharis williamsoni Girault 1911 J. N. Y. Entomol. Soc. 19:179. Lectotype ♀ designated by Frison (1927:222)

Prospaltella fasciativentris Girault 1908 Psyche 15:117. Lectotype ♀ designated by Frison (1927:222)

Prospaltella fuscipennis Girault 1908 Psyche 15:120. Lectotype ♀ designated by Frison (1927:223)

Prospaltella perspicuipennis Girault 1910 J. N. Y. Entomol. Soc. 18:234. Lectotype ♀ designated by Frison (1927:223)

Tetrastichus anthophilus Burks 1947 Entomol. News 58:85. Holotype ♀

Tetrastichus caerulescens Ashmead 1897 Proc. Entomol. Soc. Wash. 4:130. Holotype ♀

Tetrastichus carinatus Forbes 1885 Rep. State Entomol. Ill. 14:48. Lectotype ♀ designated by Frison (1927:223)

Tetrastichus cormus Burks 1943 Proc. U. S. Natl. Mus. 93(3170):579. Holotype ♀

Tetrastichus hesperius Burks 1947 Entomol. News 58:88. Holotype ♀

Trichaporus aeneoviridis Girault 1912 Can. Entomol. 44:75. Lectotype ♀ designated by Frison (1927:223)

Zagrammosoma multilineata punicea Girault 1911 Arch. Naturgesch. 77:123. Lectotype ♀ designated by Frison (1927:221)

Evaniidae

Brachygaster angustata Frison 1922 Trans. Am. Entomol. Soc. 48:17. Holotype ♂

Brachygaster eximia Frison 1922 Trans. Am. Entomol. Soc. 48:19. Holotype ♂

Brachygaster parishi Frison 1922 Trans. Am. Entomol. Soc. 48:20. Holotype ♂

Brachygaster peruviana Frison 1922 Trans. Am. Entomol. Soc. 48:16. Holotype ♀

Brachygaster rubia Frison 1922 Trans. Am. Entomol. Soc. 48:14. Holotype ♀

Chalcidopterella macgillivrayi Frison 1922 Trans. Am. Entomol. Soc. 48:4.Holotype ♀

Evania barbata Frison 1922 Trans. Am. Entomol. Soc. 48:28. Holotype ♂

Evania bella Frison 1922 Trans. Am. Entomol. Soc. 48:22. Holotype ♂

Evania cerviculata Frison 1922 Trans. Am. Entomol. Soc. 48:30. Holotype ♀

Evania clara Frison 1922 Trans. Am. Entomol. Soc. 48:27. Holotype ♂

Evania delicata Frison 1922 Trans. Am. Entomol. Soc. 48:24. Holotype ♂

Evania luculenta Frison 1922 Trans. Am. Entomol. Soc. 48:25. Holotype ♂

Evania mystica Frison 1922 Trans. Am. Entomol. Soc. 48:32. Holotype ♂

Hyptia fraudulenta Frison 1922 Trans. Am. Entomol. Soc. 48:12. Holotype ♂

Hyptia jucunda Frison 1922 Trans. Am. Entomol. Soc. 48:7. Holotype ♀

Hyptia neglecta Frison 1922 Trans. Am. Entomol. Soc. 48:10. Holotype ♂

Hyptia spinifera Frison 1922 Trans. Am. Entomol. Soc. 48:9. Holotype ♂

Formicidae

Lasius parvula Smith 1934 Psyche 41:213. Syntype 1 worker

Strumigenys jamaicensis Brown 1959 Breviora 108:6. Holotype worker

Strumigenys talpa Weber 1934 Psyche 41:63. Holotype worker

Halictidae

Agapostemon bicolor Robertson 1893 Trans. Am. Entomol. Soc. 20:148. Lectotype ♀ (Illinois, Carlinville, 22-IX-1886, C. A. Robertson, No. 3306) here designated by W. E. LaBerge

Augochlora austrina Robertson 1893 Trans. Am. Entomol. Soc. 20:147. Holotype ♀

Augochlora confusa Robertson 1897 Trans. Acad. Sci. St. Louis 7:324.Lectotype ♀ designated by Ordway (1966:601)

Augochlora matilda Robertson 1893 Trans. Am. Entomol. Soc. 20:147. Lectotype ♀ designated by Ordway (1966:601)

Augochlora similis Robertson 1893 Trans. Am. Entomol. Soc. 20:146. Lectotype ♀ designated by Ordway (1966:589)

Chloralictus coreopsis Robertson 1902 Can. Entomol. 34:249. Lectotype ♀ (Illinois, Carlinville, 23-VI-1891, C. A. Robertson, No. 11345) here designated by W. E. LaBerge

Chloralictus foveolatus Robertson 1902 Can. Entomol. 34:250. Lectotype ♂ (Illinois, Carlinville, 31-X-1901, C. A. Robertson, No. 23049) here designated by W. E. LaBerge

Chloralictus sparsus Robertson 1902 Can. Entomol. 34:249. Lectotype ♀ (Illinois, Carlinville, 2-VI-1886, C. A. Robertson, No. 1293) here designated by W. E. LaBerge

Chloralictus versatus Robertson 1902 Can. Entomol. 34:249. Lectotype ♀(Illinois, Carlinville, 8-IV-1886, C. A. Robertson, No. 543) here designated by W. E. LaBerge

Halictus anomalus Robertson 1892 Am. Nat. 26:272. Lectotype ♀ (Illinois, Carlinville, 19-V-1891, C. A. Robertson, No. 11111) here designated by W. E. LaBerge

Halictus apopkensis Robertson 1892 Am. Nat. 26:272. Lectotype ♀ (Florida, Inverness, 12-II-1891, C. A. Robertson, No. 9991) here designated by W. E. LaBerge

Halictus arcuatus Robertson 1893 Trans. Am. Entomol. Soc. 20:145. Lectotype ♀ (Illinois, Carlinville, 29-VI-1888, C. A. Robertson, No. 7993) here designated by W. E. LaBerge

Halictus ashmeadii Robertson 1892 Am. Nat. 26:271. Lectotype ♀ (Florida, Inverness, 12-II-1891, C. A. Robertson, No. 9989) here designated by W. E. LaBerge

Halictus cephalicus Robertson 1892 Am. Nat. 26:270. Lectotype ♀ (21-VII-1891) here designated by W. E. LaBerge

Halictus coeruleus Robertson 1893 Trans. Am. Entomol. Soc. 20:146. Lectotype ♀ (Illinois, Carlinville, 10-IV-1889, C. A. Robertson, No. 8806) here designated by W. E. LaBerge

Halictus floridanus Robertson 1892 Am. Nat. 26:269. Lectotype ♀ (Florida, Inverness, 7-III-1891,C. A. Robertson, No. 10232) here designated by W. E. LaBerge

Halictus hartii Robertson 1892 Am. Nat. 26:268. Holotype ♀ lost

Halictus illinoensis Robertson 1892 Am. Nat. 26:271. Lectotype ♀ (Illinois, Carlinville, 12-VIII-1891,C. A. Robertson, No. 11933) here designated by W.E. LaBerge

Halictus longiceps Robertson 1892 Am. Nat. 26:272. Lectotype ♀ (Florida, Inverness, 12-II-1891, C. A. Robertson, No. 9993) here designated by W. E. LaBerge

Halictus obscurus Robertson 1892 Am. Nat. 26:270. Lectotype ♀ (Illinois, Carlinville, 8-V-1891, C. A. Robertson, No. 10959) here designated by W. E. LaBerge

Halictus pectinatus Robertson 1890 Trans. Am. Entomol. Soc. 17:315. Holotype ♀

Halictus platyparius Robertson 1895 Trans. Am. Entomol. Soc. 22:117. Lectotype ♀ (Illinois, Carlinville, 18-V-1887, C. A. Robertson, No. 3995) here designated by W. E. LaBerge

Halictus pruinosus Robertson 1892 Am. Nat. 26:269. Lectotype ♀ (Illinois, Carlinville, 22-V-1891, C. A. Robertson, No. 11121) here designated by W. E. LaBerge

Halictus reticulatus Robertson 1892 Am. Nat. 26:268. Lectotype ♀ (Florida, Inverness, 12-II-1891, C. A. Robertson, No. 9987) here designated by W. E. LaBerge

Halictus smilacinae Robertson 1897 Trans. Acad. Sci. St. Louis 7:322. Lectotype ♀ (Illinois, Carlinville, 21-III-1894, C. A. Robertson, No. 16247) here designated by W. E. LaBerge

Halictus testaceus Robertson 1897 Trans. Acad. Sci. St. Louis 7:323. Lectotype ♀ (Illinois, Carlinville, 11-IV-1896, C. A. Robertson, No. 17843) here designated by W. E. LaBerge

Halictus truncatus Robertson 1901 Can. Entomol. 33:230. Lectotype ♀ (Illinois, Carlinville, 15-VI-1887, C. A. Robertson, No. 5076) here designated by W. E. LaBerge

Machaeris illinoensis Robertson 1903 Entomol. News 14:107. Holotype ♀

Paralictus simplex Robertson 1901 Can. Entomol. 33:230. Lectotype ♀ (Illinois, Carlinville, 17-IV-1893, C. A. Robertson, No. 13817) here designated by W. E. LaBerge

Sphecodes antennariae Robertson 1891 Trans. Am. Entomol. Soc. 18:63. Lectotype ♀ (Illinois, Carlinville, 18-IV-1886, C. A. Robertson, No. 845) here designated by W. E. LaBerge

Sphecodes clematidis Robertson 1897 Trans. Acad. Sci. St. Louis 7:320. Lectotype ♀ (Illinois, Carlinville, 27-VII-1891, C. A. Robertson, No. 11617) here designated by W. E. LaBerge

Sphecodes davisii Robertson 1897 Trans. Acad. Sci. St. Louis 7:319. Holotype ♂

Sphecodes heraclei Robertson 1897 Trans. Acad. Sci. St. Louis 7:318. Holotype ♀

Sphecodes minor Robertson 1898 Trans. Acad. Sci. St. Louis 8:45. Lectotype ♀(Illinois, Carlinville, 27-IV-1897, C. A. Robertson, No. 19186) here designated by W. E. LaBerge

Sphecodes pimpinellae Robertson 1900 Trans. Acad. Sci. St. Louis 10:51. Holotype ♀

Sphecodes pycnanthemi Robertson 1897 Trans. Acad. Sci. St. Louis 7:320. Lectotype ♀ (Illinois, Carlinville, 6-VII-1894, C. A. Robertson, No. 16864) here designated by W. E. LaBerge

Sphecodes ranunculi Robertson 1897 Trans. Acad. Sci. St. Louis 7:318. Lectotype ♀ (Illinois, Carlinville, 25-IV-1896, C. A. Robertson, No. 18133) here designated by W. E. LaBerge

Sphecodes smilacinae Robertson 1897 Trans. Acad. Sci. St. Louis 7:321. Holotype ♀

Sphecodes stygius Robertson 1893 Trans. Am. Entomol. Soc. 20:145. Lectotype ♀ (Illinois, Carlinville, 12-VIII-1891, C. A. Robertson, No. 11944) here designated by W. E. LaBerge

Sphecodium cressonii Robertson 1903 Entomol. News 14:106. Lectotype ♀ (Illinois, Carlinville, 18-V-1887, C. A. Robertson, No. 3933) here designated by W. E. LaBerge

Ichneumonidae

Cremastus cookii Weed 1888 Entomol. Am. 4:150. Lectotype ♀ designated by Frison (1927:212)

Cremastus cookii rufus Weed 1888 Entomol. Am. 4:150. Lectotype ♂ designated by Frison (1927:212)

Cremastus forbesi Weed 1887 Bull. Ill. State Lab. Nat. Hist. 3:42. Holotype ♀

Cremastus hartii Ashmead 1896 Bull. Ill. State Lab. Nat. Hist. 4:277. Lectotype ♀ designated by Frison (1927:213)

Glypta phoxopteridis Weed 1888 Entomol. Am. 4:151. Holotype ♀

Limneria (Sinophorus) canarsiae Ashmead 1897 Proc. Entomol. Soc. Wash. 4:126. Holotype ♀

Limneria elegans Weed 1887 Bull. Ill. State Lab. Nat. Hist. 3:40. Lectotype ♀ designated by Frison (1927:213)

Limneria teratis Weed 1887 Bull. Ill. State Lab. Nat. Hist. 3:40. Lectotype ♀ designated by Frison (1927:213)

Pimpla minuta Weed 1887 Bull. Ill. State Lab. Nat. Hist. 3:41. Holotype ♀

Spilocryptus canarsiae Ashmead 1897 Proc. Entomol. Soc. Wash. 4:124. Lectotype ♂ designated by Frison (1927:213)

Tricyphus ater Hopper 1939 Trans. Am. Entomol. Soc. 65:339. Holotype ♂

Trogas bolteri Cresson 1868 Trans. Am. Entomol. Soc. 2:94. Holotype ♂

Megachilidae

Ammobates heliopsis Robertson 1897 Trans. Acad. Sci. St. Louis 7:352. Holotype ♂

Anthidium psoraleae Robertson 1902 Can. Entomol. 34:322. Lectotype ♀ (Illinois, Carlinville, 22-VII-1889, C. A. Robertson, No. 8982) here designated by W. E. LaBerge

Coelioxys sayi Robertson 1897 Trans. Trans. Acad. Sci. St. Louis 7:348. Lectotype ♀(Florida, Inverness, 4-IV-1892, C. A. Robertson, No. 13022) here designated by W.E. LaBerge

Dianthidium boreale Robertson 1902 Can. Entomol. 34:323. Holotype ♂

Heriades floridanus Robertson 1897 Trans. Acad. Sci. St. Louis 7:348. Lectotype ♀ (Florida, Inverness, 4-IV-1892, C. A. Robertson, No. 13022) here designated by W. E. LaBerge

Heriades philadelphi Robertson 1891 Trans. Am. Entomol. Soc. 18:64. Lectotype ♀ (Illinois, Carlinville, 29-V-1888, C. A. Robertson, No. 7603) here designated by W. E. LaBerge

Megachile floridana Robertson 1895 Trans. Am. Entomol. Soc. 22:125. Holotype ♂ lost

Megachile rufimanus Robertson 1891 Trans. Am. Entomol. Soc. 18:65. Lectotype ♀ (Illinois, Carlinville, 26-VI-1888, C. A. Robertson, No. 7976) here designated by W. E. LaBerge

Megachile sexdentata Robertson 1895 Trans. Am. Entomol. Soc. 22:125. Holotype ♂

Megachile strophostylis Robertson 1904 Can. Entomol. 36:277. Lectotype ♀ (Illinois, Carlinville, 10-VIII-1903, C. A. Robertson, No. 23785) here designated by W. E. LaBerge

Oligotropus campanulae Robertson 1903 Trans. Am. Entomol. Soc. 29:171. Lectotype ♂ (Illinois, Carlinville, 30-VII-1888, C. A. Robertson, No. 8320) here designated by W. E. LaBerge

Osmia collinsiae Robertson 1905 Can. Entomol. 37:236. Lectotype ♂ (Illinois, Carlinville, 13-IV-1887, C. A. Robertson, No. 3606) here designated by W. E. LaBerge

Osmia conjunctoides Robertson 1893 Trans. Am. Entomol. Soc. 20:276. Lectotype ♂ (Florida, Inverness, 17-II-1891, C. A. Robertson, No. 10134) here designated by W. E. LaBerge

Osmia cordata Robertson 1902 Entomol. News 13:79. Lectotype ♂ (Illinois, Carlinville, 11-IV-1901, C. A. Robertson, No. 22899) here designated by W. E. LaBerge

Osmia illinoensis Robertson 1897 Trans. Acad. Sci. St. Louis 7:347. Holotype ♂

Osmia major Robertson 1902 Entomol. News 13:79. Lectotype ♀ (Illinois, Carlinville, 11-VI-1888, C. A. Robertson, No. 7814) here designated by W. E. LaBerge

Stelidium trypetinum Robertson 1902 Can. Entomol. 34:323. Lectotype ♀ (Illinois, Carlinville, 18-X-1902, C. A. Robertson, No. 23607) here designated by W. E. LaBerge

Trypetes barbatus Robertson 1903 Trans. Am. Entomol. Soc. 29:171. Lectotype ♀ (Illinois, Carlinville, 17-VII-1888, C. A. Robertson, No. 8125) here designated by W. E. LaBerge

Trypetes productus Robertson 1905 Can. Entomol. 37:236. Lectotype ♂ (Illinois, Carlinville, 3-VI-1891, C. A. Robertson, No. 11172) here designated by W. E. LaBerge

Melittidae

Macropis morsei Robertson 1897 Trans. Acad. Sci. St. Louis 7:338. Lectotype ♂ (Massachusetts, Winchendon, 5-VII-1892) here designated by W. E. LaBerge

Macropis steironematis Robertson 1891 Trans. Am. Entomol. Soc. 18:63. Lectotype ♀ (Illinois, Carlinville, 25-VI-1888, C. A. Robertson, No. 7944) here designated by W. E. LaBerge

Mutillidae

Lomachaeta punctinota Mickel 1936 Ann. Entomol. Soc. Am. 29:293. Holotype ♂

Mymaridae

Alaptus intonsipennis Girault 1910 J.N.Y. Entomol. Soc. 18:244. Lectotype ♀ designated by Frison (1927:226)

Anagrus armatus nigriventris Girault 1911 Trans. Am. Entomol. Soc. 37:291. Lectotype ♀ designated by Frison (1927:226)

Anagrus delicatus Dozier 1936 Proc. Hawaii. Entomol. Soc. 9:177. Holotype ♀

Anagrus epos Girault 1911 Trans. Am. Entomol. Soc. 37:292. Lectotype ♀ designated by Frison (1927:227)

Anagrus spiritus Girault 1911 Entomol. News 22:209. Holotype ♀

Anaphes hercules Girault 1911 Trans. Am. Entomol. Soc. 37:285. Holotype ♀

Anaphes nigrellus Girault 1911 Trans. Am. Entomol. Soc. 37:282. Holotype ♀

Anaphoidea pullicrura Girault 1910 J. N. Y. Entomol. Soc. 18:252. Holotype ♀

Anaphoidea sordidata Girault 1909 J. N. Y. Entomol. Soc. 17:169. Holotype ♀

Camptoptera pulla Girault 1911 Ann. Entomol. Soc. Am. 2:27. Lectotype ♀ designated by Frison (1927:227)

Gonatocerus fasciatus Girault 1911 Trans. Am. Entomol. Soc. 37:265. Lectotype ♀ designated by Frison (1927:227)

Polynema citripes Ashmead 1911 J. N. Y. Entomol. Soc. 19:19. Syntypes 2♀

Polynema zetes Girault 1911 Trans. Am. Entomol. Soc. 37:314. Holotype ♀

Stephanodes psecas Girault 1912 J. N. Y. Entomol. Soc. 20:41. Lectotype ♀ designated by Frison (1927:228)

Stethynium faunum Girault 1911 Trans. Am. Entomol. Soc. 37:298. Holotype ♀

Pamphilidae

Acantholyda modesta MacGillivray 1923 Bull. Brooklyn Entomol. Soc. 18:53. Holotype ♀

Caenolyda onekama MacGillivray 1923 Bull. Univ. Ill. 20:8. Holotype ♀

Cephaleia criddlei MacGillivray 1912 Can. Entomol. 44:296. Holotype ♀

Cephaleia dissipator MacGillivray 1923 Bull. Univ. Ill. 20:8. Holotype ♂

Cephaleia distincta MacGillivray 1912 Can. Entomol. 44:296. Holotype ♂

Cephaleia jenseni MacGillivray 1912 Can. Entomol. 44:297. Holotype ♀

Itycorsia angulata MacGillivray 1912 Can. Entomol. 44:295. Holotype ♀

Itycorsia balanata MacGillivray 1923 Bull. Univ. Ill. 20:18. Holotype ♀

Itycorsia balata MacGillivray 1923 Bull. Univ. Ill. 20:18. Holotype ♀

Itycorsia ballista MacGillivray 1923 Bull. Univ. Ill. 20:19. Holotype ♀

Pamphilius dentatus MacGillivray 1912 Can. Entomol. 44:297. Holotype ♀

Pamphilius fortuitus MacGillivray 1923 Bull. Univ. Ill. 20:27. Holotype ♀

Pamphilius persicum MacGillivray 1907 Can. Entomol. 39:308. Holotype ♀

Pamphilius transversa MacGillivray 1912 Can. Entomol. 44:297. Holotype ♂

Pamphilius unalatus MacGillivray 1920 Bull. Brooklyn Entomol. Soc. 15:112. Holotype ♀

Pergidae

Acordulecera maculata MacGillivray 1908 Can. Entomol. 40:169. Holotype ♀

Acordulecera marina MacGillivray 1908 Can. Entomol. 40:170. Holotype ♂

Acordulecera maura MacGillivray 1908 Can. Entomol. 40:168. Holotype ♀

Acordulecera maxima MacGillivray 1908 Can. Entomol. 40:168. Holotype ♀

Acordulecera media MacGillivray 1908 Can. Entomol. 40:168. Holotype ♀

Acordulecera meleca MacGillivray 1921 Bull. Brooklyn Entomol. Soc. 16:23. Holotype ♂

Acordulecera mellina MacGillivray 1908 Can. Entomol. 40:169. Holotype ♀

Acordulecera minima MacGillivray 1908 Can. Entomol. 40:168. Holotype ♀

Acordulecera minuta MacGillivray 1908 Can. Entomol. 40:169. Holotype ♀

Acordulecera mixta MacGillivray 1908 Can. Entomol. 40:169. Holotype ♀

Acordulecera munda MacGillivray 1908 Can. Entomol. 40:169. Holotype ♀

Acordulecera musta MacGillivray 1921 Bull. Brooklyn Entomol. Soc. 16:23. Holotype ♂

Platygasteridae

Elaptus aleurodis Forbes 1885 Rep. State Entomol. Ill. 14:110. Lectotype ♀ designated by Frison (1927:213)

Platygaster hiemalis Forbes 1888 Psyche 5:39. Lectotype ♂ designated by Frison (1927:214)

Pompilidae

Anoplius hispidulus Dreisbach 1950 Am. Midl. Nat. 43:577. Holotype ♂

Pompilinus bequaerti Dreisbach 1949 Entomol. Am. 29:16. Holotype ♂

Pompilus illinoensis Robertson 1901. Trans. Am. Entomol. Soc. 27:202. Syntypes 8♂, 14♀

Sphex harti Fernald 1930 Ann. Entomol. Soc. Am. 24:450. Syntypes 1♂, 3♀

Pteromalidae

Arthrolytus aeneoviridis Girault 1911 Can. Entomol. 43:372. Lectotype ♀ designated by Frison (1927:219)

Muscidifurax raptor Girault & Sanders 1910 Psyche 17:149. Lectotype ♀ designated by Frison (1927:219)

Pteromalus fulvipes Forbes 1885 Rep. State Entomol. Ill. 14:47. Lectotype ♀ designated by Frison (1927:220)

Pteromalus gelechiae Webster 1883 Rep. State Entomol. Ill. 12:151. Lectotype ♂ designated by Frison (1927:220)

Pteromalus pallipes Forbes 1885 Rep. State Entomol. Ill. 14:46. Lectotype ♀ designated by Frison (1927:220)

Tritneptis hemerocampae Girault 1908 Psyche 15:92. Lectotype ♀ designated by Frison (1927:221)

Urios vestali Girault 1911 J. N. Y. Entomol. Soc. 19:176. Holotype ♀

Scelionidae

Hoplogryon bethunei Sanders 1910 Can. Entomol. 42:15. Holotype ♂

Phanurus tabanivorus Ashmead 1896 Bull. Ill. State Lab. Nat. Hist. 4:274. Syntypes 7♂, 5♀

Siricidae

Urocerus indecisus MacGillivray 1893 Can. Entomol. 25:243. Holotype ♂

Urocerus riparius MacGillivray 1893 Can. Entomol. 25:244. Holotype ♂

Sphecidae

Notoglossa americana Robertson 1901 Trans. Am. Entomol. Soc. 27:204. Syntypes 28♂, 24♀

Notoglossa inornata Robertson 1901 Trans. Am. Entomol. Soc. 27:203. Syntypes 3♂, 1♀

Oxybelus floridanus Robertson 1901 Trans. Am. Entomol. Soc. 27:203. Syntype 1♂

Tenthredinidae

(See also Addendum, page 133.)

Adelomos cleone Ross 1935 Can. Entomol. 67:202. Holotype ♀

Aglaostigma dentatum Ross 1943 Proc. Entomol. Soc. Wash. 45:82. Holotype ♂

Allantus universus MacGillivray 1923 Bull. Univ. Ill. 20:6. Holotype ♀

Amauronematus vacalus MacGillivray 1923 Bull. Univ. Ill. 20:6. Holotype ♀

Amauronematus vacivus MacGillivray 1921 J. N. Y. Entomol. Soc. 29:28. Holotype ♂

Amauronematus valerius MacGillivray 1923 Bull. Univ. Ill. 20:6. Holotype ♂

Amauronematus vanus MacGillivray 1921 J. N. Y. Entomol. Soc. 29:27. Holotype ♀

Amauronematus venaticus MacGillivray 1921 J. N. Y. Entomol. Soc. 29:29. Holotype ♂

Amauronematus veneficus MacGillivray 1923 J. N. Y. Entomol. Soc. 31:169. Holotype ♀

Amauronematus venerandus MacGillivray 1921 J. N. Y. Entomol. Soc. 29:30. Holotype ♂

Amauronematus ventosus MacGillivray 1923 J. N. Y. Entomol. Soc. 31:169. Holotype ♀

Amauronematus verbosus MacGillivray 1921 J. N. Y. Entomol. Soc. 29:29. Holotype ♀

Amauronematus veridicus MacGillivray 1923 J. N. Y. Entomol. Soc. 31:170. Holotype ♀

Amauronematus vescus MacGillivray 1921 J. N. Y. Entomol. Soc. 29:30. Holotype ♀

Amauronematus visendus MacGillivray 1921 J. N. Y. Entomol. Soc. 29:28. Holotype ♀

Apareophora rossi Smith 1969 U. S. Dep. Agric. Tech. Bull. 1397:118. Holotype ♀

Aphanisus lobatus MacGillivray 1908 Can. Entomol. 40:295. Holotype ♀

Aphanisus muricatus MacGillivray 1908 Can. Entomol. 40:296. Holotype ♀

Aphanisus nigritus MacGillivray 1908 Can. Entomol. 40:296. Holotype ♀

Aphanisus obsitus MacGillivray 1923 Bull. Univ. Ill. 20:7. Holotype ♀

Aphanisus occiduus MacGillivray 1923 Bull. Univ. Ill. 20:7. Holotype ♀

Aphanisus odoratus MacGillivray 1908 Can. Entomol. 40:296. Holotype ♀

Aphanisus parallelus MacGillivray 1923 Bull. Univ. Ill. 20:7. Holotype ♀

Astochus aldrichi MacGillivray 1914 Can. Entomol. 46:137. Holotype ♀

Astochus fletcheri MacGillivray 1914 Can. Entomol. 46:108. Holotype ♀

Blennocampa abjecta MacGillivray 1921 Bull. Brooklyn Entomol. Soc. 16:22. Holotype ♀

Blennocampa abnorma MacGillivray 1908 Can. Entomol. 40:296. Holotype ♂

Blennocampa absona MacGillivray 1921 Bull. Brooklyn Entomol. Soc. 16:22. Holotype ♀

Blennocampa acuminata MacGillivray 1908 Can. Entomol. 40:297. Holotype ♀

Blennocampa adusta MacGillivray 1908 Can. Entomol. 40:297. Holotype ♀

Blennocampa amara MacGillivray 1923 Can. Entomol. 55:161. Holotype ♀

Blennocampa angulata MacGillivray 1908 Can. Entomol. 40:297. Holotype ♀

Blennocampa antennata MacGillivray 1908 Can. Entomol. 40:296. Holotype ♀

Blennocampa aperta MacGillivray 1908 Can. Entomol. 40:297. Holotype ♀

Blennocampa atrata MacGillivray 1893 Can. Entomol. 25:239. Holotype ♀

Blennocampa typicella MacGillivray 1923 Bull. Univ. Ill. 20:8. Holotype ♂

Caliroa labrata MacGillivray 1909 Can. Entomol. 41:360. Holotype ♂

Caliroa lacinata MacGillivray 1909 Can. Entomol. 41:357. Holotype ♀

Caliroa lata MacGillivray 1909 Can. Entomol. 41:361. Holotype ♀

Caliroa laudata MacGillivray 1909 Can. Entomol. 41:356. Holotype ♀

Caliroa lineata MacGillivray 1909 Can. Entomol. 41:350. Holotype ♀

Caliroa liturata MacGillivray 1909 Can. Entomol. 41:349. Lectotype ♀ designated by Frison (1927:238)

Caliroa lobata MacGillivray 1909 Can. Entomol. 41:355. Holotype ♀

Caliroa lorata MacGillivray 1909 Can. Entomol. 41:352. Holotype ♀

Caliroa loricata MacGillivray 1909 Can. Entomol. 41:351. Holotype ♀

Caliroa lunata MacGillivray 1909 Can. Entomol. 41:353. Holotype ♀

Caliroa nortonia MacGillivray 1894 Can. Entomol. 26:324. Holotype ♂

Claremontia typica Rohwer 1909 Can. Entomol. 41:397. Syntypes 1♂, 1♀

Cockerellonis occidentalis MacGillivray 1908 Can. Entomol. 40:365. Holotype (sex unkown)

Craterocercus cervinus MacGillivray 1923 Bull. Univ. Ill. 20:9. Holotype ♀

Craterocercus circulus MacGillivray 1923 Bull. Univ. Ill. 20:9. Holotype ♀

Craterocercus cordleyi MacGillivray 1923 Bull. Univ. Ill. 20:9. Holotype ♀

Craterocercus infuscatus MacGillivray 1916 Conn. State Geol. Nat. Hist. Surv. Bull. 22:106. Holotype ♀

Dimorphopteryx desidiosus MacGillivray 1923 Bull. Univ. Ill. 20:10. Holotype ♀

Dimorphopteryx enucleatus MacGillivray 1923 Bull. Univ. Ill. 20:10. Holotype ♀

Dimorphopteryx ithacus MacGillivray 1923 Bull. Univ. Ill. 20:10. Holotype ♀

Dimorphopteryx morsei MacGillivray 1923 Bull. Univ. Ill. 20:11. Holotype ♀

Dimorphopteryx oronis MacGillivray 1923 Bull. Univ. Ill. 20:11. Holotype ♀

Dimorphopteryx salinus MacGillivray 1923 Bull. Univ. Ill. 20:11. Holotype ♀

Dimorphopteryx scopulosus MacGillivray 1923 Bull. Univ. Ill. 20:12. Holotype ♀

Dolerus abdominalis Norton 1861 Proc. Boston Soc. Nat. Hist. 8:153. Neotype ♀ designated by Ross (1931:66)

Dolerus acritus MacGillivray 1908 Can. Entomol. 40:130. Holotype ♀

Dolerus agcistus MacGillivray 1908. Can. Entomol. 40:129. Holotype ♀

Dolerus agcistus maroa Ross 1931 Ill. Biol. Monogr. 12(3):61. Holotype ♀

Dolerus apricus Norton 1867 Trans. Am. Entomol. Soc. 1:236. Neotype ♀ designated by Ross (1931:94)

Dolerus aprilis Norton 1861 Proc. Boston Soc. Nat. Hist. 8:152. Neotype ♀ designated by Ross (1931:85)

Dolerus apriloides MacGillivray 1908 Can. Entomol. 40:126. Holotype ♀

Dolerus bicolor Beauvois 1805 Insectes Recueillis en Afrique et en Amerique p. 96. Neotype ♀ designated by Ross (1931:58)

Dolerus bicolor nigrata Ross 1931 Ill. Biol. Monogr. 12(3):59. Holotype ♀

Dolerus borealis MacGillivray 1893 Can. Entomol. 25:238. Holotype ♀

Dolerus clypealis Ross 1931 Ill. Biol. Monogr. 12(3):50. Holotype ♀

Dolerus cohaesus MacGillivray 1908 Can. Entomol. 40:128. Holotype ♀

Dolerus collaris Say 1823 West. Q. Rep. 2:720. Neotype ♀ designated by Ross (1931:54)

Dolerus collaris erebus Ross 1931 Ill. Biol. Monogr. 12(3):55. Holotype ♀

Dolerus colosericeus MacGillivray 1908 Can. Entomol. 40:125. Holotype ♀

Dolerus conjugatus MacGillivray 1908 Can. Entomol. 40:128. Holotype ♀

Dolerus dysporus MacGillivray 1908 Can. Entomol. 40:128. Holotype ♀

Dolerus elderi auraneus Ross 1931 Ill. Biol. Monogr. 12(3):69. Holotype ♀

Dolerus elderi rubicanus Ross 1931 Ill. Biol. Monogr. 12(3):70. Holotype ♀

Dolerus eurybis Ross 1931 Ill. Biol. Monogr. 12(3):65. Holotype ♀

Dolerus graenicheri MacGillivray 1914 Can. Entomol. 46:107. Holotype ♀

Dolerus icterus MacGillivray 1908 Can. Entomol. 40:127. Holotype ♀

Dolerus idahoensis Ross 1931 Ill. Biol. Monogr. 12(3):63. Holotype ♀

Dolerus illini Ross 1931 Ill. Biol. Monogr. 12(3):39. Holotype ♀

Dolerus illini rufilobus Ross 1931 Ill. Biol. Monogr. 12(3):41. Holotype ♂

Dolerus inspectus MacGillivray 1908 Can. Entomol. 40:128. Holotype ♂

Dolerus inspiratus MacGillivray 1914 Can. Entomol. 46:105. Holotype ♀

Dolerus interjectus Ross 1931 Ill. Biol. Monogr. 12(3):63. Holotype ♀

Dolerus kennedyi Ross 1935 Proc. Entomol. Soc. Wash. 37:90. Holotype ♀

Dolerus konowi MacGillivray 1914 Can. Entomol. 46:106. Holotype ♀

Dolerus lesticus MacGillivray 1914 Can. Entomol. 46:105. Holotype ♀

Dolerus luctatus MacGillivray 1908 Can. Entomol. 40:127. Holotype ♀

Dolerus minusculus MacGillivray 1908 Can. Entomol. 40:126. Holotype ♀

Dolerus monosericeus MacGillivray 1908 Can. Entomol. 40:126. Holotype ♀

Dolerus moramus Ross 1931 Ill. Biol. Monogr. 12(3):62. Holotype ♂

Dolerus napaeus MacGillivray 1923 Can. Entomol. 55:65. Holotype ♀

Dolerus narratus MacGillivray 1923 Can. Entomol. 55:65. Holotype ♀

Dolerus nasutus MacGillivray 1923 Can. Entomol. 55:65. Holotype ♀

Dolerus nativus MacGillivray 1923 Insecutor Inscit. Menstr. 11:32. Holotype ♂

Dolerus nauticus MacGillivray 1923 Insecutor Inscit. Menstr. 11:35. Holotype ♀

Dolerus necessarius MacGillivray 1923 Insecutor Inscit. Menstr. 11:35. Holotype ♀

Dolerus necosericeus MacGillivray 1923 Bull. Univ. Ill. 20:13. Holotype ♀

Dolerus nectareus MacGillivray 1923 Insecutor Inscit. Menstr. 11:33. Holotype ♂

Dolerus nefastus MacGillivray 1923 Can. Entomol. 55:66. Holotype ♀

Dolerus negotiosus MacGillivray 1923 J. N. Y. Entomol. Soc. 31:164. Holotype ♂

Dolerus nemorosus MacGillivray 1923 J. N. Y. Entomol. Soc. 31:164. Holotype ♀

Dolerus neoagcistus MacGillivray 1923 Bull. Brooklyn Entomol. Soc. 18:55. Holotype ♀

Dolerus neoaprilis MacGillivray 1908 Can. Entomol. 40:126. Holotype ♀

Dolerus neocollaris MacGillivray 1908 Can. Entomol. 40:127. Holotype ♂

Dolerus neosericeus MacGillivray 1908 Can. Entomol. 40:125. Holotype ♀

Dolerus neostugnus MacGillivray 1923 Bull. Brooklyn Entomol. Soc. 18:55. Holotype ♀

Dolerus nepotulus MacGillivray 1923 Can. Entomol. 55:68. Holotype ♂

Dolerus nervosus MacGillivray 1923 Insecutor Inscit. Menstr. 11:31. Holotype ♀

Dolerus nescius MacGillivray 1923 Bull. Univ. Ill. 20:12. Holotype ♀

Dolerus nicaeus MacGillivray 1923 Can. Entomol. 55:68. Holotype ♀

Dolerus nidulus MacGillivray 1923 Insecutor Inscit. Menstr. 11:31. Holotype ♀

Dolerus nimbosus MacGillivray 1923 Insecutor Inscit. Menstr. 11:33. Holotype ♀

Dolerus nivatus MacGillivray 1923 J. N. Y. Entomol. Soc. 31:164. Holotype ♀

Dolerus nocivus MacGillivray 1923 Bull. Univ. Ill. 20:12. Holotype ♀

Dolerus nocuus MacGillivray 1923 Insecutor Inscit. Menstr. 11:34. Holotype ♀

Dolerus nominatus MacGillivray 1923 Insecutor Inscit. Menstr. 11:34. Holotype ♀

Dolerus nortoni Ross 1931 Ill. Biol. Monogr. 12(3):51. Holotype ♀

Dolerus novellus MacGillivray 1923 Can. Entomol. 55:67. Holotype ♀

Dolerus novicius MacGillivray 1923 Can. Entomol. 55:67. Holotype ♀

Dolerus nugatorius MacGillivray 1923 Can. Entomol. 55:66. Holotype ♀

Dolerus numerosus MacGillivray 1923 Can. Entomol. 55:67. Holotype ♀

Dolerus nummarius MacGillivray 1923 Can. Entomol. 55:159. Holotype ♀

Dolerus nummatus MacGillivray 1923 Can. Entomol. 55:159. Holotype ♀

Dolerus nundinus MacGillivray 1923 Can. Entomol. 55:159. Holotype ♂

Dolerus nuntius MacGillivray 1923 Can. Entomol. 55:158. Holotype ♀

Dolerus nutricius MacGillivray 1923 Can. Entomol. 55:159. Holotype ♂

Dolerus nyctelius MacGillivray 1923 J. N. Y. Entomol. Soc. 31:163. Holotype ♂

Dolerus osagensis Ross 1935 Proc. Entomol. Soc. Wash. 37:89. Holotype ♀

Dolerus parasericeus MacGillivray 1908 Can. Entomol. 40:125. Holotype ♀

Dolerus plesius MacGillivray 1908 Can. Entomol. 40:129. Holotype ♀

Dolerus polysericeus MacGillivray 1908 Can. Entomol. 40:125. Holotype ♀

Dolerus refugus MacGillivray 1908 Can. Entomol. 40:127. Holotype ♀

Dolerus salmani Ross 1935 Proc. Entomol. Soc. Wash. 37:88. Holotype ♀

Dolerus sericeus Say 1824 From the Narrative of the Expedition to the Source of the St. Peter's River, etc., Under the Command of Stephen H. Long, Major U.S.T.E. 2:320. Neotype ♀ designated by Ross (1931:45)

Dolerus sericeus centralis Ross 1931 Ill. Biol. Monogr. 12(3):46. Holotype ♀

Dolerus similis nordanus Ross 1931 Ill. Biol. Monogr. 12(3):80. Holotype ♀

Dolerus stugnus MacGillivray 1908 Can. Entomol. 40:129. Holotype ♀

Dolerus tectus MacGillivray 1914 Can. Entomol. 46:104. Holotype ♀

Dolerus unicolor Beauvois 1805 Insectes Recueillis en Afrique et en Amerique p. 97. Neotype ♂ designated by Ross (1931:37)

Dolerus wanda Ross 1935 Proc. Entomol. Soc. Wash. 37:91. Holotype ♀

Emphytus gemitus MacGillivray 1923 J. N. Y. Entomol. Soc. 31:163. Holotype ♀

Emphytus gillettei MacGillivray 1902 Colo. Agric. Exp. Stn. Annu. Rep. 15:113. Holotype ♀

Emphytus halesus MacGillivray 1923 Bull. Univ. Ill. 20:13. Holotype ♀

Emphytus haliartus MacGillivray 1923 Bull. Univ. Ill. 20:14. Holotype ♀

Emphytus halitus MacGillivray 1923 Bull. Univ. Ill. 20:14. Holotype ♂

Emphytus haustus MacGillivray 1923 Bull. Univ. Ill. 20:14. Holotype ♂

Emphytus heroicus MacGillivray 1923 Bull. Univ. Ill. 20:14. Holotype ♀

Emphytus hiatus MacGillivray 1923 Bull. Univ. Ill. 20:15. Holotype ♀

Emphytus hiulcus MacGillivray 1923 Bull. Univ. Ill. 20:15. Holotype ♀

Emphytus hospitus MacGillivray 1923 Bull. Univ. Ill. 20:15. Holotype ♀

Emphytus hyacinthus MacGillivray 1923 Bull. Univ. Ill. 20:16. Holotype ♀

Emphytus yuasi MacGillivray 1921 Psyche 28:31. Holotype ♀

Empria cadurca MacGillivray 1923 Can. Entomol. 55:158. Holotype ♀

Empria caeca MacGillivray 1911 Can. Entomol. 43:308. Holotype ♀

Empria caetrata MacGillivray 1911 Can. Entomol. 43:305. Holotype ♀

Empria calda MacGillivray 1911 Can. Entomol. 43:307. Holotype ♀

Empria callida MacGillivray 1911 Can. Entomol. 43:306. Holotype ♀

Empria callosa MacGillivray 1911 Can. Entomol. 43:305. Holotype ♀

Empria candidula MacGillivray 1911 Can. Entomol. 43:310. Holotype ♀

Empria canora MacGillivray 1911 Can. Entomol. 43:310. Holotype ♀

Empria capillata MacGillivray 1911 Can. Entomol. 43:341. Holotype ♀

Empria caprina MacGillivray 1911 Can. Entomol. 43:307. Holotype ♀

Empria captiosa MacGillivray 1911 Can. Entomol. 43:308. Holotype ♀

Empria carbasea MacGillivray 1911 Can. Entomol. 43:341. Holotype ♀

Empria cariosa MacGillivray 1911 Can. Entomol. 43:309. Holotype ♀

Empria casca MacGillivray 1911 Can. Entomol. 43:310. Holotype ♂

Empria casta MacGillivray 1911 Can. Entomol. 43:308. Holotype ♀

Empria castigata MacGillivray 1911 Can. Entomol. 43:309. Holotype ♀

Empria cata MacGillivray 1911 Can. Entomol. 43:307. Holotype ♂

Empria cauduca MacGillivray 1911 Can. Entomol. 43:309. Holotype ♀

Empria cauta MacGillivray 1911 Can. Entomol. 43:311. Holotype ♀

Empria cava MacGillivray 1911 Can. Entomol. 43:306. Holotype ♀

Empria cavata MacGillivray 1911 Can. Entomol. 43:305. Holotype ♀

Empria celebrata MacGillivray 1911 Can. Entomol. 43:308. Holotype ♀

Empria celsa MacGillivray 1911 Can. Entomol. 43:306. Holotype ♀

Empria cerina MacGillivray 1921 Psyche 28:34. Holotype ♀

Empria cetaria MacGillivray 1921 Psyche 28:33. Holotype ♀

Empria cirrha MacGillivray 1923 Bull. Univ. Ill. 20:16. Holotype ♀

Empria cista MacGillivray 1923 Bull. Univ. Ill. 20:16. Holotype ♀

Empria cistula MacGillivray 1923 Bull. Univ. Ill. 20:16. Holotype ♀

Empria cithara MacGillivray 1923 Bull. Univ. Ill. 20:17. Holotype ♀

Empria columna MacGillivray 1923 Bull. Brooklyn Entomol. Soc. 18:54. Holotype ♀

Empria conciliata MacGillivray 1911 Can. Entomol. 43:344. Holotype ♀

Empria concisa MacGillivray 1911 Can. Entomol. 43:346. Holotype ♀

Empria concitata MacGillivray 1911 Can. Entomol. 43:342. Holotype ♂

Empria concreta MacGillivray 1911 Can. Entomol. 43:344. Holotype ♀

Empria condensa MacGillivray 1911 Can. Entomol. 43:342. Holotype ♀

Empria condita MacGillivray 1911 Can. Entomol. 43:342. Holotype ♀

Empria conferta MacGillivray 1911 Can. Entomol. 43:344. Holotype ♀

Empria confirmata MacGillivray 1911 Can. Entomol. 43:341. Holotype ♀

Empria contexta MacGillivray 1911 Can. Entomol. 43:345. Holotype ♀

Empria contorta MacGillivray 1911 Can. Entomol. 43:343. Holotype ♀

Empria costata MacGillivray 1914 Can. Entomol. 46:103. Holotype ♀

Empria culpata MacGillivray 1911 Can. Entomol. 43:343. Holotype ♀

Empria cumulata MacGillivray 1911 Can. Entomol. 43:343. Holotype ♀

Empria cuneata MacGillivray 1911 Can. Entomol. 43:345. Holotype ♀

Empria cupida MacGillivray 1911 Can. Entomol. 43:346. Holotype ♀

Empria curata MacGillivray 1911 Can. Entomol. 43:345. Holotype ♀

Empria evecta MacGillivray 1911 Can. Entomol. 43:310. Holotype ♀

Empria nordica Ross 1936 Pan-Pac. Entomol. 12:175. Holotype ♀

Euura maculata MacGillivray 1914 Can. Entomol. 46:366. Holotype ♀

Euura minuta MacGillivray 1914 Can. Entomol. 46:366. Holotype ♀

Euura moenia MacGillivray 1923 Bull. Univ. Ill. 20:17. Holotype ♀

Euura salicicola Smith 1879 North Am. Entomol. 1:41. Syntypes 1♂, 1♀

Fenusa lucifex Ross 1936 Trans. Ill. State Acad. Sci. 29:266. Holotype ♀

Hemitaxonus dediticius MacGillivray 1923 Psyche 30:77. Holotype ♂

Hoplocampa idaho Ross 1943 Trans. Am. Entomol. Soc. 69:81. Holotype ♂

Hoplocampa makila Ross 1943 Trans. Am. Entomol. Soc. 69:68. Holotype ♀

Hoplocampa nalema Ross 1943 Trans. Am. Entomol. Soc. 69:82. Holotype ♂

Hoplocampa oskina Ross 1943 Trans. Am. Entomol. Soc. 69:71. Holotype ♂

Hoplocampa padusa MacGillivray 1923 Bull. Univ. Ill. 20:17. Holotype ♂

Hoplocampa pallipes MacGillivray 1893 Can. Entomol. 25:239. Syntypes 3♀

Hoplocampa ritcheri Ross 1943 Trans. Am. Entomol. Soc. 69:72. Holotype ♂

Hoplocampa sialica Ross 1943 Trans. Am. Entomol. Soc. 69:67. Holotype ♂

Hoplocampa spala Ross 1943 Trans. Am. Entomol. Soc. 69:83. Holotype ♂

Hoplocampa stricklandi Ross 1943 Trans. Am. Entomol. Soc. 69:73. Holotype ♂

Hoplocampa texas Ross 1943 Trans. Am. Entomol. Soc. 69:69. Holotype ♂

Hypargyricus infuscatus MacGillivray 1908 Can. Entomol. 40:290. Holotype ♀

Isiodyctium atratum MacGillivray 1908 Can. Entomol. 40:290. Holotype ♀

Kerita fidala Ross 1937 Ill. Biol. Monogr. 15(2):80. Holotype ♀

Leucopelmonus annulatus MacGillivray 1916 Conn. State Geol. Nat. Hist. Surv. Bull. 22:83. Holotype ♀

Loderus accuratus MacGillivray 1923 Bull. Univ. Ill. 20:19. Holotype ♀

Loderus acerbus MacGillivray 1923 Bull. Univ. Ill. 20:19. Holotype ♀

Loderus acidus MacGillivray 1923 Bull. Univ. Ill. 20:20. Holotype ♀

Loderus acriculus MacGillivray 1923 Bull. Univ. Ill. 20:20. Holotype ♀

Loderus alticinctus MacGillivray 1923 Bull. Univ. Ill. 20:20. Holotype ♀

Loderus ancisus MacGillivray 1923 Bull. Univ. Ill. 20:21. Holotype ♀

Loderus niger Rohwer 1910 Can. Entomol. 42:49. Syntype 1♂

Macremphytus bicornis MacGillivray 1923 Bull. Univ. Ill. 20:21. Holotype ♀

Macremphytus lovetti MacGillivray 1923 Psyche 30:77. Holotype ♀

Macrophya bellula MacGillivray 1923 Bull. Brooklyn Entomol. Soc. 18:55. Holotype ♀

Macrophya bilineata MacGillivray 1916 Conn. State Geol. Nat. Hist. Surv. Bull. 22:96. Holotype ♀

Macrophya confusa MacGillivray 1914 Can. Entomol. 46:139. Holotype ♀

Macrophya fascialis puella Ross 1931 Ann. Entomol. Soc. Am. 24:123. Holotype ♀

Macrophya fistula MacGillivray 1920 Bull. Brooklyn Entomol. Soc. 15:114. Holotype ♀

Macrophya flaccida MacGillivray 1920 Bull. Brooklyn Entomol. Soc. 15:113. Holotype ♀

Macrophya flicta MacGillivray 1920 Bull. Brooklyn Entomol. Soc. 15:114. Holotype ♀

Macrophya magnifica MacGillivray 1893 Can. Entomol. 25:240. Holotype ♀

Macrophya melanopleura MacGillivray 1914 Can. Entomol. 46:139. Holotype ♀

Macrophya minuta MacGillivray 1895 Can. Entomol. 27:286. Holotype ♂

Macrophya mixta MacGillivray 1895 Can. Entomol. 27:77. Holotype ♀

Macrophya nidonea MacGillivray 1895 Can. Entomol. 27:77. Holotype ♂

Macrophya obaerata MacGillivray 1923 Bull. Univ. Ill. 20:21. Holotype ♀

Macrophya obnata MacGillivray 1923 Bull. Univ. Ill. 20:22. Holotype ♀

Macrophya obrussa MacGillivray 1923 Bull. Univ. Ill. 20:22. Holotype ♂

Macrophya oregona dukiae Ross 1931 Ann. Entomol. Soc. Am. 24:122. Holotype ♂

Macrophya ornata MacGillivray 1914 Can. Entomol. 46:139. Holotype ♀

Macrophya pluricinctella Rohwer 1909 Can. Entomol. 41:332. Syntypes 2♀

Macrophya pulchella alba MacGillivray 1895 Can. Entomol. 27:285. Holotype ♀

Macrophya punctata MacGillivray 1895 Can. Entomol. 27:285. Holotype ♀

Macrophya trisyllabus sinannula Ross 1931 Ann. Entomol. Soc. Am. 24:127. Holotype ♀

Macrophya truncata Rohwer 1909 Can. Entomol. 41:331. Syntypes 1♂, 1♀

Macrophya varius festana Ross 1931 Ann. Entomol. Soc. Am. 24:124. Holotype ♀

Macrophya varius nordicola Ross 1931 Ann. Entomol. Soc. Am. 24:125. Holotype ♀

Messa alsia MacGillivray 1923 Bull. Univ. Ill. 20:22. Holotype ♀

Messa alumna MacGillivray 1923 Bull. Univ. Ill. 20:23. Holotype ♀

Messa amica MacGillivray 1923 Bull. Univ. Ill. 20:23. Holotype ♀

Messa anita MacGillivray 1923 Bull. Univ. Ill. 20:23. Holotype ♀

Messa appota MacGillivray 1923 Bull. Univ. Ill. 20:24. Holotype ♂

Metallus bethunei MacGillivray 1914 Can. Entomol. 46:366. Holotype ♀

Metallus rohweri MacGillivray 1909 Ann. Entomol. Soc. Am. 2:267. Holotype ♀

Metallus rubi Forbes 1885 Rep. State Entomol. Ill. 14:87. Lectotype ♂ designated by Frison (1927:210)

Mogerus emarginatus MacGillivray 1895 Can. Entomol. 27:281. Holotype ♂

Monardis pulla Smith 1969 U. S. Dep. Agric. Tech. Bull. 1397:114. Holotype ♀

Monophadnoides circinus MacGillivray 1923 Bull. Univ. Ill. 20:24. Holotype ♂

Monophadnoides collaris MacGillivray 1908 Can. Entomol. 40:295. Holotype ♀

Monophadnoides concessus MacGillivray 1908 Can. Entomol. 40:294. Holotype ♀

Monophadnoides conductus MacGillivray 1923 Bull. Univ. Ill. 20:24. Holotype ♀

Monophadnoides consobrinus MacGillivray 1908 Can. Entomol. 40:294. Holotype ♀

Monophadnoides consonus MacGillivray 1923 Bull. Univ. Ill. 20:25. Holotype ♀
Monophadnoides conspersus MacGillivray 1908 Can. Entomol. 40:294. Holotype ♀
Monophadnoides conspiculata MacGillivray 1908 Can. Entomol. 40:293. Holotype ♀
Monophadnoides conspicuus MacGillivray 1908 Can. Entomol. 40:293. Holotype ♀
Monophadnoides constitutus MacGillivray 1923 Bull. Univ. Ill. 20:25. Holotype ♀
Monophadnoides contortus MacGillivray 1923 Psyche 30:78. Holotype ♀
Monophadnoides coracinus MacGillivray 1908 Can. Entomol. 40:295. Holotype ♂
Monophadnoides cordatus MacGillivray 1908 Can. Entomol. 40:294. Holotype ♀
Monophadnoides corytus MacGillivray 1923 Psyche 30:79. Holotype ♂
Monophadnoides costalis MacGillivray 1908 Can. Entomol. 40:295. Holotype ♀
Monophadnoides crassus MacGillivray 1908 Can. Entomol. 40:294. Holotype ♀
Monophadnoides curiosus MacGillivray 1923 Bull. Univ. Ill. 20:25. Holotype ♀
Monophadnoides kincaidi MacGillivray 1923 Bull. Univ. Ill. 20:26. Holotype ♀
Monophadnoides shawi MacGillivray 1923 Bull. Univ. Ill. 20:26. Holotype ♀
Monophadnus aequalis MacGillivray 1908 Can. Entomol. 40:292. Holotype ♀
Monophadnus aeratus MacGillivray 1923 Psyche 30:79. Holotype ♂
Monophadnus assaracus MacGillivray 1923 Bull. Univ. Ill. 20:26. Holotype ♂
Monophadnus atracornus MacGillivray 1893 Can. Entomol. 25:239. Holotype ♀
Monophadnus bipunctatus MacGillivray 1908 Can. Entomol. 40:292. Holotype ♀
Monophadnus distinctus MacGillivray 1908 Can. Entomol. 40:291. Holotype ♀
Monophadnus minutus MacGillivray 1908 Can. Entomol. 40:291. Holotype ♀
Monophadnus planus MacGillivray 1921 Bull. Brooklyn Entomol. Soc. 16:23. Holotype ♂
Monophadnus plicatus MacGillivray 1908 Can. Entomol. 40:292. Holotype ♀
Monophadnus ruscullus MacGillivray 1923 Psyche 30:80. Holotype ♂
Monophadnus transversus MacGillivray 1908 Can. Entomol. 40:292. Holotype ♀
Monostegia kincaidii MacGillivray 1893 Can. Entomol. 25:239. Holotype ♀
Monostegia martini MacGillivray 1908 Can. Entomol. 40:366. Holotype ♀
Nematus robiniae Forbes 1885 Rep. State Entomol. Ill. 14:116. Holotype ♀
Neocharactus bakeri MacGillivray 1908 Can. Entomol. 40:293. Holotype ♂
Neopareophora martini MacGillivray 1908 Can. Entomol. 40:289. Holotype ♀
Neopareophora scelesta MacGillivray 1908 Can. Entomol. 40:289. Holotype ♀
Neotomostethus hyalinus MacGillivray 1908 Can. Entomol. 40:290. Holotype ♀
Pachynematus absyrtus MacGillivray 1923 Bull. Univ. Ill. 20:27. Holotype ♀
Pachynematus academus MacGillivray 1923 Bull. Univ. Ill. 20:27. Holotype ♀
Pachynematus allegatus MacGillivray 1923 Can. Entomol. 55:162. Holotype ♀
Pachynematus corticosus MacGillivray 1901 N. Y. State Mus. Bull. 47:584. Holotype ♀
Pachynematus falonus Ross 1945 Proc. Entomol. Soc. Wash. 47:113. Holotype ♂
Pachynematus jamesi Ross 1945 Proc. Entomol. Soc. Wash. 47:112. Holotype ♂
Pachynematus miscus Ross 1945 Proc. Entomol. Soc. Wash. 47:114. Holotype ♂
Pachynematus painteri Ross 1945 Proc. Entomol. Soc. Wash. 47:115. Holotype ♂
Pachynematus rarus MacGillivray 1921 J. N. Y. Entomol. Soc. 29:30. Holotype ♀
Pachynematus refractarius MacGillivray 1921 J. N. Y. Entomol. Soc. 29:31. Holotype ♀
Pachynematus remissus MacGillivray 1921 J. N. Y. Entomol. Soc. 29:32. Holotype ♀
Pachynematus repertus MacGillivray 1921 J. N. Y. Entomol. Soc. 29:31. Holotype ♀
Pachynematus roscidus MacGillivray 1921 J. N. Y. Entomol. Soc. 29:31. Holotype ♀

Pachynematus rufocinctus MacGillivray 1916 Conn. State Geol. Nat. Hist. Surv. Bull. 22:117. Holotype ♀
Pachynematus setator Ross 1945 Proc. Entomol. Soc. Wash. 47:113. Holotype ♂
Pachynematus smithae Ross 1945 Proc. Entomol. Soc. Wash. 47:116. Holotype ♂
Pachynematus sporax Ross 1945 Proc. Entomol. Soc. Wash. 47:115. Holotype ♂
Pachynematus uvator Ross 1945 Proc. Entomol. Soc. Wash. 47:114. Holotype ♂
Parabates histrionicus MacGillivray 1909 Ann. Entomol. Soc. Am. 2:263. Holotype ♀
Paracharactus obscuratus MacGillivray 1908 Can. Entomol. 40:293. Holotype ♀
Paracharactus obtentus MacGillivray 1923 Bull. Univ. Ill. 20:28. Holotype ♀
Paracharactus obversus MacGillivray 1923 Bull. Univ. Ill. 20:28. Holotype ♀
Paracharactus offensus MacGillivray 1923 Bull. Univ. Ill. 20:28. Holotype ♀
Pareophora aldrichi MacGillivray 1923 Bull. Univ. Ill. 20:28. Holotype ♀
Pareophora guana MacGillivray 1923 Bull. Univ. Ill. 20:29. Holotype ♂
Pareophora guara MacGillivray 1923 Bull. Brooklyn Entomol. Soc. 18:54. Holotype ♀
Periclista confusa MacGillivray 1908 Can. Entomol. 40:291. Holotype ♀
Periclista electa MacGillivray 1923 Psyche 30:80. Holotype ♂
Periclista entella MacGillivray 1923 Bull. Univ. Ill. 20:29. Holotype ♂
Periclista leucostoma Rohwer 1909 Can. Entomol. 41:397. Syntypes 1♂, 1♀
Periclista linea Stannard 1949 Trans. Am. Entomol. Soc. 75:19. Holotype ♀
Periclista naranga Stannard 1949 Trans. Am. Entomol. Soc. 75:20. Holotype ♀
Periclista occidentalis Rohwer 1909 Can. Entomol. 41:398. Syntype 1♀
Periclista patchi MacGillivray 1923 Bull. Univ. Ill. 20:29. Holotype ♀
Periclista sulfurana Stannard 1949 Trans. Am. Entomol. Soc. 75:28. Holotype ♀
Perineura kincaidia MacGillivray 1895 Can. Entomol. 27:7. Holotype ♀
Phlebatrophia mathesoni MacGillivray 1909 Can. Entomol. 41:345. Holotype ♀
Phrontosoma atrum MacGillivray 1908 Can. Entomol. 40:367. Holotype ♂
Phrontosoma collaris MacGillivray 1908 Can. Entomol. 40:367. Holotype ♀
Phrontosoma daeckei MacGillivray 1908 Can. Entomol. 40:367. Holotype ♀
Platycampus vierecki MacGillivray 1920 Can. Entomol. 52:60. Holotype ♀
Poecilostoma convexa MacGillivray 1909 Can. Entomol. 41:402. Holotype ♀
Polybates slossonae MacGillivray 1909 Ann. Entomol. Soc. Am. 2:265. Holotype ♀
Pontania daedala MacGillivray 1921 J. N. Y. Entomol. Soc. 29:33. Holotype ♀
Pontania decrepita MacGillivray 1921 J. N. Y. Entomol. Soc. 29:33. Holotype ♀
Pontania dedecora MacGillivray 1921 J. N. Y. Entomol. Soc. 29:32. Holotype ♀
Pontania demissa MacGillivray 1921 J. N. Y. Entomol. Soc. 29:33. Holotype ♀
Pontania derosa MacGillivray 1921 J. N. Y. Entomol. Soc. 29:34. Holotype ♀
Pontania destricta MacGillivray 1923 J. N. Y. Entomol. Soc. 31:168. Holotype ♀
Pontania devincta MacGillivray 1921 J. N. Y. Entomol. Soc. 29:34. Holotype ♀
Pontania dotata MacGillivray 1921 J. N. Y. Entomol. Soc. 29:34. Holotype ♂
Pontania mariana Ross 1929 Proc. Entomol. Soc. Wash. 31:91. Holotype ♀
Pontania pepii Ross 1929 Proc. Entomol. Soc. Wash. 31:96. Holotype ♀
Priophorus acericaulis MacGillivray 1906 Can. Entomol. 38:306. Holotype ♀
Priophorus modestius MacGillivray 1921 Entomol. News 32:49. Holotype ♀
Priophorus moratus MacGillivray 1921 Entomol. News 32:50. Holotype ♀
Priophorus munditus MacGillivray 1921 Entomol. News 32:50. Holotype ♀
Pristiphora ostiaria MacGillivray 1920 Can. Entomol. 52:236. Holotype ♀
Pristola macnabi Ross 1945 Pan-Pac. Entomol. 21:154. Holotype ♂

Profenusa collaris MacGillivray 1914 Can. Entomol. 46:364. Holotype ♀
Prototaxonus typicus Rohwer 1910 Can. Entomol. 42:50. Syntype 1♂
Pseudodineura rileda Smith 1976 Proc. Entomol. Soc. Wash. 78:77. Holotype ♀
Pseudoselandria oxalata MacGillivray 1914 Can. Entomol. 46:104. Holotype ♀
Pteronidea edessa MacGillivray 1923 Bull. Univ. Ill. 20:30. Holotype ♀
Pteronidea edita MacGillivray 1920 Can. Entomol. 52:235. Holotype ♂
Pteronidea edura MacGillivray 1920 Can. Entomol. 52:233. Holotype ♀
Pteronidea effeta MacGillivray 1920 Can. Entomol. 52:234. Holotype ♀
Pteronidea effrenatus MacGillivray 1923 J. N. Y. Entomol. Soc. 31:171. Holotype ♀
Pteronidea effusa MacGillivray 1920 Can. Entomol. 52:233. Holotype ♀
Pteronidea egeria MacGillivray 1923 Can. Entomol. 55:161. Holotype ♀
Pteronidea egnatia MacGillivray 1923 Can. Entomol. 55:162. Holotype ♀
Pteronidea electra MacGillivray 1923 Bull. Univ. Ill. 20:30. Holotype ♀
Pteronidea elelea MacGillivray 1923 Can. Entomol. 55:162. Holotype ♀
Pteronidea emerita MacGillivray 1920 Can. Entomol. 52:234. Holotype ♀
Pteronidea enavata MacGillivray 1920 Can. Entomol. 52:236. Holotype ♀
Pteronidea equatia MacGillivray 1923 Bull. Univ. Ill. 20:30. Holotype ♂
Pteronidea equina MacGillivray 1920 Can. Entomol. 52:235. Holotype ♀
Pteronidea erratus MacGillivray 1923 J. N. Y. Entomol. Soc. 31:170. Holotype ♀
Pteronidea erudita MacGillivray 1920 Can. Entomol. 52:234. Holotype ♀
Pteronidea evanida MacGillivray 1920 Can. Entomol. 52:233. Holotype ♀
Pteronidea exacta MacGillivray 1920 Can. Entomol. 52:235. Holotype ♂
Pteronidea excessus MacGillivray 1923 J. N. Y. Entomol. Soc. 31:170. Holotype ♀
Rhadinoceraea similata MacGillivray 1908 Can. Entomol. 40:290. Holotype ♀
Rhogogastera respectus MacGillivray 1923 J. N. Y. Entomol. Soc. 31:165. Holotype ♀
Rhogogastera respersus MacGillivray 1923 J. N. Y. Entomol. Soc. 31:165. Holotype ♂
Rhogogastera ruga MacGillivray 1923 Can. Entomol. 55:160. Holotype ♀
Selandria floridana MacGillivray 1895 Can. Entomol. 27:281. Holotype ♂
Selandria urbis Ross 1930 Can. Entomol. 62:186. Holotype ♀
Simplemphytus pacificus MacGillivray 1914 Can. Entomol. 46:363. Holotype ♀
Strongylogaster annulosus cingulescens Ross 1932 Can. Entomol. 64:250. Holotype ♀
Strongylogaster pacificus MacGillivray 1893 Can. Entomol. 25:241. Syntypes 1♂, 1 ♀
Strongylogaster primativus MacGillivray 1893 Can. Entomol. 25:241. Syntype 1♀
Strongylogaster rufoculus MacGillivray 1894 Can. Entomol. 26:327. Holotype ♀
Strongylogastroidea confusa MacGillivray 1908 Can. Entomol. 40:369. Holotype ♀
Strongylogastroidea depressata MacGillivray 1921 Psyche 28:31. Holotype ♀
Strongylogastroidea potulenta MacGillivray 1923 Bull. Univ. Ill. 20:31. Holotype ♀
Strongylogastroidea rufinerva MacGillivray 1923 Bull. Univ. Ill. 20:31. Holotype ♀
Strongylogastroidea rufocinctana MacGillivray 1923 Bull. Univ. Ill. 20:31. Holotype ♀
Strongylogastroidea rufocinctella MacGillivray 1923 Bull. Univ. Ill. 20:32. Holotype ♀
Strongylogastroidea rufula MacGillivray 1923 Bull. Univ. Ill. 20:32. Holotype ♀
Strongylogastroidea shermani MacGillivray 1923 Bull. Univ. Ill. 20:32. Holotype ♀
Strongylogastroidea spiculatus MacGillivray 1908 Can. Entomol. 40:369. Holotype ♀
Strongylogastroidea unicinctella MacGillivray 1923 Bull. Univ. Ill. 20:33. Holotype ♀
Taxonus borealis MacGillivray 1895 Can. Entomol. 27:78. Holotype ♀

Taxonus inclinatus MacGillivray 1923 Psyche 30:78. Holotype ♂

Taxonus innominatus MacGillivray 1901 N. Y. State Mus. Bull. 47:585. Holotype ♀

Tenthredella glacialis Ross 1931 Ann. Entomol. Soc. Am. 24:110. Holotype ♀

Tenthredella stricklandi Ross 1931 Ann. Entomol. Soc. Am. 24:117. Holotype ♀

Tenthredella tricolor savanna Ross 1931 Ann. Entomol. Soc. Am. 24:116. Holotype ♀

Tenthredo aequalis MacGillivray 1895 Can. Entomol. 27:284. Holotype ♀

Tenthredo aldrichii MacGillivray 1900 Can. Entomol. 32:183. Holotype ♀

Tenthredo alphius MacGillivray 1900 Can. Entomol. 32:182. Holotype ♀

Tenthredo atracostus MacGillivray 1900 Can. Entomol. 32:183. Holotype ♀

Tenthredo atravenus MacGillivray 1895 Can. Entomol. 27:283. Holotype ♂

Tenthredo bilineatus MacGillivray 1895 Can. Entomol. 27:282. Holotype ♀

Tenthredo capitatus MacGillivray 1897 J. N. Y. Entomol. Soc. 5:108. Holotype ♀

Tenthredo causatus MacGillivray 1900 Can. Entomol. 32:178. Holotype ♂

Tenthredo dubitatus MacGillivray 1897 J. N. Y. Entomol. Soc. 5:103. Holotype ♂

Tenthredo fernaldii MacGillivray 1900 Can. Entomol. 32:177. Holotype ♀

Tenthredo hyalinus MacGillivray 1897 J. N. Y. Entomol. Soc. 5:108. Holotype ♂

Tenthredo junghannsii MacGillivray 1900 Can. Entomol. 32:179. Holotype ♀

Tenthredo lateralbus MacGillivray 1897 J. N. Y. Entomol. Soc. 5:108. Holotype ♀

Tenthredo linipes MacGillivray 1897 J. N. Y. Entomol. Soc. 5:104. Holotype ♂

Tenthredo lunatus MacGillivray 1900 Can. Entomol. 32:180. Holotype ♀

Tenthredo magnatus MacGillivray 1897 J. N. Y. Entomol. Soc. 5:107. Holotype ♂

Tenthredo messica MacGillivray 1897 J. N. Y. Entomol. Soc. 5:107. Holotype ♂

Tenthredo neoslossoni MacGillivray 1914 Can. Entomol. 46:138. Holotype ♀

Tenthredo nigricoxi MacGillivray 1900 Can. Entomol. 32:181. Holotype ♂

Tenthredo nigrifascia MacGillivray 1900 Can. Entomol. 32:184. Holotype ♀

Tenthredo nigritibiales MacGillivray 1897 J. N. Y. Entomol. Soc. 5:107. Holotype ♂

Tenthredo novus MacGillivray 1897 J. N. Y. Entomol. Soc. 5:106. Holotype ♀

Tenthredo obliquatus MacGillivray 1897 J. N. Y. Entomol. Soc. 5:105. Holotype ♀

Tenthredo olivatipes MacGillivray 1900 Can. Entomol. 32:180. Holotype ♀

Tenthredo pallicola MacGillivray 1895 Can. Entomol. 27:80. Holotype ♀

Tenthredo pallipectis MacGillivray 1897 J.N.Y. Entomol. Soc. 5:106. Holotype ♂

Tenthredo pallipunctus MacGillivray 1895 Can. Entomol. 27:282. Holotype ♀

Tenthredo perplexus MacGillivray1897 J.N.Y. Entomol. Soc. 5:104. Holotype ♀

Tenthredo prosopa Stannard 1947 Ann. Entomol. Soc. Am. 40:434. Holotype ♀

Tenthredo rabida MacGillivray 1923 J. N. Y. Entomol. Soc. 31:110. Holotype ♀

Tenthredo rabiosa MacGillivray 1923 J. N. Y. Entomol. Soc. 31:112. Holotype ♀

Tenthredo rabula MacGillivray 1923 J. N. Y. Entomol. Soc. 31:112. Holotype ♂

Tenthredo racilia MacGillivray 1923 J. N. Y. Entomol. Soc. 31:112. Holotype ♂

Tenthredo ralla MacGillivray 1923 J. N. Y. Entomol. Soc. 31:111. Holotype ♀

Tenthredo redimacula MacGillivray 1895 Can. Entomol. 27:78. Holotype ♀

Tenthredo reduvia MacGillivray 1923 J. N. Y. Entomol. Soc. 31:108. Holotype ♀

Tenthredo reflua MacGillivray 1923 J. N. Y. Entomol. Soc. 31:111. Holotype ♂

Tenthredo refractaria MacGillivray 1923 J. N. Y. Entomol. Soc. 31:113. Holotype ♀

Tenthredo refuga MacGillivray 1923 J. N. Y. Entomol. Soc. 31:167. Holotype ♀

Tenthredo regula MacGillivray 1923 J. N. Y. Entomol. Soc. 31:166. Holotype ♀

Tenthredo reliquia MacGillivray 1923 J. N. Y. Entomol. Soc. 31:168. Holotype ♀

Tenthredo remea MacGillivray 1923 J. N. Y. Entomol. Soc. 31:107. Holotype ♀

Tenthredo remissa MacGillivray 1923 J. N. Y. Entomol. Soc. 31:114. Holotype ♂

Tenthredo remora MacGillivray 1923 J. N. Y. Entomol. Soc. 31:108. Holotype ♂

Tenthredo remota MacGillivray 1895 Can. Entomol. 27:81. Holotype ♀

Tenthredo reperta MacGillivray 1923 J. N. Y. Entomol. Soc. 31:115. Holotype ♀

Tenthredo replata MacGillivray 1923 J. N. Y. Entomol. Soc. 31:115. Holotype ♀

Tenthredo repleta MacGillivray 1923 J. N. Y. Entomol. Soc. 31:111. Holotype ♀

Tenthredo reposita MacGillivray 1923 J. N. Y. Entomol. Soc. 31:116. Holotype ♂

Tenthredo reputina MacGillivray 1923 J. N. Y. Entomol. Soc. 31:114. Holotype ♂

Tenthredo reputinella MacGillivray 1923 Bull. Univ. Ill. 20:33. Holotype ♂

Tenthredo requieta MacGillivray 1923 J. N. Y. Entomol. Soc. 31:167. Holotype ♀

Tenthredo resegmina MacGillivray 1923 J. N. Y. Entomol. Soc. 31:115. Holotype ♂

Tenthredo resima MacGillivray 1923 J. N. Y. Entomol. Soc. 31:109. Holotype ♀

Tenthredo resticula MacGillivray 1923 J. N. Y. Entomol. Soc. 31:168. Holotype ♀

Tenthredo restricta MacGillivray 1923 J. N. Y. Entomol. Soc. 31:110. Holotype ♂

Tenthredo resupina MacGillivray 1923 J. N. Y. Entomol. Soc. 31:113. Holotype ♂

Tenthredo reticentia MacGillivray 1923 J. N. Y. Entomol. Soc. 31:114. Holotype ♀

Tenthredo retinentia MacGillivray 1923 J. N. Y. Entomol. Soc. 31:166. Holotype ♀

Tenthredo retosta MacGillivray 1923 J. N. Y. Entomol. Soc. 31:109. Holotype ♂

Tenthredo retroversa MacGillivray 1923 J. N. Y. Entomol. Soc. 31:167. Holotype ♂

Tenthredo rhammisia MacGillivray 1923 Bull. Univ. Ill. 20:33. Holotype ♀

Tenthredo rima MacGillivray 1923 J. N. Y. Entomol. Soc. 31:110. Holotype ♂

Tenthredo ripula MacGillivray 1923 J. N. Y. Entomol. Soc. 31:109. Holotype ♂

Tenthredo rota MacGillivray 1923 Bull. Univ. Ill. 20:34. Holotype ♀

Tenthredo rotula MacGillivray 1923 Bull. Univ. Ill. 20:34. Holotype ♂

Tenthredo rubicunda MacGillivray 1923 Bull. Univ. Ill. 20:34. Holotype ♀

Tenthredo rubrica MacGillivray 1923 Bull. Univ. Ill. 20:35. Holotype ♀

Tenthredo rubricosa MacGillivray 1923 Bull. Univ. Ill. 20:35. Holotype ♂

Tenthredo rubripes MacGillivray 1900 Can. Entomol. 32:178. Holotype ♂

Tenthredo rubrisommus MacGillivray 1900 Can. Entomol. 32:181. Holotype ♀

Tenthredo rudicula MacGillivray 1923 Bull. Univ. Ill. 20:35. Holotype ♀

Tenthredo rufostigmus MacGillivray 1895 Can. Entomol. 27:283. Holotype ♂

Tenthredo ruina MacGillivray 1923 Bull. Univ. Ill. 20:36. Holotype ♀

Tenthredo ruinosa MacGillivray 1923 Bull. Univ. Ill. 20:36. Holotype ♀

Tenthredo ruma MacGillivray 1923 Bull. Univ. Ill. 20:36. Holotype ♂

Tenthredo rumina MacGillivray 1923 Can. Entomol. 55:160. Holotype ♀

Tenthredo rurigena MacGillivray 1923 Bull. Univ. Ill. 20:36. Holotype ♀

Tenthredo russa MacGillivray 1923 Bull. Univ. Ill. 20:37. Holotype ♀

Tenthredo rustica MacGillivray 1923 J. N. Y. Entomol. Soc. 31:113. Holotype ♂

Tenthredo rusticana MacGillivray 1923 Bull. Univ. Ill. 20:37. Holotype ♀

Tenthredo rusticula MacGillivray 1923 J. N. Y. Entomol. Soc. 31:166. Holotype ♂

Tenthredo ruta MacGillivray 1923 Bull. Univ. Ill. 20:37. Holotype ♀

Tenthredo rutata MacGillivray 1923 Bull. Univ. Ill. 20:38. Holotype ♀

Tenthredo rutila MacGillivray 1923 Can. Entomol. 55:160. Holotype ♀

Tenthredo savagei MacGillivray 1900 Can. Entomol. 32:184. Holotype ♀

Tenthredo secundus MacGillivray 1897 J. N. Y. Entomol. Soc. 5:105. Holotype ♀

Tenthredo sicatus MacGillivray 1900 Can. Entomol. 32:179. Holotype ♂

Tenthredo simulatus MacGillivray 1897 J. N. Y. Entomol. Soc. 5:105. Holotype ♀

Tenthredo slossonii MacGillivray 1900 Can. Entomol. 32:179. Holotype ♂

Tenthredo smectica MacGillivray 1920 Bull. Brooklyn Entomol. Soc. 15:113. Holotype ♀

Tenthredo stigmatus MacGillivray 1897 J. N. Y. Entomol. Soc. 5:108. Holotype ♂

Tenthredo terminatus MacGillivray 1895 Can. Entomol. 27:283. Holotype ♀

Tenthredo ventricus MacGillivray 1895 Can. Entomol. 27:284. Holotype ♂

Tenthredo yuasi MacGillivray 1920 Bull. Brooklyn Entomol. Soc. 15:112. Holotype ♀

Tenthredopsis ruficorna MacGillivray 1893 Can. Entomol. 25:242. Holotype ♀

Thrinax pullatus MacGillivray 1921 Psyche 28:34. Holotype ♂

Tomostethus nortonii MacGillivray 1908 Can. Entomol. 40:291. Holotype ♀

Trichiocampus pacatus MacGillivray 1921 Entomol. News 32:48. Holotype ♀

Trichiocampus paetulus MacGillivray 1921 Entomol. News 32:48. Holotype ♀

Trichiocampus palliolatus MacGillivray 1921 Entomol. News 32:49. Holotype ♀

Trichiocampus patchiae MacGillivray 1921 Entomol. News 32:48. Holotype ♀

Unitaxonus repentinus MacGillivray 1921 Psyche 28:32. Holotype ♀

Unitaxonus rumicis MacGillivray 1921 Psyche 28:33. Holotype ♀

Tiphiidae

Dipogon femur-aureus Dreisbach 1953 Am. Midl. Nat. 49:832. Holotype ♀

Myrmosa nocturna rufigastra Krombein 1940 Trans. Am. Entomol. Soc. 65:454. Holotype ♂

Neotiphia acuta Malloch 1918 Bull. Ill. State Nat. Hist. Surv. 13:9. Syntypes 3♂, 1♀

Tiphia affinis Malloch 1918 Bull. Ill. State Nat. Hist. Surv. 13:19. Syntypes 4♂, 1♀

Tiphia arida Malloch 1918 Bull. Ill. State Nat. Hist. Surv. 13:20. Holotype ♀

Tiphia aterrima Malloch 1918 Bull. Ill. State Nat. Hist. Surv. 13:19. Syntypes 5♀

Tiphia clypeata Robertson 1901 Trans. Am. Entomol. Soc. 27:196. Syntypes 6♂

Tiphia conformis Malloch 1918 Bull. Ill. State Nat. Hist. Surv. 13:22. Syntypes 1♂, 2♀

Tiphia floridana Robertson 1901 Trans. Am. Entomol. Soc. 27:195. Syntypes 2♂, 1♀

Tiphia illinoensis Robertson 1901 Trans. Am. Entomol. Soc. 27:196. Syntypes 6♂

Tiphia inaequalis Malloch 1918 Bull. Ill. State Nat. Hist. Surv. 13:22. Syntypes 5♂

Tiphia punctata Robertson 1901 Trans. Am. Entomol. Soc. 27:196. Holotype ♂

Tiphia punctata intermedia Malloch 1918 Bull. Ill. State Nat. Hist. Surv. 13:21. Syntype 1♀

Tiphia robertsoni Malloch 1918 Bull. Ill. State Nat. Hist. Surv. 13:23. Syntypes 8♀

Tiphia rugulosa Malloch 1918 Bull. Ill. State Nat. Hist. Surv. 13:15. Syntypes 1♂, 2♀

Tiphia similis Malloch 1918 Bull. Ill. State Nat. Hist. Surv. 13:18. Syntypes 2♂

Tiphia texensis Malloch 1918 Bull. Ill. State Nat. Hist. Surv. 13:20. Syntype 1♀

Tiphia tuberculata Malloch 1918 Bull. Ill. State Nat. Hist. Surv. 13:14. Syntypes 79♂, 11♀

Tiphia vulgaris Robertson 1901 Trans. Am. Entomol. Soc. 27:195. Syntypes 32♂, 1♀

Trichogrammatidae

Aphelinoidea plutella Girault 1912 Entomol. News 23:297. Holotype ♀

Aphelinoidea semifuscipennis Girault 1911 Trans. Am. Entomol. Soc. 37:4. Lectotype designated by Frison (1927:224)

Neotrichogramma acutiventre Girault 1911 Trans. Am. Entomol. Soc. 37:40. Syntypes 1♂, 2♀

Oligosita americana Ashmead 1909 Psyche 16:107. Lectotype ♀ designated by Frison (1927:224)

Oophthora semblidis Aurivillius 1897 Entomol. Tidskr. 18:253. Syntypes 4♂, 15♀

Westwoodella clarimaculosa Girault 1911 Trans. Am. Entomol. Soc. 37:67. Holotype ♀

Westwoodella sanguinea Girault 1911 Trans. Am. Entomol. Soc. 37:58. Holotype ♀

Vespidae

Odynerus apopkensis Robertson 1901 Trans. Am. Entomol. Soc. 27:200. Syntypes 2♂

Odynerus australis Robertson 1901 Trans. Am. Entomol. Soc. 27:200. Syntypes 4♂, 1♀

Odynerus bicornis Robertson 1904 Trans. Am. Entomol. Soc. 27:198. Syntypes 3♂, 1♀

Odynerus bifurcus Robertson 1901 Trans. Am. Entomol. Soc. 27:198. Syntypes 3♂, 1♀

Odynerus clypeatus Robertson 1901 Trans. Am. Entomol. Soc. 27:199. Syntypes 51♂, 6♀

Odynerus floridanus Robertson 1901 Trans. Am. Entomol. Soc. 27:200. Syntype 1♀

Odynerus fundatiformis Robertson 1901 Trans. Am. Entomol. Soc. 27:200. Holotype ♂

Odynerus histrionalis Robertson 1901 Trans. Am. Entomol. Soc. 27:199. Syntypes 18♂, 13♀

Odynerus illinoensis Robertson 1901 Trans. Am. Entomol. Soc. 27:202. Syntypes 3♂, 10♀

Odynerus oculeus Robertson 1901 Trans. Am. Entomol. Soc. 27:201. Syntypes 12♂, 4♀

Odynerus zendaloides Robertson 1901 Trans. Am. Entomol. Soc. 27:202. Syntypes 2♂

Xiphydridae

Xiphydria polia Smith 1976 Trans. Am. Entomol. Soc. 102:119. Holotype ♀

Xyelidae

Macroxyela bicolor MacGillivray 1912 Can. Entomol. 44:294. Holotype ♂

Macroxyela bicolor harti Ross 1932 Ann. Entomol. Soc. Am. 25:166. Holotype ♂

Macroxyela distincta MacGillivray 1912 Can. Entomol. 44:295. Holotype ♀

Macroxyela obsoleta MacGillivray 1912 Can. Entomol. 44:294. Holotype ♀

Megaxyela langstoni Ross 1936 Entomol. News 47:131. Holotype ♀

Pleroneura aldrichi Ross 1932 Ann. Entomol. Soc. Am. 25:158. Holotype ♀

Xyela deserti Burdick 1961 Univ. Calif. Publ. Entomol. 17:347. Holotype ♀

Xyela intrabilis MacGillivray 1923 Bull. Brooklyn Entomol. Soc. 18:53. Holotype ♂

Xyela linsleyi Burdick 1961 Univ. Calif. Publ. Entomol. 17:344. Holotype ♀

Xyelecia nearctica Ross 1932 Ann. Entomol. Soc. Am. 25:160. Holotype ♀

ADDENDUM

COLEOPTERA

Limnichidae

Eulimnichus rugulosus Wooldridge 1979 Great Lakes Entomol. 12:6. Holotype ♂

Eulimnichus visendus Wooldridge 1979 Great Lakes Entomol. 12:1. Holotype ♂

Limnichites rudis Wooldridge 1977 Great Lakes Entomol. 10:183. Holotype ♂

HYMENOPTERA

Tenthredinidae

Melastola ferruginosa Wong 1968 Can. Entomol. 100:1054. Holotype ♀

Pristiphora aphanta Wong & Ross 1960 Can. Entomol. 92:196. Holotype ♀

Pristiphora hucksena Wong & Ross 1960 Can. Entomol. 92:194. Holotype ♀

Pristiphora paloma Wong & Ross 1960 Can. Entomol. 92:196. Holotype ♀

Pristiphora valvangula Wong & Ross 1960 Can. Entomol. 92:194. Holotype ♂

Pristiphora venatta Wong & Ross 1960 Can. Entomol. 92:196. Holotype ♀

LITERATURE CITED

Bouseman, J. K., and W. E. LaBerge. 1979. A revision of the bees of the genus *Andrena* of the western hemisphere. Part IX. Subgenus *Melandrena*. American Entomological Society Transactions 104:275-389.

Daly, H. V. 1973. Bees of the genus *Ceratina* in America north of Mexico (Hymenoptera: Apoidea). University of California Publications in Entomology 74. 114 p.

Davis, D. R. 1967. A revision of the moths of the subfamily Prodoxinae (Lepidoptera: Incurvariidae). U. S. National Museum Bulletin 255. 170 p.

Frick, K. E. 1952. The status of *Agromyza illinoensis* Malloch, 1934, and its correct generic position (Agromyzidae, Diptera). Kansas Entomological Society Journal 25:150-154.

Frison, T. H. 1927. A list of the insect types in the collection of the Illinois State Natural History Survey and the University of Illinois. Illinois State Natural History Survey Bulletin 16:137-309.

Gerdes, C. 1977. Thysanoptera types in collection of Illinois Natural History Survey. Entomological News 88:271-279.

Hottes, F.C., and T. H. Frison. 1931. The plant lice, or Aphiidae, of Illinois. Illinois State Natural History Survey Bulletin 19:121-447.

International Commission on Zoological Nomenclature. 1964. International code of zoological nomenclature adopted by the XV international congress of zoology. London. 176 p.

Kelsey, L. P. 1969. A revision of the Scenopinidae (Diptera) of the world. U. S. National Museum Bulletin 277. 336 p.

LaBerge, W. E. 1956*a*. A revision of the bees of the genus *Melissodes* in North and Central America. Part I (Hymenoptera, Apidae). University of Kansas Science Bulletin 37:911-1194.

———. 1956*b*. A revision of the bees of the genus *Melissodes* in North and Central America. Part II (Hymenoptera, Apidae). University of Kansas Science Bulletin 38:533-578.

———. 1961. A revision of the bees of the genus *Melissodes* in North and Central America. Part III (Hymenoptera, Apidae). University of Kansas Science Bulletin 42:283-663.

———. 1967. A revision of the bees of the genus *Andrena* of the western hemisphere. Part I *Callandrena*. (Hymenoptera: Andrenidae). University of Nebraska State Museum Bulletin 7:1-316.

———. 1969. A revision of the bees of the genus *Andrena* of the western hemisphere. Part II. *Plastandrena*, *Aporandrena*, *Charitandrena*. American Entomological Society Transactions 95:1-47.

———. 1971. A revision of the bees of the genus *Andrena* of the western hemisphere. Part IV. *Scrapteropsis*, *Xiphandrena* and *Rhaphandrena*. American Entomological Society Transactions 97:441-520.

———. 1973. A revision of the bees of the genus *Andrena* of the western hemisphere. Part VI. Subgenus *Trachandrena*. American Entomological Society Transactions 99:235-371.

———. 1977. A revision of the bees of the genus *Andrena* of the western hemisphere. Part VIII. Subgenera *Thysandrena*, *Dasyandrena*, *Psammandrena*, *Rhacandrena*, *Euandrena*, *Oxyandrena* American Entomological Society Transactions 103:1-143.

———, and J. K. Bouseman. 1970. A revision of the bees of the genus *Andrena* of the western hemisphere. Part III. *Tylandrena*. American Entomological Society Transactions 96:543-605.

———, and D. W. Ribble. 1972. A revision of the bees of the genus *Andrena* of the western hemisphere. Part V. *Gonandrena*, *Geissandrena*, *Parandrena*, *Pelicandrena*. American Entomological Society Transactions 98:217-358.

Mari Mutt, J. A. 1978. The types of Collembola (Insecta) at the Illinois Natural History Survey. Illinois Natural History Survey Biological Notes 103. 7 p.

Milliron, H. E. 1971. A monograph of the western hemisphere bumblebees (Hymenoptera: Apidae; Bombinae). I. The genera *Bombus* and *Megabombus* subgenus *Bombias*. Entomological Society of Canada Memoirs 82. 80 p.

Ordway, E. 1966. Systematics of the genus *Augochlorella* (Hymenoptera, Halictidae) north of Mexico. University of Kansas Science Bulletin 46:509-624.

Pacheco, F. 1964. Sistematica, filogenia y distribucion de los Heteroceridos de America (Coleoptera: Heteroceridae). Escuela Nacional de Agricultura, Colegio de Post-Graduados, Monografias Miscelaneas 1. Chapingo, Mexico. 155 p.

Ribble, D. W. 1967. The monotypic North American subgenus *Larandrena* of *Andrena* (Hymenoptera: Apoidea). University of Nebraska State Museum Bulletin 6:27-42.

———. 1968. Revisions of two subgenera of *Andrena*: *Micrandrena* Ashmead and *Derandrena*, new subgenus (Hymenoptera: Apoidea). University of Nebraska State Museum Bulletin 8:237-394.

———. 1974. A revision of the bees of the genus *Andrena* of the western hemisphere subgenus *Scaphandrena*. American Entomological Society Transactions 100:101-189.

Ross, H. H. 1931. Sawflies of the sub-family Dolerinae of America north of Mexico. Illinois Biological Monographs 12. University of Illinois, Urbana. 116 p.

———. 1944. The Caddis Flies, or Trichoptera, of Illinois. Illinois Natural History Survey Bulletin 23:1-326.

Schoof, H. F. 1942. The genus *Conotrachelus* Dejean (Coleoptera, Curculionidae) in the north central United States. Illinois Biological Monographs 19.University of Illinois, Urbana. 170 p.

Shapiro, A. M. 1971. Notes of the biology of *Poanes viator* (Hesperiidae) with the description of a new subspecies. Journal of Research on the Lepidoptera 9:109-123.

Stephen, W. P. 1954. A revision of the bee genus *Colletes* in America north of Mexico. (Hymenoptera, Colletidae). University of Kansas Science Bulletin 36:149-527.

PUBLICATIONS REFERRED TO IN THE LIST OF PRIMARY INSECT TYPES

Journal Names and Abbreviations

Am. Midl. Nat. — American Midland Naturalist
Am. Mus. Novit. — American Museum Novitates
Am. Nat. — American Naturalist
Ann. Entomol. Soc. Am. — Annals of the Entomological Society of America
Ann. Mag. Nat. Hist. — Annals and Magazine of Natural History
Ann. Soc. Entomol. Belg. — Annales de la Societe Entomologique de Belgique
Arch. Hydrobiol. — Archiv für Hydrobiologie
Arch. Naturgesch. — Archiv für Naturgeschichte
Arkansas Acad. Sci. Proc. — Arkansas Academy of Science Proceedings
Biol. Cent-Am., Insecta-Diptera — Biologia Centrali-Americana, Insecta-Diptera
Breviora — Breviora
Bull. Am. Mus. Nat. Hist. — Bulletin of the American Museum of Natural History
Bull. Brooklyn Entomol. Soc. — Bulletin of the Brooklyn Entomological Society
Bull. Chic. Acad. Sci. — Bulletin of the Chicago Academy of Sciences
Bull. Ill. State Lab. Nat. Hist. — Bulletin of the Illinois State Laboratory of Natural History
Bull. Ill. State Nat. Hist. Surv. — Bulletin of the Illinois State Natural History Survey
Bull. Mus. Comp. Zool. — Bulletin of the Museum of Comparative Zoology
Bull. Univ. Ill. — Bulletin of the University of Illinois
Bull. Univ. Nebr. State Mus. — Bulletin of the University of Nebraska State Museum
Can. Entomol. — Canadian Entomologist
Can. J. Zool. — Canadian Journal of Zoology
Caribb. J. Sci. — Caribbean Journal of Science
Coleopt. Bull. — Coleopterists' Bulletin
Colo. Agric. Exp. Stn. Annu. Rep. — Colorado Agricultural Experiment Station Annual Report
Conn. State Geol. Nat. Hist. Surv. Bull. — Connecticut State Geological and Natural History Survey Bulletin
Dtsch. Entomol. Z. — Deutsche Entomologische Zeitschrift
Entomol. Am. — Entomologica Americana
Entomol. News — Entomological News
Entomol. Tidskr. — Entomologisk Tidskrift
Esc. Nac. Agric. Chapingo Monogr. — Escuela Nacional de Agricultura, Chapingo, Monografias
Field Mus. Nat. Hist. Publ. Zool. Ser. — Field Museum of Natural History Publication Zoological Series
Fla. Entomol. — Florida Entomologist
For. Sci. — Forest Science
Great Basin Nat. — Great Basin Naturalist
Great Lakes Entomol. — Great Lakes Entomologist
Ill. Biol. Monogr. — Illinois Biological Monographs
Ill. Nat. Hist. Surv. Bull. — Illinois Natural History Survey Bulletin
Indiana Univ. Publ. Sci. Ser. — Indiana University Publications in Science Series
Insecutor Inscit. Menstr. — Insecutor Inscitiae Menstruers
Iowa State J. Sci. — Iowa State Journal of Science
J. Acad. Nat. Sci. Phila. — Journal of the Academy of Natural Sciences of Philadelphia
J. Econ. Entomol. — Journal of Economic Entomology
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Books

Beauvois, Palisot De. 1895. Insectes recueillis en Afrique et en Amerique. Levrault, Paris.

Curran, C. H. 1934. The families and genera of North American Diptera. Henry Tripp, Woodhaven, N.Y.

Kissinger, D. G. 1974. Apioninae occurring in the West Indies (Curculionidae, Coleoptera). Kissinger Taxonomic Publications, Riverside, Calif.

Malloch, J. R. 1919. The Diptera collected by the Canadian expedition, 1913-1918. Pages 34c-90c *in* Report of the Canadian Arctic expedition 1913-18. Vol. 3. Ottawa.

———. 1934. Diptera of Patagonia and South Chile. Vol. 6. British Museum (Natural History), London.

Milne, L. J. 1935-1936. Studies in North American Trichoptera. Vol. 2 and 3. Cambridge, Mass.

Ross, H. H. 1956. Evolution and classification of the mountain caddisflies. University of Illinois Press, Urbana.

Say, T. 1824. From the narrative of the expedition to the source of the St. Peter's River, etc., under the command of Stephen H. Long, Major U. S. T. E. Vol. 2. Philadelphia.

———. 1828. American entomology, or descriptions of the insects of North America. Vol. 3. Philadelphia.

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This report is printed by authority of the State of Illinois. It is a contribution from the Section of Economic Entomology of the Illinois Natural History Survey.

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(48940—1M—11-80)

Fig. 1. — *Thereva frontalis* Say adult female.

The Genera of Nearctic Therevidae

Michael E. Irwin and Leif Lyneborg

The first description of a North American therevid was of *Bibio abdominalis* from the West Indies (Fabricius 1805). Next, descriptions of Nearctic Therevidae were published by a European, C. R. W. Wiedemann (1821, 1824, and 1828), and an American, Thomas Say (1823, 1824, and 1829). Further descriptions followed thereafter by Macquart (1840), Walker (1848, 1850, 1852, and 1857), Rondani (1856), Bellardi (1861), Loew (1869*a*, 1869*b*, 1872, 1874, and 1876), Osten Sacken (1877 and 1887), Williston (1886), and Bigot (1889). The turn of the century brought a few new American dipterists into the picture (Johnson 1902 and 1926; Adams 1903 and 1904), but by far the most important therevid worker of that time was D. W. Coquillett, who published revisionary monographs of the Therevidae (1893*a* and 1893*b*) and added greatly to the concepts within the family (1894, 1898, 1904*a*, 1904*b*, and 1910). Following Coquillett, Otto Kröber of Germany became the reigning world authority on the Therevidae, and he added considerably to the number of described species in North America through revisions and new descriptions (1911, 1912, 1914, 1928*a*, 1928*b*, and 1929). In 1923 Frank Cole (1923*a*) published a monographic revision of the Therevidae of North America. This work has remained the definitive treatment for the area for the past 57 years. American workers, including Cole (1923*b*, 1925, 1959, 1960*a*, and 1960*b*), Hardy (1938 and 1943), James (1936 and 1949), James & Huckett (1952), and Bromley (1937), added occasional new descriptions and names to the slowly growing list of Therevidae of North America. In the late 1960's and 1970's, we became active in the area of therevid systematics. Lyneborg (1972) revised the *Xestomyza* group of Therevidae, including the genus *Henicomyia* from the Western Hemisphere, and Irwin (1977*a* and 1977*b*) revised three genera of North American Therevidae.

During the course of preparing the Therevidae chapter for the soon-to-be-published *Manual of Nearctic Diptera* (Canada Department of Agriculture 1981), we found that the previously published descriptions of genera were totally inadequate to form a framework for the therevid species of North America. The genus *Psilocephala* Zett., for instance, was found to be polyphyletic, containing species from several diverse ancestors. An effort to describe the many new genera contained herein was begun because we realized the definitive nature of the forthcoming *Manual of Nearctic Diptera* and the importance of establishing a generic base for the Therevidae founded on synapomorphies. We have restrained ourselves from grouping the genera beyond the subfamilial level simply because we feel that better natural groupings can be formed once genera from other parts of the world are included in the scheme.

We have attempted to place the described species in the new generic concepts at the end of each diagnosis. All North American genera are diagnosed, and male terminalia are figured for all genera. In total, 29 genera and 143 currently valid species have been described for North America, excluding *Apsilocephala* Kröber (1914) and its included species, *longistyla* Kröber (1914), which we feel does not belong within the family Therevidae. We have not included *Melanothereva* Malloch (1932:249) that occurs in Chile, Peru, and parts of Argentina and contains a single Nearctic species, *nigra* (Bellardi) [1861:92, ♂

(*Psilocephala*)] that, to our knowledge, has not been rediscovered since it was first described from Mexico.

The descriptions and keys follow morphological terminology developed by us. Male terminalia characters were originally defined and described by Lyneborg (1968*a*) and have since been modified slightly by Lyneborg (1972, 1976, and 1978) and by Irwin (1977*a* and 1977*b*). Female terminalia characters were defined and described by Irwin (1976). Other morphological features are generally accepted in Diptera literature, and we refrain from detailing them here. The immature stages of Therevidae have not been used in developing this preliminary classification. Larval and pupal stadia are being gathered and associated with adults in the hope that eventually they will help to elucidate the proper phylogenetic placement of species within genera and genera within supra-generic taxa.

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ABBREVIATIONS USED IN DESCRIPTIONS AND FIGURES

ad: anterodorsal
ae: aedeagus
av: anteroventral
c: cerci
dap: dorsal apodeme
dc: dorsocentral
dp: distiphallus
eap: ejaculatory apodeme
ep: epandrium
f_1: fore femur
f_2: middle femur
f_3: hind femur
gc: gonocoxite
gs: gonostylus
h: hypandrium
np: notopleural
pa: postalar
pap: parameral apodeme

pd: posterodorsal
pp: parameral process
pv: posteroventral
sa: supra-alar
sc: scutellar
t_1: fore tibia
t_2: middle tibia
t_3: hind tibia
vap: ventral apodeme
veps: ventral epandrial sclerite
vl: ventral lobe

FAMILY THEREVIDAE

Description of Adult

Slender to moderately thick-bodied flies (Fig. 1); length, excluding antennae, 2.5–15 mm. Background color light yellow to black. Body wholly or partly pilose, tomentose, pruinose, or some combination of these characters; setae usually prominent.

Head. — Hemispherical, not depressed at vertex, hypognathous to prognathous. Eyes dichoptic in female, holoptic in most males, usually without hairs in both sexes. Frons of female wide, reaching ocellar tubercle, often covered variously with pollen and scattered hairs; frons of male usually small, acutely to broadly triangular, tomentose to bare, often without hairs. Three prominent ocelli set at vertex or slightly anterior of vertex. Antenna three segmented, sometimes set on prominent frontal protuberance; scape variously setose; pedicel usually with a ring or two of short setae; first flagellomere without setae, or with setae usually confined to basal third; flagellar style comprises 1 or 2 flagellomeres and a terminal or subterminal spine set apically or subapically on apical flagellomere; spine elongate and prominent in some genera, but almost undetectable in others. Face often tomentose; lateral areas pilose or not; genae pilose or not, often with a darkened tomentose or bare stripe; occiput finely tomentose, often densely pilose from midpoint ventrally and prominently setose dorsally; postocular setae usually present though often slender. Palps one or two segmented, usually pilose and not prominent, set beside proboscis in subcranial cavity; proboscis slightly longer than palps, usually carried within subcranial cavity.

Thorax. — Scutum varies from nearly square to elongately rectangular when viewed from above, often sparsely to densely tomentose or pilose or both. Scutellum prominent, often without pile, but almost always tomentose. Pleuron variously pilose; upper portion usually densely tomentose; lower portion sometimes without pollen. One pair postalar setae; 1–6 pairs notopleural setae or more; 1 or 2 pairs supra-alar setae; usually 0–2 pairs dorsocentral setae, but 3 or more in a few species; 0–3, rarely 4, pairs scutellar setae.

Wing. — Venation remarkably uniform (Fig. 32); R_1 setose or not; R_4 elongate, usually S-shaped; cell d has m_1, m_2, m_3 arising from apex; CuA_1 does not meet posterior margin of cell d; crossvein m-cu present; cell cu-p closed behind; cell m_3 open or closed; abnormalities common in wing venation. Stigma usually well-developed. Wing hyaline to infuscate, sometimes banded or spotted, veins often surrounded by darker infuscation. Microtrichia from sparse to dense. Calypter well-developed. Halter large and well-developed.

Legs. — Usually fairly long and slender; hind legs longer than others. Fore coxa (Fig. 3) with none to several setae on anterior surface; middle coxa with (Fig. 4) or without (Fig. 5) pile on posterior surface; all femora bare to heavily setose, especially anteroventrally, often with long scalelike pile along dorsal surface; tibiae and tarsi setulose in definite longitudinal rows; fore tibia lacks setae anteroventrally. Five tarsomeres present; first tarsomere longest and sometimes swollen; claw with 2 pulvilli and a setalike central empodium or without empodium.

Abdomen. — Usually convex to flattened dorsally and tapering at apex, sometimes laterally compressed, always with 8 well-developed pregenital segments. Fine silvery pollen often adorns abdomen, covering it completely in male of many species and in patterns on female. Tomentum and pile present or absent, usually longer and denser on male.

FEMALE TERMINALIA. — Characterized by large conspicuous sternite 8, functioning variously as a digging-anchoring apparatus for oviposition, a floor for genital chamber, and a guide for penial insertion during copulation (Irwin 1976). Sternite 9 (furca), acting as roof of genital chamber, completely internal, with 2 lateral sclerites fused posteriorly

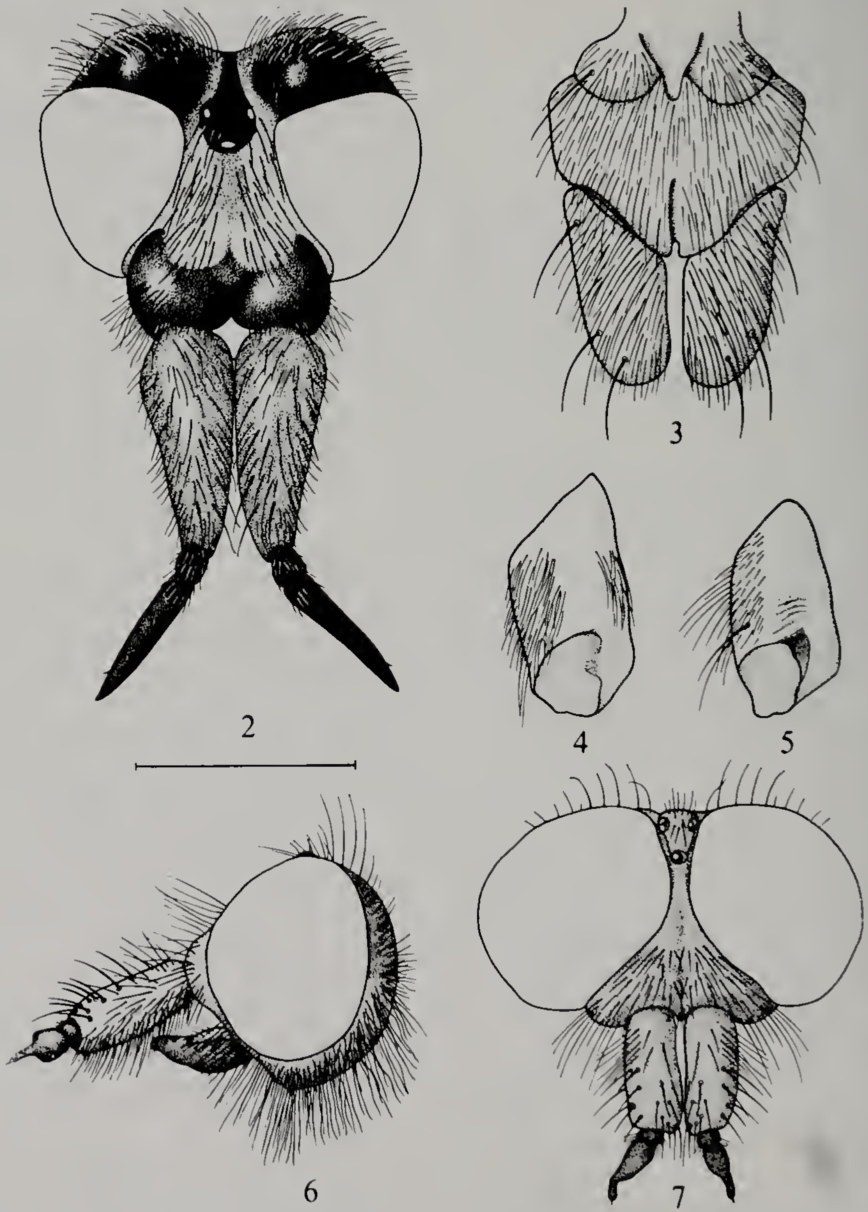

Fig. 2–7. 2. — *Nebritus pellucidus* Coq. male head in dorsal view. 3. — *Megalinga insignata* Irw. & Lyn. fore coxae, prosternum, and cervical lobes. 4. — *Pallicephala variegata* (Lw.) middle coxa. 5. — *Ozodiceromya mexicana* Big. middle coxa. 6. — *Tabuda varia* (Wlk.) head in lateral view. 7. — Dorsofrontal view. Scale: 1 mm.

to a sclerotized bar that contains a membranous central sheath through which pass ducts of spermathecae and accessory glands. Three unsclerotized spermathecae and 2 accessory glands present. Tergite 8 generally unmodified. Tergite 9 usually

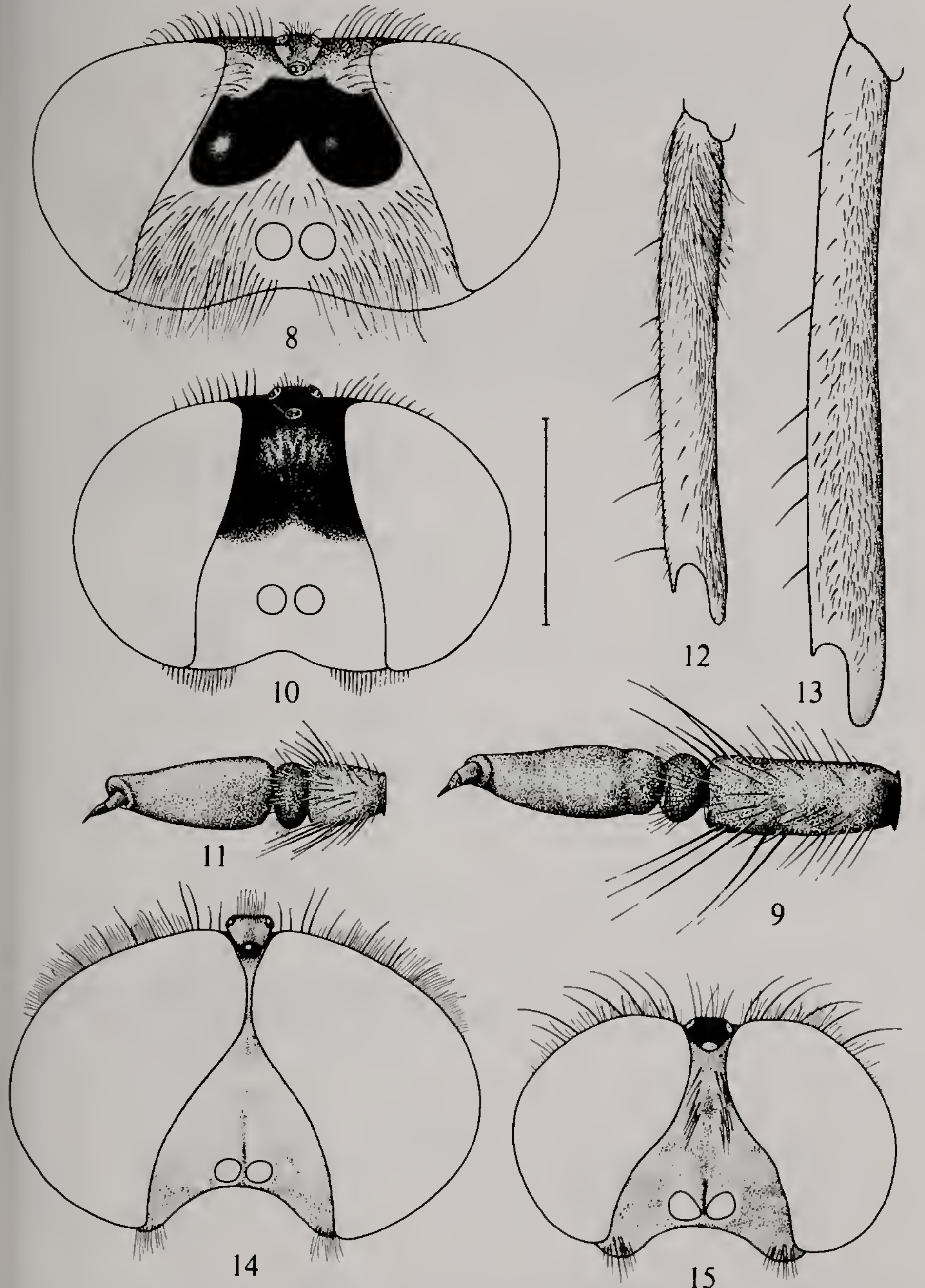

Fig. 8–15. 8.—*Thereva plebeja* (L.) female head in frontal view. 9.—Antenna. 10.—*Psilocephala munda* Lw. female head in frontal view. 11.—Antenna. 12.—*Pandivirilia limata* (Coq.) hind femur in entral view. 13.—*Viriliricta montivaga* (Coq.) hind femora in ventral view. 14.—*Pandivirilia limata* Coq.) male head in frontal view. 15.—*Dichaglena amplifrans* (Cole) male head in frontal view. Scale: .5 mm for 9 and 11, 1 mm for others.

a single sclerite, generally with extended lateral margins fused to posterolateral margins of furca. Tergite 10 always divided though often fused with tergite 9; digging-anchoring spines often present posterodorsally and anterolaterally although reduced in Phycinae. Sternites 10 and 11 (hypoproct or subanal plate) generally a single plate, usually heavily sclerotized though more thinly so in some genera of Phycinae. Cerci disc shaped, attached to tergite 10 in most groups, but fused into a single sclerite in *Pherocera, Parapherocera,* and *Schlingeria.*

Male Terminalia (Fig. 107–114). — Fairly uniform in plan. Sclerites forming sternite 8 and tergite 8 unmodified to narrowly constricted medially. Tergite

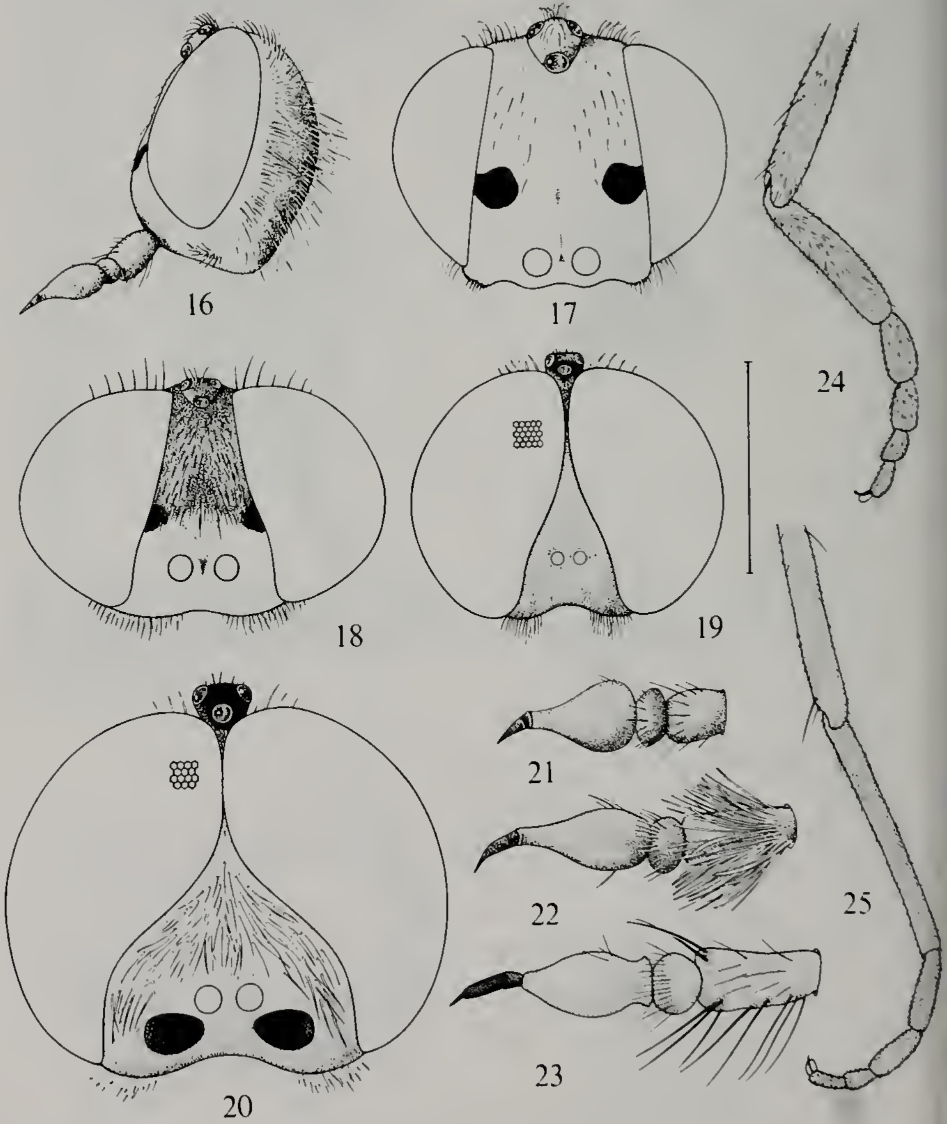

Fig. 16–25. 16. — *Litolinga acuta* (Adams) female head in lateral view. 17. — Frontal view. 18. — *Brachylinga baccata* (Coq.) female head in frontal view. 19. — *Arenigena semitaria* (Coq.) male head in frontal view. 20. — *Ammonaios niveus* (Kröb.) male head in frontal view. 21. — *Arenigena semitaria* (Coq.) antenna. 22. — *Ammonaios niveus* (Kröb.) antenna. 23. — *Rhagioforma maculipennis* (Kröb.) antenna. 24. — *Cyclotelus rufiventris* (Lw.) female fore tarsus. 25. — *Penniverpa festina* (Coq.) female fore tarsus. Scale: 0.5 mm for 21–23, 1 mm for others.

9, the epandrium, acting as a large covering for terminalia, variously haired, often with posterolateral lobes of various sizes and shapes; bears ventral epandrial sclerite and cerci apically. Sternite 9, the hypandrium, large in some genera, nar-

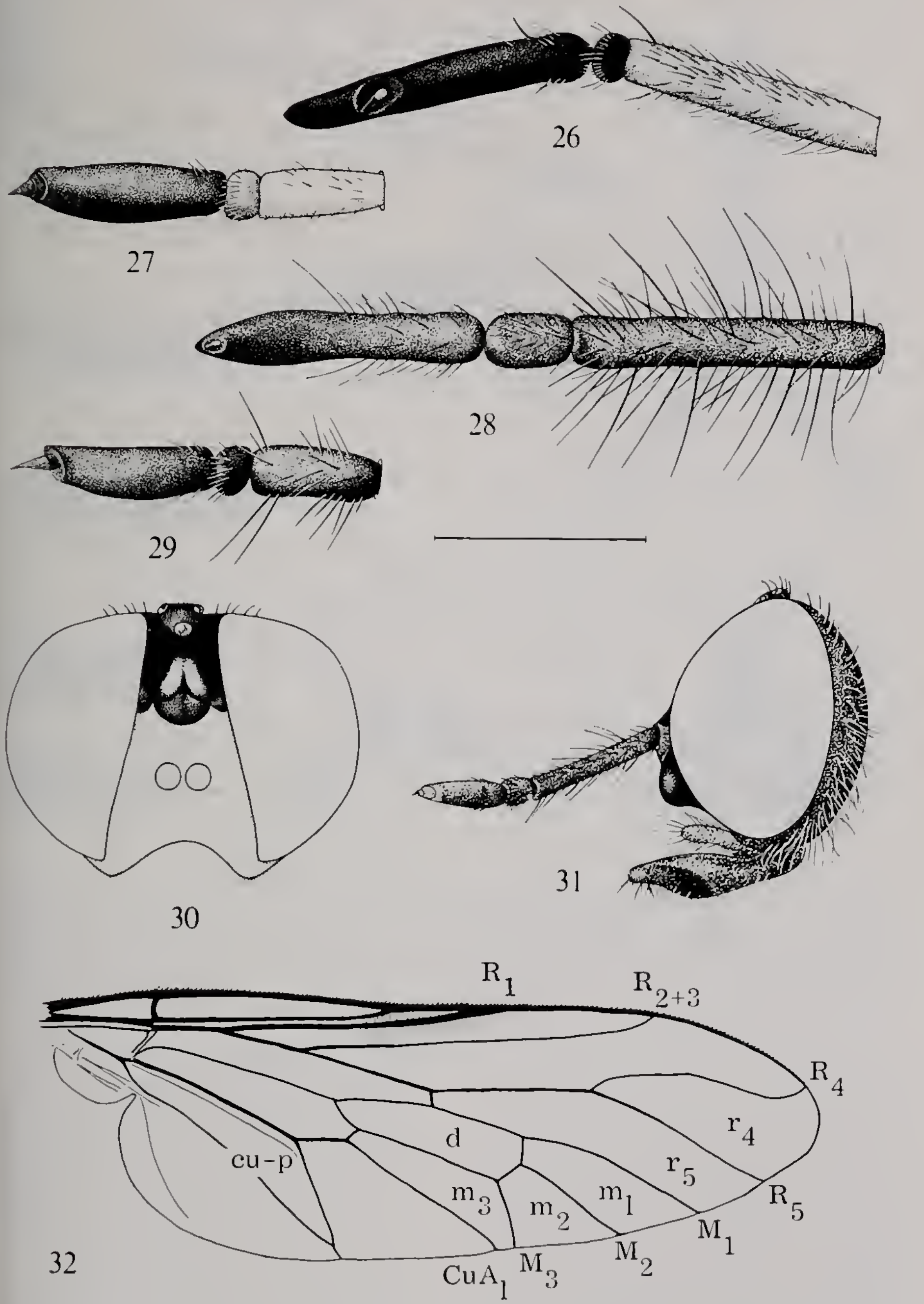

Fig. 26–32. 26. — *Cyclotelus pruinosus* Wlk. antenna. 27. — *Cyclotelus rufiventris* (Lw.) antenna. 28. — *Ozodiceromya mexicana* Big. antenna. 29. — *Ozodiceromya signatipennis* (Cole) antenna. 30. — *Cyclotelus rufiventris* (Lw.) female head in frontal view. 31. — *Chromolepida bella* Cole male head in lateral view. 32. — *Pandivirilia limata* (Coq.) wing. Scale: 1.3 mm for 26, 0.5 mm for 27–29, 1 mm for 30, and 0.7 mm for 31.

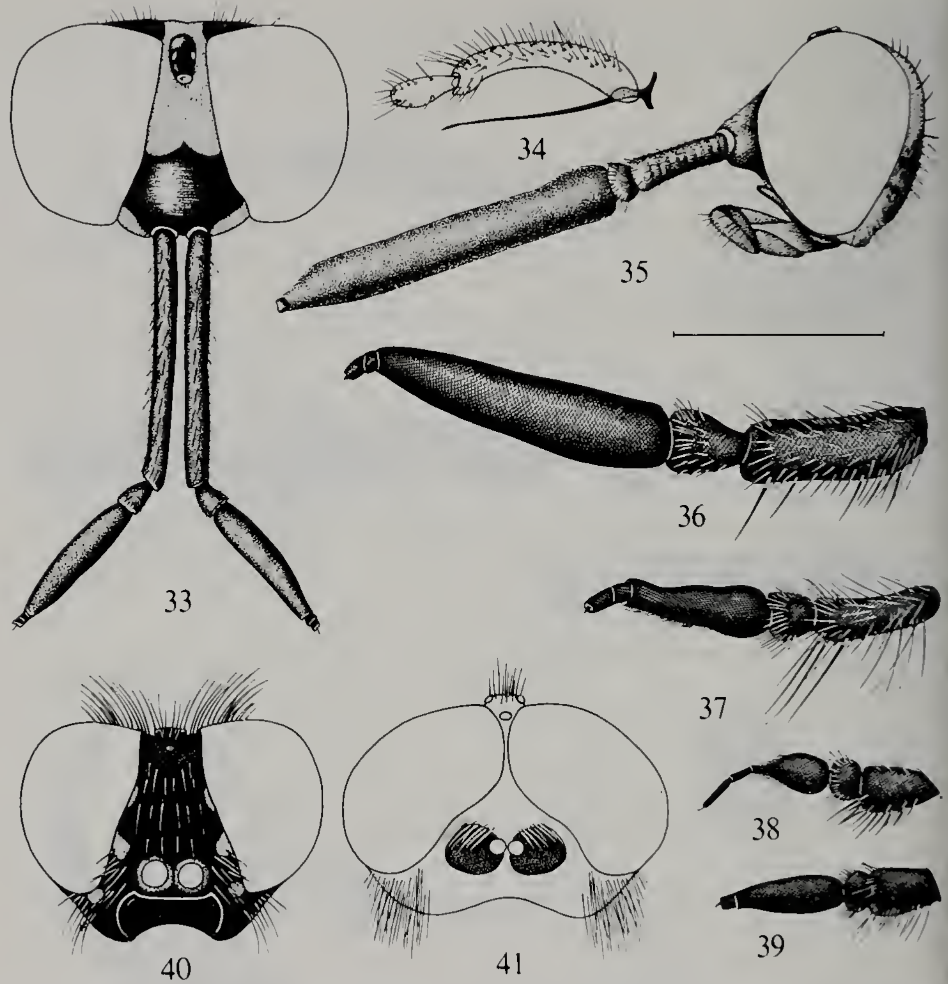

Fig. 33–41. 33. — *Phycus brunneus* (Wlk.) male head in anterodorsal view. 34. — *Phycus brunneus* (Wlk.) palp. 35. — *Henicomyia hubbardii* Coq. male head in lateral view. 36. — Antenna of an unnamed species of *Phycus* from southern California. 37. — *Parapherocera montana* Irw. antenna. 38. — *Pherocera* sp. antenna. 39. — *Schlingeria ammobata* Irw. antenna. 40. — *Parapheracera montana* Iwr. male head in frontal view. 41. — *Pherocera* sp. male head in frontal view. Scale: 0.5 mm for 34 and 36–39; 1 mm for 33, 35, 40, and 41.

row to absent in others, variously free from or fused to gonocoxites. Gonocoxites fused or free ventrally. Each gonocoxite often extends posteriorly as a broad to narrow lobe well beyond insertion of gonostylus, usually with one or more additional appendages. These appendages include ventromedially a ventral lobe that appears to function as an aedeagal guide and dorsally a paramere (= dorsal gonocoxal process). Paramere composed of (1) a rod-shaped apodeme most anteriorly on gonocoxite and in some groups with a connecting sclerotized bridge to aedeagus, (2) a midsection closely fused with dorsal edge of gonocoxite, and (3) a free distal portion, the parameral process, usually shaped as a style bearing setae apically, but entirely absent in many genera. Gonostylus variously shaped, moving in a dorsoventral or oblique direction and not opposed, seemingly lying within genital cavity of female during copulation. Aedeagus consists of a short to long variously twisted distiphallus, an elongate or vestigial dorsal apodeme, a simple or forked ventral apodeme sometimes having 2 extensions toward tip of distiphallus, and a variously shaped ejaculatory apodeme. Aedeagus attached at one or more of three sites, (1) by anterior edge of intersegmental membrane below epandrium (usually as a basal extension of ventral epandrial sclerite) to distal margin of dorsal apodome, (2) by parameral apodeme to dorsolateral portion of aedeagus, or (3) by ventral lobe to midventral section of aedeagus.

KEY TO THE GENERA OF NEARCTIC THEREVIDAE

1. Middle coxa with pile on posterior surface (Fig. 4).................. 2
Middle coxa without pile on posterior surface or with only a few appressed scalelike hairs (Fig. 5)............. 20

2. Prosternum with pile in and around central depression (Fig. 3).......... 3
Prosternum without pile in and around central depression 15

3. Lower frons in both sexes entirely shiny; head strongly protruding anteriorly; compound eyes of male separated by more than width of ocellar tubercle (Fig. 2)........................... **Nebritus Coquillett** (p. 249)
Lower frons at least partially tomentose; head not strongly protruding anteriorly; compound eyes separated at most by width of ocellar tubercle 4

4. Lateral portion of face, at least upper part, without pile................. 5
Lateral portion of face, at least upper part, with pile.................... 13

5. Paired cervical lobes anterior to prosternum, each with a strong black seta in addition to whitish pile (Fig. 3). Veins R_{2+3} and R_4 have a deep curve before wing margin. Distiphallus deeply cleft at apex (Fig. 164)....**Megalinga Irwin & Lyneborg** (p. 242)
Paired cervical lobes anterior to prosternum without a strong black seta, with only whitish pile present. Vein R_{2+3} usually has a gentle curve before wing margin. Distiphallus not cleft 6

6. Macrosetae of mesonotum all pale. Parameral process present, enlarged, and modified distally (Fig. 149 and 156). Cell m_3 closed................ ...**Arenigena Irwin & Lyneborg** (p. 238)
Macrosetae of mesonotum usually all black; if macrosetae pale (some *Lysilinga*), then cell m_3 open. Parameral process absent or present and simple. Cell m_3 only rarely closed.......... 7

7. Scape in lateral view distinctly wider than first flagellomere (Fig. 54 and 55); pile of scape long and dense.... 8
Scape in lateral view narrower than or as wide as first flagellomere (Fig. 21–23); pile of scape short and sparse 9

8. Male frons has pile. Lower part of female frons has pile. Fore and middle femora without setae. Epandrium (Fig. 42 and 43) has posterolateral corners only slightly projecting and not extending to distal margin of cerci and ventral epandrial sclerite; the latter often greatly enlarged. Hypandrium absent (Fig. 44).............................. **Dialineura Rondani** (p. 204)
Male frons without pile. Lower part of female frons without pile. Fore and/or middle femora usually have some short setae. Epandrium (Fig. 48 and 49) has posterolateral corners strongly projecting, extending to or beyond distal margin of cerci and ventral epandrial sclerite. Hypandrium (Fig. 50) present as a small narrow transverse sclerite between anteroventral margins of gonocoxites.. **Pallicephala Irwin & Lyneborg** (p. 206)

9. One pair of scutellar setae and genal area (Fig. 16) have darkened wedge or stripe; ocellar tubercle very prominent, especially in male............ ...**Litolinga Irwin & Lyneborg** (p. 234)
Two pairs of scutellar setae or genal area not darker than lower portion of occiput, uniform in color and texture; ocellar tubercle normal............ 10

10. Palps constricted a short distance before apex. Wing strongly maculated. Male frons prominent, with long, dense, black pile. Female abdomen yellowish brown with median row of dark spots .... **Rhagioforma Irwin & Lyneborg** (p. 236)
Palps not constricted apically. Wing not strongly maculated. Male frons with or without long, dense pile. Female abdomen variously colored, usually brownish to grayish, without median row of dark spots.......... 11

11. Pile of fore femur pale and erect, composed of long, uniform, thin hairs. Parameral process large, free; gonostylus simple, slender (Fig. 66 and 67) ....**Pandivirilia Irwin & Lyneborg**, in part (p. 212)

Pile of fore femur composed of appressed whitish, scaly hairs and slender, erect hairs that are whitish or blackish. Paramere without a distal portion; gonostylus hook-shaped, bearing groups of setae (Fig. 122, 129, and 130) 12

12\. Dorsocentral setae absent. Abdomen orange to reddish brown in both sexes. Aedeagus (Fig. 122) about half as long as gonocoxite; distal section of distiphallus subapical, projecting downward (Fig. 125) ....
...**Lysilinga** Irwin & Lyneborg (p. 230)

One or two pairs of dorsocentral setae present. Abdomen gray or black. Aedeagus (Fig. 129) usually more than half as long as gonocoxite; distal section of distiphallus apical (Fig. 133) ....
Brachylinga Irwin & Lyneborg (p. 232)

13\. Frons (Fig. 20) in both sexes has dense, appressed pile of whitish, scaly hairs. Macrosetae of mesonotum pale. A circular blackish area usually present in and around each anterior tentorial pit ....
Ammonaios Irwin & Lyneborg (p. 240)

Frons in both sexes has pile of erect, normal hairs. Macrosetae of mesonotum black. Area in and around anterior tentorial pits not differently colored from rest of face.......... 14

14\. Male has epandrium as long as or longer in midline than wide (Fig. 103); aedeagus has ventral projections adjoining distiphallus (Fig. 104). Male abdomen covered entirely by whitish pile. Female frons has pattern formed by dull pale or dark colored tomentum, without subshiny to shiny calli ....
...**Acrosathe** Irwin & Lyneborg (p. 223)

Male epandrium much shorter in midline than wide (Fig. 81); aedeagus without ventral projections adjoining distiphallus (Fig. 83). Male abdomen covered entirely by whitish pile only in a few species. Female frons (Fig. 8) in most species has callus or calli that are large, shiny, black or at least subshiny medially ....
.............**Thereva** Latreille (p. 216)

15\. Scape (Fig. 6) distinctly longer and wider than first flagellomere. Head protruding anteriorly 16

Scape not longer or wider than first flagellomere. Head not strongly protruding anteriorly 17

16\. Male has compound eyes (Fig. 7) separated by at least width of anterior ocellus. Two supra-alar setae and 1 dorsocentral seta present. Cell m_3 broadly open. Parameral process knoblike (Fig. 96)...**Tabuda** Walker (p. 221)

Male has compound eyes separated by less than width of anterior ocellus. One supra-alar seta present; dorsocentral setae absent. Cell m_3 closed or narrowly open. Parameral process extends beyond level of gonocoxite (Fig. 88)
Tabudamima Irwin & Lyneborg (p. 219)

17\. Mesonotal pile of male short, sparse, and appressed; hairs shorter than width of scape. Hind femur (Fig. 13) has sparse, appressed pile and many short, scattered, black setae on entire ventral surface in addition to normal row of strong, anteroventral setae....
..**Viriliricta** Irwin & Lyneborg (p. 208)

Mesonotal pile of male long, abundant, erect; hairs distinctly longer than width of scape. Hind femur (Fig 12) has denser, usually erect pile and at most a few short, black, posteroventral setae apically in addition to usual row of strong anteroventral setae........ 18

18\. Male compound eyes (Fig. 15) separated by at least width of anterior ocellus. Female has black or blackish brown tibiae. Female has tergite 4 entirely shiny black..................
Dichoglena Irwin & Lyneborg (p. 210)

Male compound eyes (Fig. 14) separated by less than half width of anterior ocellus. Female has yellowish brown tibiae. Female has tergite 4 at least partly tomentose 19

19\. Lower frons of both sexes has whitish pile; upper, lateral portion of face with long, whitish pile. Hypandrium (Fig. 73) present; distiphallus long, its tip twisted (Fig. 75)..............
..**Spiriverpa** Irwin & Lyneborg (p. 214)

Lower frons of both sexes either without pile or with blackish pile; upper, lateral portion of face in most species without pile, but if pile present, then black. Hypandrium (Fig. 66) absent; distiphallus short, its tip not twisted (Fig. 68) ....
........**Pandivirilia** Irwin & Lyneborg, in part (p. 212)

20\. Prosternum has pile in and around central depression (Fig. 3)......... 21

Prosternum without pile in and around central depression.......... 24

21\. A pair of shiny, black, raised calli on upper face below antennal bases (Fig. 31). Thorax and abdomen clothed with totally appressed, broad scales in addition to normal pile....
...........**Chromolepida** Cole (p. 258)

Face without shiny calli. Pile of thorax and abdomen composed of semi-appressed, scaly hairs and erect, normal hairs 22

22. Cell m_3 broadly open. Male frons entirely tomentose and without pile; female frons entirely tomentose. Fore tibia has at most 2 or 3 very short posteroventral setae; fore tibia and first tarsomere very slender (Fig. 25) ..**Penniverpa** Irwin & Lyneborg (p. 227)

Cell m_3 closed or narrowly open (in some *Breviperna*). Male frons usually partly shining and with pile; female frons variously shining (not in *Breviperna*). Fore tibia has several stout posteroventral setae; fore tibia and first tarsomere stout (Fig. 24) 23

23. Entire frons in both sexes covered with tomentum, without shiny areas. Male dichoptic. Large, broadly built species with short broad antennae.......... ....**Breviperna** Irwin (p. 247)

Frons in both sexes at least partly shiny. Small and slenderly built species, with slender antennae (Fig. 28 and 29)...**Ozodiceromya** Bigot (p. 254)

24. Hind femur has appressed, scaly hairs, usually also some anteroventral setae. Tergite 10 of female heavily spinose; distal spines stout, short, projecting dorsally and laterally; basal spines slim, long, projecting ventrally...... 25

Hind femur has erect, normal hairs, without anteroventral setae. Tergite 10 of female slenderly spinose; spines of only one kind. PHYCINAE......... 26

25. First tarsomere of foreleg swollen (Fig. 24). Scutellum short, with pile on margin only; katepisternum without pile. Male terminalia partly telescoped and concealed within abdomen, usually yellowish. Parameral process absent (Fig. 182)................. ....**Cyclotelus** Walker (p. 251)

First tarsomere of foreleg not swollen. Scutellum long, with long pile on disc; katepisternum has long, pale pile. Male terminalia prominently projecting, polished black; parameral process large, prominently extends beyond gonocoxite (Fig. 107)............. ....**Psilocephala** Zetterstedt (p. 225)

26. Scutellar setae absent.............. 27

One pair scutellar setae present..... 28

27. One or two notopleural setae present; mesopleuron without pile. First flagellomere much longer than scape (Fig. 35). Middle and hind tarsi have very short setae. Genital opening of female directed dorsally.................. ....**Heniconyia** Coquillett (p. 262)

Three notopleural setae; mesopleuron has long pile. First flagellomere only slightly longer than scape (Fig. 39). Middle and hind tarsi have very long, thin setae. Genital opening of female posteriorly directed ....**Schlingeria** Irwin (p. 268)

28. Palps distinctly two segmented, with apical segment shorter (Fig. 34). Hind femur has very short, uniform hairs. Cerci of male project posteriorly beyond ventral epandrial sclerite (Fig. 204). Antenna distinctly longer than depth of head (Fig. 33)............ ....**Phycus** Walker (p. 260)

Palps one segmented. Hind femur has elongate hairs. Cerci and ventral epandrial sclerite of male project the same distance posteriorly. Antenna shorter than or about as long as depth of head 29

29. Antenna at least as long as depth of head; shining, raised callus present between antennal base and subcranial cavity (Fig. 40); male dichoptic.... ....**Parapherocera** Irwin (p. 264)

Antenna shorter than depth of head; no raised callus between antennal base and subcranial cavity; male holoptic (Fig. 41) (except for a single undescribed species from Mexico)....... ....**Pherocera** Cole (p. 266)

Subfamily Therevinae

These attributes characterize the North American members of the subfamily Therevinae.

1. Usually without a strong sclerotized bridge between dorsal apodeme of aedeagus and paramere; if such a bridge is present (*Cyclotelus,* some *Ozodiceromya*), hypandrium undetectable.
2. Ventral apodeme of aedeagus not forked and not vestigial, projects anteriorly as a simple sclerite.
3. Tergite 10 of female has a group of thickened spines (acanthophorites) set in posterodorsal and posterolateral positions and a second group of thinner, often longer spines set lateroventrally on tergite 9; tergite 9 fused with tergite 10.
4. Intersegmental membrane between sternite 8 and sternite 9 (furca) of female sclerotized.
5. Pregenital abdominal segments have spiracles in the pleural membrane.
6. Vein R_1 not setose.

Genus Dialineura Rondani

(Fig. 42–47)

Dialineura Rondani 1856:155. Type-species: *Musca anilis* Linnaeus 1761:442 by original designation. Type-locality: Sweden.

Reference: Lyneborg 1968*b*.

Diagnosis

Small- to medium-sized, moderately slender species.

Head. — Frons of male at its narrowest narrower than half width of anterior ocellus; frons of female at level of anterior ocellus 2.0–2.5× as wide as ocellar tubercle; male frons entirely tomentose with long pile over most of its surface; female frons entirely and uniformly tomentose, sometimes with a dull, dark, transverse band over middle, with tomentum of lower frons sometimes paler than that of upper frons; female frons has short, rather sparse pile over most of its surface; head markedly protruding anteriorly, antennae thus set on a distinct protuberance; a dark, dull band at antennal level apparent in certain views,

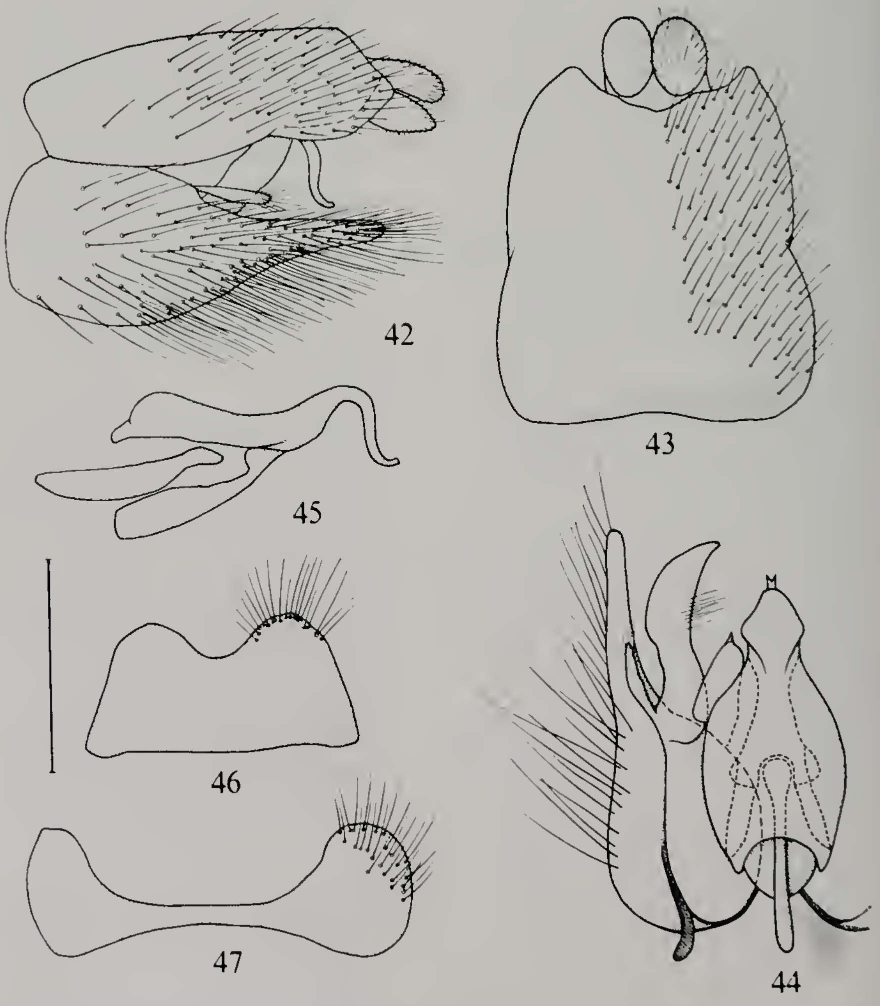

Fig. 42–47. — *Dialineura anilis* (L.) male terminalia. 42. — Genitalia in lateral view. 43. — Epandrium with appendages in dorsal view. 44. — Right gonocoxite with appendages and aedeagus in dorsal view. 45. — Aedeagus in lateral view. 46. — Sternite 8. 47. — Tergite 8. Scale: 0.5 mm.

but facial and genal calli absent; lateral portion of face usually bare, only pilose in *affinis* Lyneborg (1968*b*:157 ♂) from China; gena has long, pale pile; depth of head 1.1–1.3× length of antennae; scape 1.0–1.3× as long as flagellum, thickened; flagellar style apical and two segmented, with a small terminal spine; palps one segmented.

Thorax. — np 2–4 (usually 3), sa 2, pa 1, dc 1–3; sc 2; mesonotal pile in male long, uniform, erect, pale, with a few black hairs intermixed; mesonotal pile in female of two types: in the first, moderately long, sparse, erect, black and in the other short, rather dense, semi-appressed, pale; prosternum has long, pale pile in and around central depression. Wing. — Cell m_3 open; veins R_4 and R_5 of equal length; cell r_4 2.1–2.4× as long as wide at apex; color hyaline with faint grayish or brownish tinge; stigma pale brownish to dark brownish. Legs. — Fore coxa has 2–4 apical setae on anterior surface; middle coxa has long pile on posterior surface; hind femur has 6–10 anteroventral setae.

Abdomen. — Slender to moderately broad, gradually tapering from segment 3 onward; abdomen not telescoped; dorsum somewhat flattened in female, more convex in male; male dorsum covered entirely by silvery gray tomentum and whitish pile; female dorsum extensively tomentose, some species having distinct, dark, shining, anterior bands.

Male Terminalia (Fig. 42–47). — Tergite 8 (Fig. 47) rather large and markedly constricted medially; sternite 8 (Fig. 46) comparatively large, bilobed (i.e., has a deep V- or U-shaped incision in posterior margin); epandrium (Fig. 43) longer medially than wide, in most species more markedly narrowing posteriorly than in the type-species and has a distinct, lateral incision (Lyneborg 1968*a*); cerci free (Fig. 43), well sclerotized, never extending beyond ventral epandrial sclerite; ventral epandrial sclerite varies greatly in size, in the type-species (Fig. 43) not extending beyond cerci, but in other species from moderately (e.g., in *gorodkovi*) to noticeably extending beyond cerci, being longer than half length of epandrium; ventral epandrial membrane weak, reaching to near anterior margin of epandrium, but not attached to anterior margin of aedeagus; parameral apodeme not attached to aedeagus; distiphallus (Fig. 44) in dorsal view comparatively long and wide, sometimes provided with small spines; in lateral view, distiphallus (Fig. 45) suddenly downcurved with extreme apex upcurved; dorsal apodeme 2–4× as wide as distiphallus base, often with 2 tooth-shaped outshoots dorsally, its distal margin has a semicircular incision; ventral apodeme large, usually extending beyond dorsal apodeme and narrowly spoon shaped; ejaculatory apodeme simple, slightly thickened both proximally and distally; ventral lobes of gonocoxite long, slender, lamellate, directed obliquely upward and loosely attached to midventral surface of aedeagus; parameral process short, narrow, reaching far short of posterior apex of gonocoxite and rarely visible in lateral view (Fig. 42); parameral apodeme short and narrow; some species show an additional small, finger-like process on inner side of gonocoxite slightly distad of parameral process insertion (Lyneborg 1975: Fig. 2); gonocoxites not united ventrally except by a weak membrane; gonocoxite (Fig. 42) in lateral view characteristically projects and gradually narrows posteriorly; hypandrium totally absent.

Habitat

The habitat of the North American species is totally unknown.

Distribution

The one species recorded from the Nearctic Region has been found only in Manitoba, Canada. Several described species occur throughout the Palearctic Region.

Included Species

gorodkovi Zaitzev 1971:191 ♂, ♀. Distribution.—Fort Churchill, Manitoba, Canada; also Siberia in Asia.

No undescribed specimens are known to us.

Genus **Pallicephala** Irwin & Lyneborg, new genus (Fig. 4 and 48–55)

Feminine

Derivation of name: *palla* (Greek) = ball; *kephale* (Greek) = head.

Type-species: *Psilocephala variegata*

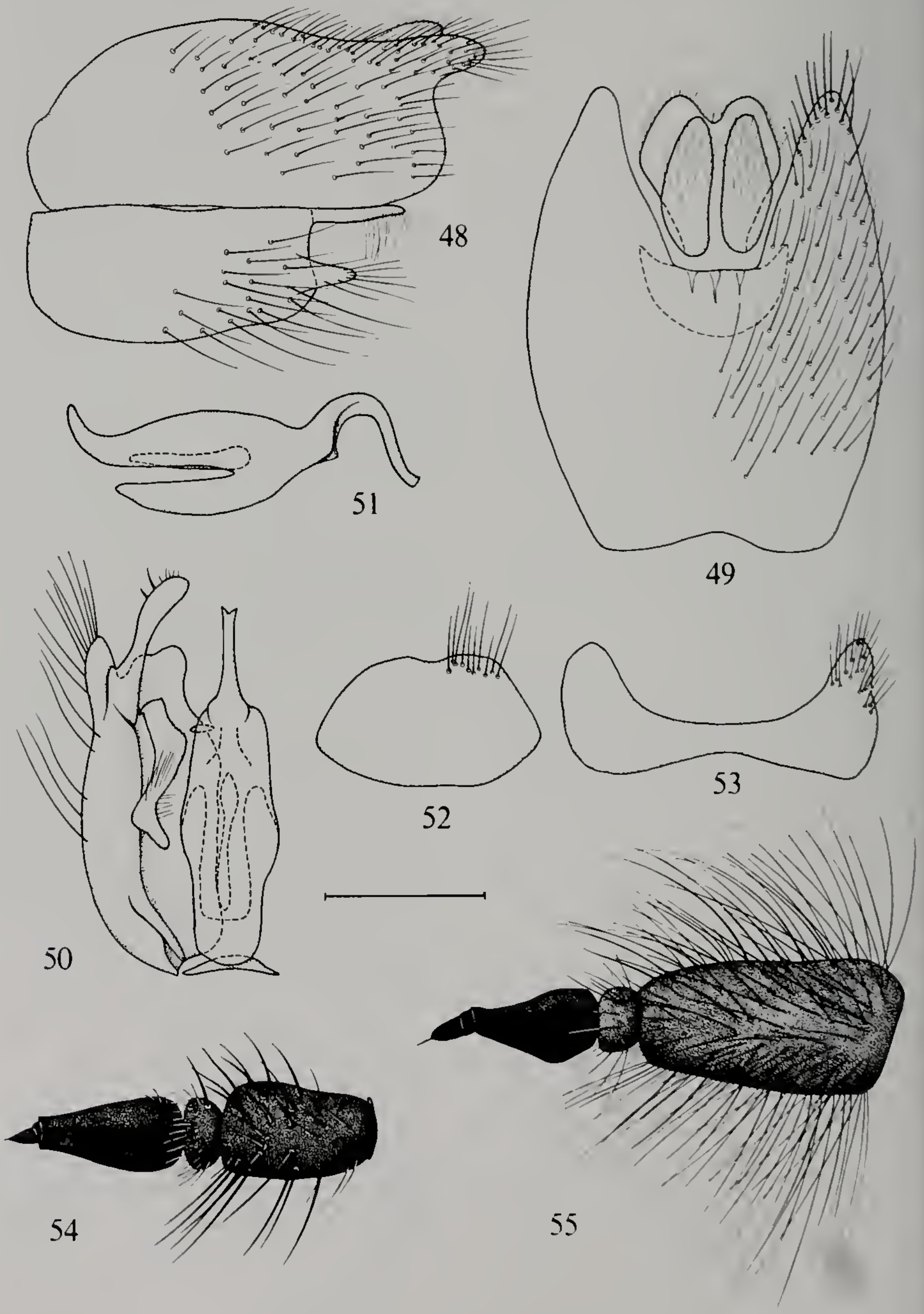

Fig. 48–55. — *Pallicephala* spp. 48–53. — *P. willistoni* (Cole) male terminalia. 48. — Genitalia in lateral view. 49. — Epandrium with appendages in dorsal view. 50. — Right gonocoxite with appendages and aedeagus in dorsal view. 51. — Aedeagus in lateral view. 52. — Sternite 8. 53. — Tergite 8. 54. — Antenna of *P. variegata* (Lw.). 55. — Antenna of *P. willistoni* (Cole). Scale: 0.5 mm.

Loew 1869*b*:170 by present designation. Type-locality: "Canada" (probably eastern Canada).

Diagnosis

Moderate to large-sized, slender to heavy-bodied species.

Head. — Frons of male at its narrowest narrower than half width of anterior ocellus; frons of female at level of anterior ocellus 2.2–2.5× as wide as ocellar tubercle; male frons entirely tomentose, uniformly colored, and without pile; female frons entirely tomentose, either uniformly colored or upper part darker than lower part, or has a pair of dark, velvety spots; pile of female frons restricted to upper two-thirds and in most species short and sparse; head rather prominently protrudes anteriorly; a dull, darkened band crosses frons at antennal level, but facial and genal calli absent; lateral portion of face without pile; genae have long pile; head 1.1–1.5× deeper than antennal length (Fig. 54 and 55); scape 0.8–1.2× as long as flagellum, thickened in most species; flagellar style apical, stout, two segmented, with a small, terminal spine; palps one segmented.

Thorax. — np 3–5, sa 1–2, pa 1, dc 1–4, sc 1–2; mesonotal pile in most species short, pale, and semi-erect to appressed, but short, black, erect pile also occurs, and *willistoni* has long pile composed of black and white hairs; prosternum has long, pale pile in and around central depression. Wing. — Cell m_3 open (except in *variegata*); vein R_4 distinctly longer than vein R_5; cell r_4 1.9–2.5× as long as wide at apex; color hyaline with faint grayish-brown tinge, sometimes maculated; most species have a distinct, brown stigma. Legs. — Fore coxa has 2–3 pale or black, ventrally directed setae close to apical margin; these setae are slender in most species, but stout in *willistoni;* middle coxa has pile on posterior surface (Fig. 4); hind femur with 2–10 anteroventral setae.

Abdomen. — Moderately broad to broad, gradually tapering from base to apex; abdomen not telescoped; dorsum of male convex, of female more flattened; dorsum of male entirely tomentose or has blackish anterior bands on anterior tergites; dorsum of female has blackish anterior bands, with posterior parts of tergites tomentose.

Male Terminalia (Fig. 48–53). — Tergite 8 (Fig. 53) small and only moderately constricted medially; sternite 8 (Fig. 52) small, often without a distinct incision; epandrium (Fig. 49) shorter or slightly longer in midline than wide, posterolateral corners greatly project and broadly rounded, extending beyond cerci and ventral epandrial sclerite; cerci free (Fig. 49), well sclerotized, not extended beyond ventral epandrial sclerite; ventral epandrial sclerite sclerotized only as a bilobed area below cerci; membrane below epandrium reduced to 2 narrowly triangular sections posteriorly; parameral apodeme not attached to aedeagus; distiphallus (Fig. 50) in dorsal view short compared with dorsal apodeme, seen laterally (Fig. 51) suddenly downcurved; ventral apodeme forms a short spoon; ejaculatory apodeme short and simple; ventral lobes of gonocoxites directed upward, lamellate, narrowing distally, and have an attachment to ventral surface of aedeagus; parameral process large, extending beyond posterior margin of gonocoxite; gonocoxites not fused ventrally, but attached for a long distance by a membrane; gonocoxite in lateral view (Fig. 48) shows a process posteroventrally; hypandrium well developed, free (Fig. 50).

Habitat

Nothing is known of the habitats that species of this genus occupy except for *willistoni,* often found in oak grasslands along dry or nearly dry stream beds.

Distribution

Species in the genus *Pallicephala* are largely found in western North America; one species is found in the Great Lakes region of North America.

Included Species

flavipilosa (Cole) 1923*a*:62 ♂, ♀ (*Psilocephala* as a subspecies of *var-*

iegata Loew), new combination. Distribution. — Central California.

fuscipennis (Cole) 1923*a*:62 ♀ (*Psilocephala*), new combination. Distribution. — Washington.

occidentalis (Cole) 1923*a*:61 ♂ (*Psilocephala* as a subspecies of *variegata* Loew), new combination. Distribution. — Oregon.

variegata (Loew) 1869*b*:170 ♂ (*Psilocephala*), new combination. Distribution. — Great Lakes region of North America.

willistoni (Cole) 1965:352 (*Dialineura*), new combination. Distribution. — Pacific northwest southward to San Francisco Bay and Santa Cruz County, California.

crassicornis Williston 1886:293 ♂, ♀ (*Thereva*), not Bellardi 1861:88.

No undescribed species of this genus are at hand.

Genus **Viriliricta** Irwin & Lyneborg, new genus (Fig. 13 and 56–60)

Feminine

Derivation of name: *virilia* (Latin) = male genitals; *rictus* (Latin) = open, gaped.

Type-species: *Psilocephala montivaga* Coquillett 1893*b*:226 by present designation. Type-locality: Los Angeles County, California.

Diagnosis

Large though rather slender flies.

Head. — Frons of male at its narrowest at least as wide as width of anterior ocellus; frons of female narrow, at level of anterior ocellus 1.3–1.8× as wide as ocellar tubercle; male frons dull to subshiny, usually extensively darkened over most of its area, silver-gray to whitish tomentum usually restricted to lower, lateral parts; upper male frons has lateral rows of short, black, semi-appressed hairs (a few hairs may occur on lower frons); female frons extensively tomentose or subshiny black, tomentum dark, with richer, but shorter pile than that of male; head moderately to greatly protruding anteriorly; facial and genal calli absent; lateral portion of face without pile; gena has a few short hairs; head depth 1.2–1.4× antennal length; flagellum slender, 1.4–1.7× as long as scape; scape slender; flagellar style apical, two segmented, with a minute terminal spine; palps one segmented.

Thorax. — np 4–5, sa 2, pa 1, dc 1–2, sc 2; mesonotal pile of both sexes short, sparse and semi-appressed, not longer than width of scape; prosternum bare in and around central depression. Wing. — Cell m_3 open; vein R_4 distinctly longer than vein R_5; cell r_4 2.7–3.0× as long as wide at apex; color hyaline with grayish to brownish tinge; stigma distinct. Legs. — Fore coxa has 2–3 apical setae on anterior surface; middle coxa has sparse, short, whitish pile on posterior surface; hind femur (Fig. 13) has sparse, appressed pile, especially at base, 5–7 anteroventral setae, many additional, short, scattered, black setae on ventral surface; fore and middle femora usually have ventral setae in similar position.

Abdomen. — Male abdomen distinct; rather wide, short, tapering from base to apex (in *montivaga*); in other species longer, more slender, and nearly equally wide throughout; dorsum always distinctly convex; male dorsum may be entirely tomentose or may have a pattern of shiny black and tomentose areas; female dorsum shiny brownish to blackish with tomentose areas laterally on first few segments.

Male Terminalia (Fig. 56–60). — Tergite 8 (Fig. 60) comparatively large and strongly constricted medially; sternite 8 (Fig. 59) also rather large, more or less distinctly incised along posterior margin; epandrium (Fig. 58) about as long at midline as wide, with large, broadly rounded posterolateral corners; cerci free, well sclerotized, not projecting beyond ventral epandrial sclerite; ventral epandrial sclerite large, reaching or nearly reaching anterior margin of epandrium, without distinct attachment to anterior

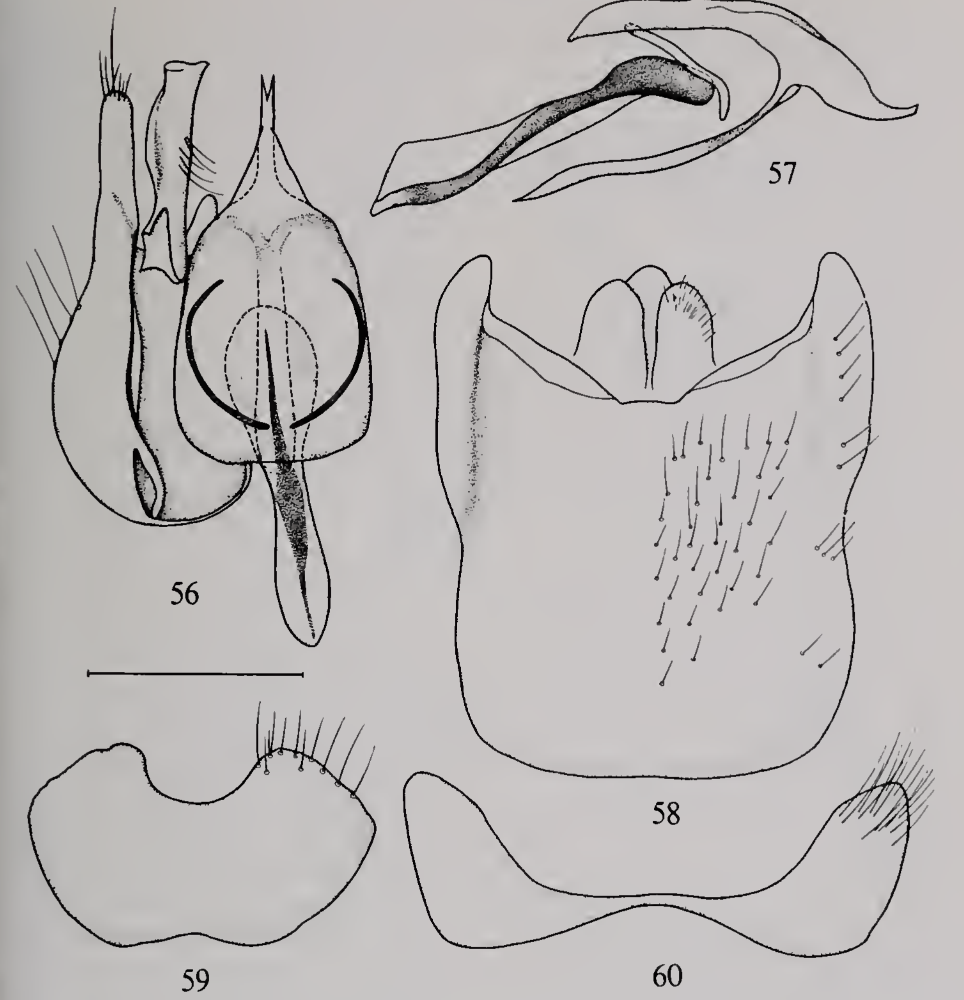

Fig. 56–60. — *Viriliricta montivaga* (Coq.) male terminalia. 56. — Right gonocoxite with appendages and aedeagus in dorsal view. 57. — Aedeagus in lateral view. 58. — Epandrium with appendages in dorsal view. 59. — Sternite 8. 60. — Tergite 8. Scale: 0.5 mm.

margin of aedeagus; ventral epandrial sclerite rather well sclerotized, especially posteriorly, where it is pointed and keel shaped, and diverges from cerci; parameral apodeme without attachment to aedeagus; distiphallus in dorsal view gradually tapering, in lateral view positioned in same plane as longitudinal axis of aedeagus (Fig. 57); dorsal apodeme large, rectangular; ventral apodeme long, slender; ejaculatory apodeme extends slightly anteriorly beyond dorsal apodeme; ventral lobes of gonocoxites moderately large, rounded and directed toward and loosely attached to ventral surface of aedeagus; ventral lobes not attached ventrally along midline; parameral process protrudes prominently beyond level of posterior margin of gonocoxite; parameral apodeme moderately long and slender; gonocoxites not united ventrally (Fig. 66) even by a membrane; gonocoxites in lateral view short and truncate posteriorly; hypandrium absent.

Habitat

Little is known about the habitat of these species. An adult of *V. montivaga* was captured while resting on a leaf of a bush near a stream. All species seem to inhabit mountainous areas.

Distribution

Two species exist in the mountains of eastern North America and a third in western North America.

Included Species

canadensis (Cole) 1923*a*:57 ♀ (*Psilocephala*), new combination. Distribution. — Ontario, Canada. This species may prove to be conspecific with *grandis* (Johnson).

grandis (Johnson) 1902:24 ♀ (*Psilocephala*), new combination. Distribution. — Quebec, Canada, and New York.

montivaga (Coquillett) 1893*b*:226 ♂, ♀ (*Psilocephala*), new combination. Distribution. — Mountains of California, Nevada, Arizona, and Utah.

One undescribed species from Tennessee is at hand.

Genus **Dichoglena** Irwin & Lyneborg, new genus (Fig. 15 and 61–65)

Feminine

Derivation of name: *dicha* (Greek) = in two parts; *glene* (Greek) = eyeball.

Type-species: *Psilocephala amplifrons* Cole 1925:85 by present designation. Type-locality: New York, West Danby. This species was erected as *latifrons* Cole 1923*a*:73 not *latifrons* Frey 1921:82 (*Aristothereva*).

Diagnosis

Medium- to large-sized flies from somewhat slender to slightly broad.

HEAD. — Frons of male (Fig. 15) at its narrowest distinctly wider than, and up to twice as wide as, width of anterior ocellus; frons of female narrow, at level of anterior ocellus only 1.4–1.5× as wide as ocellar tubercle; male frons in frontal view dull brownish to blackish, in dorsal view shows silver gray tomentum, with sparse but rather long, black pile laterally on upper and/or lower part; female frons subshiny to shiny black or brown nearly overall, or on upper half only; pile denser than in male; head only slightly protrudes anteriorly; facial and genal calli absent; lateral portion of face bare; gena has short, stiff pile which may extend to lower face; head depth 1.2–1.3× length of antennae; scape slender, 0.5–0.6× as long as flagellum; flagellar style apical, two segmented, with a minute terminal spine; palps one segmented.

THORAX. — np 3–4, sa 2, pa 1, dc 0–2, sc 2; mesonotal pile of male long, erect, uniform, whitish; hairs much longer than width of scape; mesonotal pile of female much shorter, semi-appressed, black; prosternum bare in and around central depression. WING. — Cell m_3 open; vein R_4 longer than vein R_5; cell r_4 2.1–2.5× as long as wide at apex; color hyaline with grayish brown tinge; stigma distinct. LEGS. — Fore coxa has 2 or 3 apical setae on anterior surface; middle coxa has whitish pile on posterior surface; hind femur has 4–5 anteroventral setae.

ABDOMEN. — Slender, only slightly tapering from base to apex, and not telescoped; dorsum convex to rather flattened; male dorsum entirely covered by silver gray tomentum and by whitish pile: female dorsum extensively shiny to subshiny blackish, with small areas of tomentum on posterolateral corners of tergites 2–3 and 5–6; tergite 4 entirely shiny (cf. *Viriliricta, Pandivirilia,* and *Spiriverpa*).

MALE TERMINALIA (Fig. 61–65). — Tergite 8 (Fig. 64) comparatively very large, wider than epandrium, moderately constricted in middle; sternite 8 (Fig. 65) also large, only indistinctly incised posteriorly; epandrium (Fig. 63) shorter in midline than wide; posterolateral corners of epandrium greatly projecting; cerci free, well sclerotized, do not project beyond ventral epandrial sclerite; ventral epandrial sclerite well sclerotized overall, short, tapering anteriorly, far short of reaching anterior margin of epandrium: parameral apodeme without attachment to aedeagus; distiphallus in dorsal view (Fig. 61) narrow and short compared

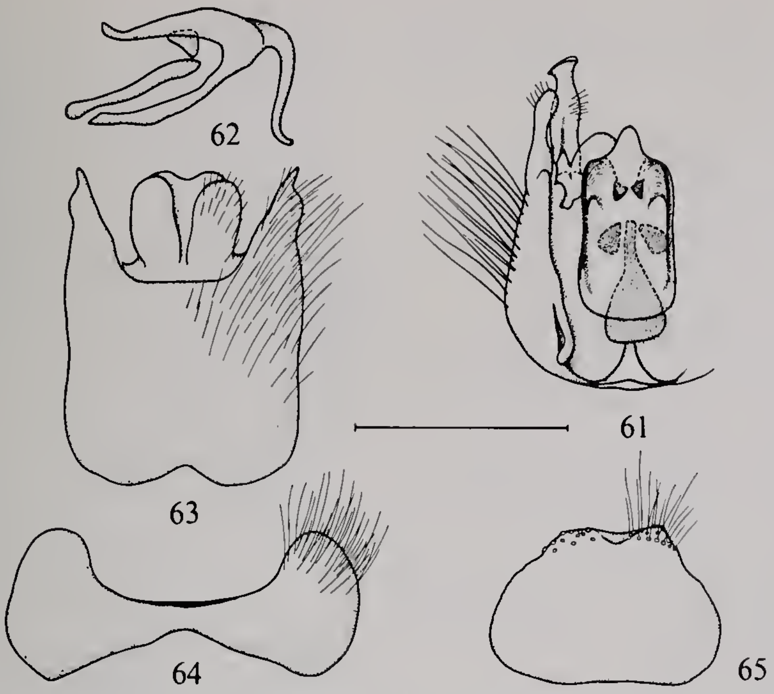

Fig. 61–65. — *Dichaglena amplifrons* (Cole) male terminalia. 61. — Right gonocoxite with appendages and aedeagus in dorsal view. 62. — Aedeagus in lateral view. 63. — Epandrium with appendages in dorsal view. 64. — Tergite 8. 65. — Sternite 8. Scale: 0.5 mm.

with rest of aedeagus, suddenly downcurved, terminating in a long, S-curved tube (Fig. 62); in caudal view straight; dorsal apodeme rectangular; ventral apodeme narrow and longer than dorsal apodeme; ejaculatory apodeme flat in lateral view, greatly enlarged distally in dorsal view; ventral lobes of gonocoxites large, rounded, directed obliquely upward and backward, with a strong attachment to ventral surface of aedeagus; parameral process slender, prominently protruding beyond posterior margin of gonocoxites; parameral apodeme rather long and narrow; gonocoxites (Fig. 67) not united ventrally, but touch for a long distance; gonocoxite in lateral view truncate with lower, posterior corner projecting; hypandrium present as a band-shaped sclerite firmly attached to gonocoxites (Fig. 61).

Habitat

Nothing is known of the habitat occupied by adults or larvae of species in this genus. All specimens examined were apparently collected in forested areas.

Distribution

Members of this genus are found in the western, central, northeastern, and eastern portions of the United States (California, Colorado, Vermont, Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, North Carolina, South Carolina, Florida, Illinois, and Kansas) and in eastern Canada (Ontario).

Included Species

amplifrons (Cole) 1925:85 ♂ (*Psilocephala*), new combination. Distribution. — Southeastern Canada and northeastern to eastern USA.
  latifrons (Cole) 1923*a*:73 ♂ (*Psilocephala*), not Frey 1921:82 (*Aristothereva*).
borealis (Cole) 1923*a*:126 ♀ (*Thereva*), new combination. Distribution. — Michigan, northern Illinois.

melampodia (Loew) 1869*a*:9 ♀ (*Psilocephala*), new combination. Distribution. — Central to southeastern USA.

nigrina (Kröber) 1914:53 ♀ (*Psilocephala*), new combination. Distribution. — Florissant, Colorado.

A few undescribed species fit within the boundaries of this genus; these are from western North America.

Genus **Pandivirilia** Irwin & Lyneborg, new genus (Fig. 12, 14, 32, and 66–71)

Neuter, but as adjective takes feminine form.

Derivation of name: *pando* (Latin) = lay open; *virilia* (Latin) = male genitals.

Type-species: *Psilocephala limata* Coquillett 1894:99 by present designation. Type-locality: Colorado and Washington.

Diagnosis

Head. — Frons of male (Fig. 14) at its narrowest distinctly narrower than width of anterior ocellus; frons of female narrow, at level of anterior ocellus 1.5–1.8× as wide as ocellar tubercle; male frons usually has silver gray to whitish tomentum, in a few species tomentum somewhat darker above; frons without pile, or with dark pile on lateral, lower part only; female frons darker on upper half than lower half, either caused by brownish tomentum or because upper frons distinctly subshiny to shiny brownish black to black overall, never forming bare, polished calli, since upper darkened frons has distinct, black pile; head moderately protrudes anteriorly; facial and genal calli absent; lateral portion of face and gena without pile or pile sparse and restricted to lower face and gena; head depth 1.4–1.8× antennal length; scape slender, 0.5–0.8× as long as flagellum; flagellar style apical, two segmented, with a small terminal spine; palps one segmented.

Thorax. — np 3–6, sa 2, pa 1, dc 1–2. sc 2; mesonotal pile of male long, erect, uniform, sometimes composed of both pale and dark hairs; pile distinctly longer than width of scape; mesonotal pile of female shorter and more appressed; prosternum bare in and around central depression. Wing (Fig. 32). — Cell m_3 open; vein R_4 longer than, or at least as long as, vein R_5; cell r_4 2.0–2.5× as long as wide at apex; color hyaline, often with a grayish or brownish tinge; stigma usually distinct. Legs. — Fore coxa has 1–3 apical setae on anterior surface; middle coxa with long, whitish pile on posterior surface; hind femur (Fig. 12) has 5–8 anteroventral setae and usually a few short posteroventral setae near apex.

Abdomen. — Rather slender, gradually tapering from base to apex, not telescoped; dorsum convex to rather flattened; male dorsum with silver-gray to whitish tomentum and exclusively whitish pile; female dorsum has broad, shiny, blackish, anterior bands on anterior segments.

Male Terminalia (Fig. 66–71). — Tergite 8 (Fig. 70) small and greatly constricted medially; sternite 8 (Fig. 71) small, bilobate, with deep, V-shaped incision on posterior margin; epandrium (Fig. 69) from nearly as long along midline as to distinctly longer along midline than wide, with prominently projecting posterolateral corners and with a deep incision in posterior margin; cerci free, well sclerotized, do not project beyond ventral epandrial sclerite; ventral epandrial sclerite large, reaching to anterior margin of epandrium, with or without a weak, membranous attachment to anterior margin of aedeagus; ventral epandrial sclerite largely membranous, only a small area below cerci sclerotized; parameral apodeme without attachment to aedeagus; distiphallus in dorsal view (Fig. 67) short and narrow compared with rest of aedeagus, suddenly downcurved and slightly S-curved (Fig. 68), in caudal view straight; dorsal apodeme rectangular, arched; ventral apodeme long, equally wide or slightly widening distally; ejaculatory apodeme usually

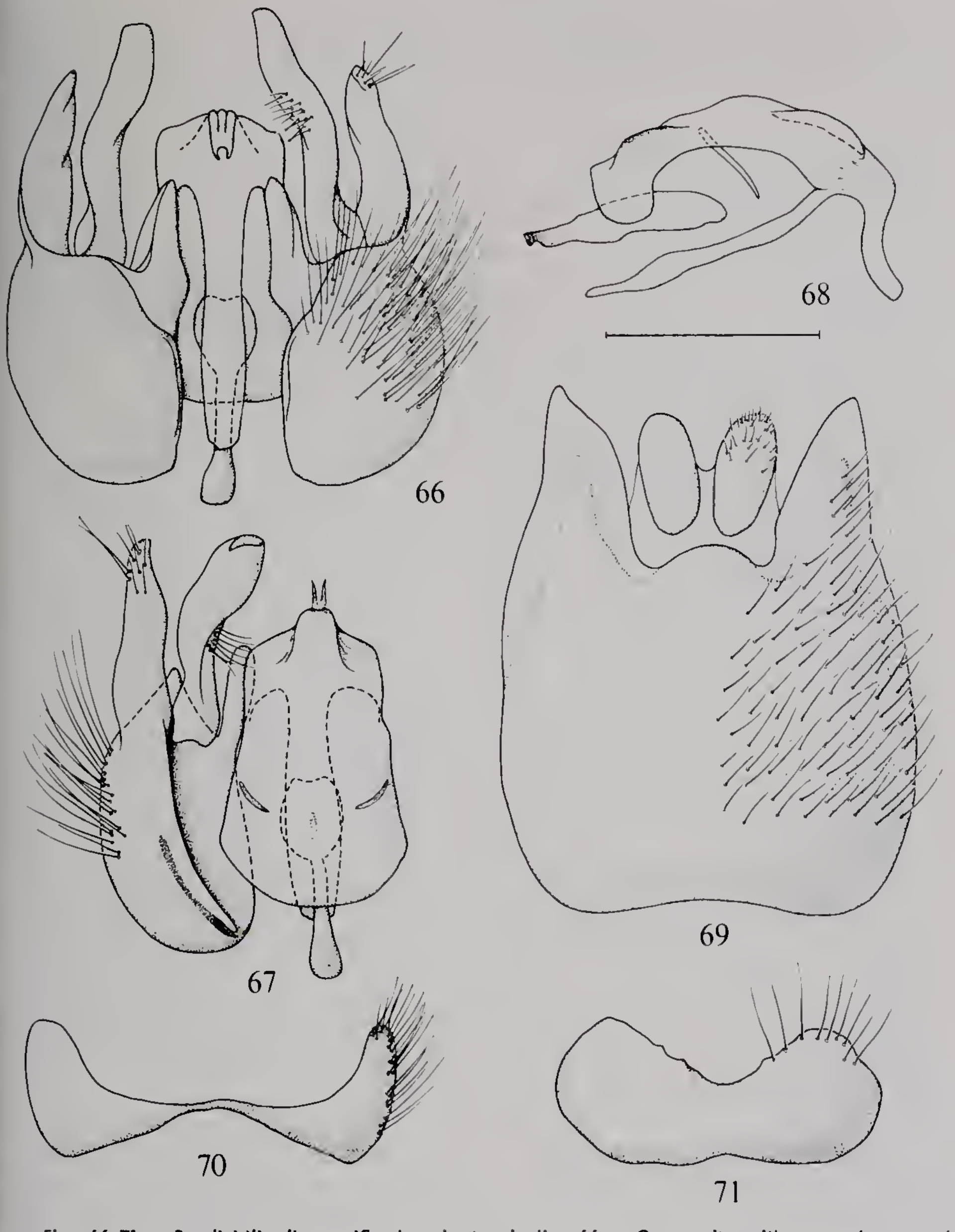

Fig. 66–71. — *Pandivirilia limata* (Caq.) male terminalia. 66. — Gonacaxite with appendages and aedeagus in ventral view. 67. — Right ganocoxite with appendages and aedeagus in darsal view. 68. — Aedeagus in lateral view. 69. — Epandrium with appendages in darsal view. 70. — Tergite 8. 71. — Sternite 8. Scale: 0.5 mm.

slightly extended anteriorly beyond dorsal apodeme; ventral lobes of gonocoxites large, rounded, directed obliquely upward, with a membranous attachment to ventral surface of aedeagus; ventral lobes connected along midline by a membrane; parameral process protrudes prominently beyond level of posterior margin of gonocoxite; parameral apodeme short and narrow; gonocoxites not united ventrally

(Fig. 66), in lateral view short and truncate posteriorly; hypandrium absent.

Habitat

Specimens of this genus have been collected in forested areas in mountains of western North America. A pupa was collected from an old pine log in the San Bernardino Mountains, California.

Distribution

Most species are from western North America (British Columbia, Washington, Oregon, California, Idaho, Utah, Colorado, Montana, Nevada, Arizona) with at least one species from the northern and eastern United States (Wisconsin, New York, Maine) and eastern Canada (Nova Scotia, Ontario).

Included Species

- *argentifrons* (Cole) 1923*a*:56 ♂ (*Psilocephala*), new combination. Distribution. — Pennsylvania.
- *bussi* (James) *in* James & Huckett 1952:265 ♂, ♀ (*Psilocephala*), new combination. Distribution. — Canada (Yukon Territory) southward into northwestern USA (Washington).
- *limata* (Coquillett) 1894:99 ♀ (*Psilocephala*), new combination. Distribution. — Western North America.
- *pollinosa* (Cole) 1923*a*:72 ♂ (*Psilocephala*), new combination. Distribution. — Sierra Nevada Mountains, California.

Several undescribed species are at hand.

Genus **Spiriverpa** Irwin & Lyneborg, new genus (Fig. 72–79)

Feminine

Derivation of name: *spira* (Latin) = twist; *verpa* (Latin) = penis.

Type-species: *Thereva lunulata* Zetterstedt 1838:523 by present designation. Type-locality: Norway.

Diagnosis

Medium-sized, moderately broad species.

HEAD. — Frons of male at its narrowest no wider than half width of anterior ocellus; frons of female at level of anterior ocellus 1.8–2.0× as wide as ocellar tubercle; tomentum on male frons uniformly whitish silver, or at most indistinctly darker on upper lateral part; pile all whitish and long, restricted to lower lateral portion of frons; tomentum on female frons darker on upper half than on lower half; pile blackish above, whitish below, shorter and more appressed than in male; head moderately protrudes anteriorly; facial and genal calli absent: lateral portion of face and gena has long, whitish pile; antennae (Fig. 79) 0.7–0.8× as long as depth of head; scape slender, 0.6–0.7× as long as flagellum; flagellar style apical, two segmented, with a minute terminal spine; palps one segmented.

THORAX. — np 2–4 (usually 3), sa 2–3 (usually 2), pa 1, dc 1–2 (usually 2), sc 2; mesonotal pile in male dense, uniform, erect, rather long and whitish; in female two types of pile; one is moderately long, scalelike, appressed, whitish, and the other is longer, normal, erect, and blackish; prosternum without pile in and around central depression. WING. — Cell m_3 open at wing margin (closed in some males); vein R_4 longer than vein R_5; cell r_4 2.1–2.3× as long as wide at apex; color grayish hyaline with pale brownish stigma. LEGS. — Fore coxa has 2 apical setae on anterior surface; middle coxa has long, whitish pile on posterior surface; hind femur has 5–7 anteroventral setae.

ABDOMEN. — Rather slender, gradually tapering from anterior margin of segment 3 to apex; abdomen not telescoped, rather flattened on dorsum: male dorsum has silver-grayish tomentum and long, whitish pile; female dorsum has blackish anterior bands on first segments and shorter, partly blackish pile.

MALE TERMINALIA (Fig. 72–78). — Tergite 8 (Fig. 77) rather large and greatly constricted medially; sternite 8 (Fig. 78) also large with a wide incision in posterior margin; epandrium (Fig. 76) from nearly as long in midline as to distinctly longer in midline than wide, with strongly projecting, posterolateral corners forming a deep incision in posterior margin; cerci free, well sclero-

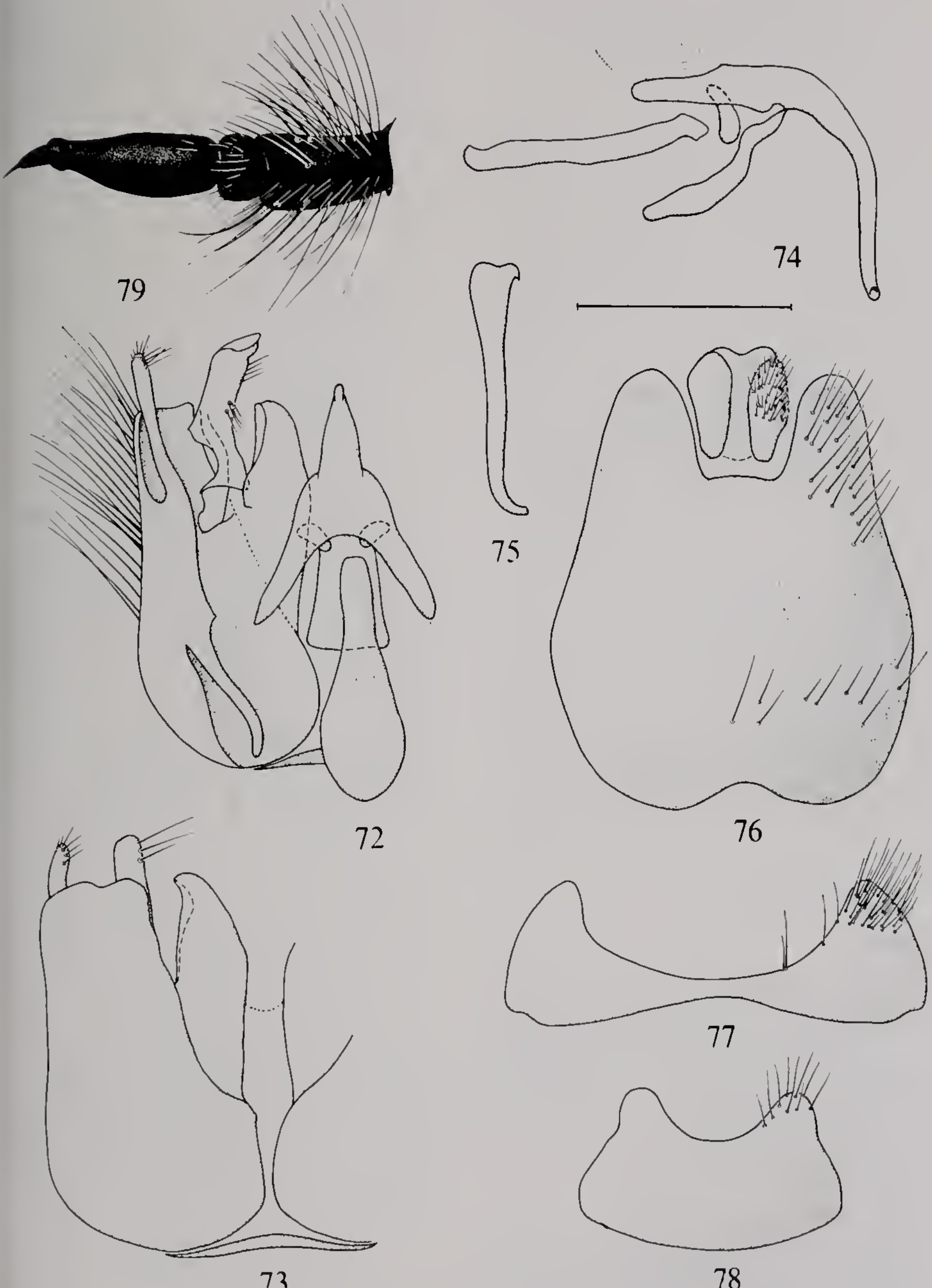

Fig. 72–79. — *Spiriverpa lunulata* (Zett.). 72–78. — Male terminalia. 72. — Right gonocoxite with appendages and aedeagus in dorsal view. 73. — Gonocoxites and hypandrium in ventral view. 74. — Aedeagus in lateral view. 75. — Distiphallus in caudal view. 76. — Epandrium with appendages in dorsal view. 77. — Tergite 8. 78. — Sternite 8. 79. — Antenna. Scale: 0.5 mm.

tized, not projecting beyond ventral epandrial sclerite; ventral epandrial sclerite large, reaching to anterior margin of epandrium, with a membranous attachment to anterior margin of aedeagus; ventral epandrial sclerite largely membranous, only portion below cerci well sclerotized; parameral apodeme without attachment to aedeagus; distiphallus (Fig. 74) very long, slender, its apex (Fig. 75) twisted to the right (with respect to specimen as a whole); dorsal apodeme short, V shaped, continuing into a membrane; ventral apodeme narrowly spoon shaped; ejaculatory apodeme flat in lateral view, with a spoon-shaped distal extension in dorsal view; ventral lobes of gonocoxite large and complex, directed upward at an angle of about 45° to longitudinal axis; ventral lobes connected on their ventral surface by a weakly sclerotized membrane; this membrane binds the gonocoxites posteroventrally (Fig. 73); a membranous attachment also present between ventral lobes and ventral surface of aedeagus; parameral process long, very slender, may or may not reach beyond level of posterior margin of gonocoxite; parameral apodeme also long and slender; gonocoxites not united ventrally, in lateral view obliquely truncate posteriorly; hypandrium (Fig. 73) free, forming a narrow band adjoining anterior margin of gonocoxites.

Habitat

We do not know the exact habitat of this group of species, but many specimens have been collected in the sand dunes along the Great Lakes, especially along the eastern shore of Lake Michigan. We suspect that species in this genus inhabit sandy substrates.

Distribution

Species of the genus *Spiriverpa* are found along the Atlantic coast from Florida to Vermont, in Ontario and New Brunswick, Canada, and throughout the New England, Great Lakes, and Midwest states (including Kansas) westward through Colorado to Oregon and northward to Alaska, including parts of Canada.

Included Species

albiceps (Loew) 1869*b*:166 ♀ (*Thereva*), new combination. Distribution. — Northeastern United States.

? *albifrons* (Say) 1829:156 ♂ (*Thereva*), new combination. Distribution. — Indiana.

bella (Kröber) 1914:64 ♂, ♀ (*Thereva*), new combination. Distribution. — Northeastern United States. (This species may be conspecific with *senex* (Walker).)

bella nigrimana (Kröber) 1914:64 ♂ (*Thereva*), new combination. Distribution. — Massachusetts. (This subspecies may be the same as *bella* (Kröber).)

candidata (Loew) 1869*a*:8 ♂ (*Thereva*), new combination. Distribution. — Eastern North America and westward along the Great Lakes. (This species may be synonymous with *senex* (Walker).)

cinerascens (Cole) 1923*a*:97 ♀ (*Thereva*), new combination. Distribution. — Oregon.

cockerelli (Cole) 1923*a*:99 ♂, ♀ (*Thereva*), new combination. Distribution. — Rocky Mountains, especially Colorado northward into Canada.

nitoris (Coquillett) 1894:101 ♀ (*Thereva*), new combination. Distribution. — Southern portion of midwestern United States.

senex (Walker) 1848:224 ♀ (*Thereva*), new combination. Distribution. — Southeastern Canada.

There are a few undescribed species within this genus from western North America and one described species from northern Europe.

Genus Thereva Latreille
(Fig. 8, 9, and 80–87)

Feminine

Thereva Latreille 1796:167. Type-species: *Musca plebeja* Linnaeus 1758: subsequent monotypy by Latreille

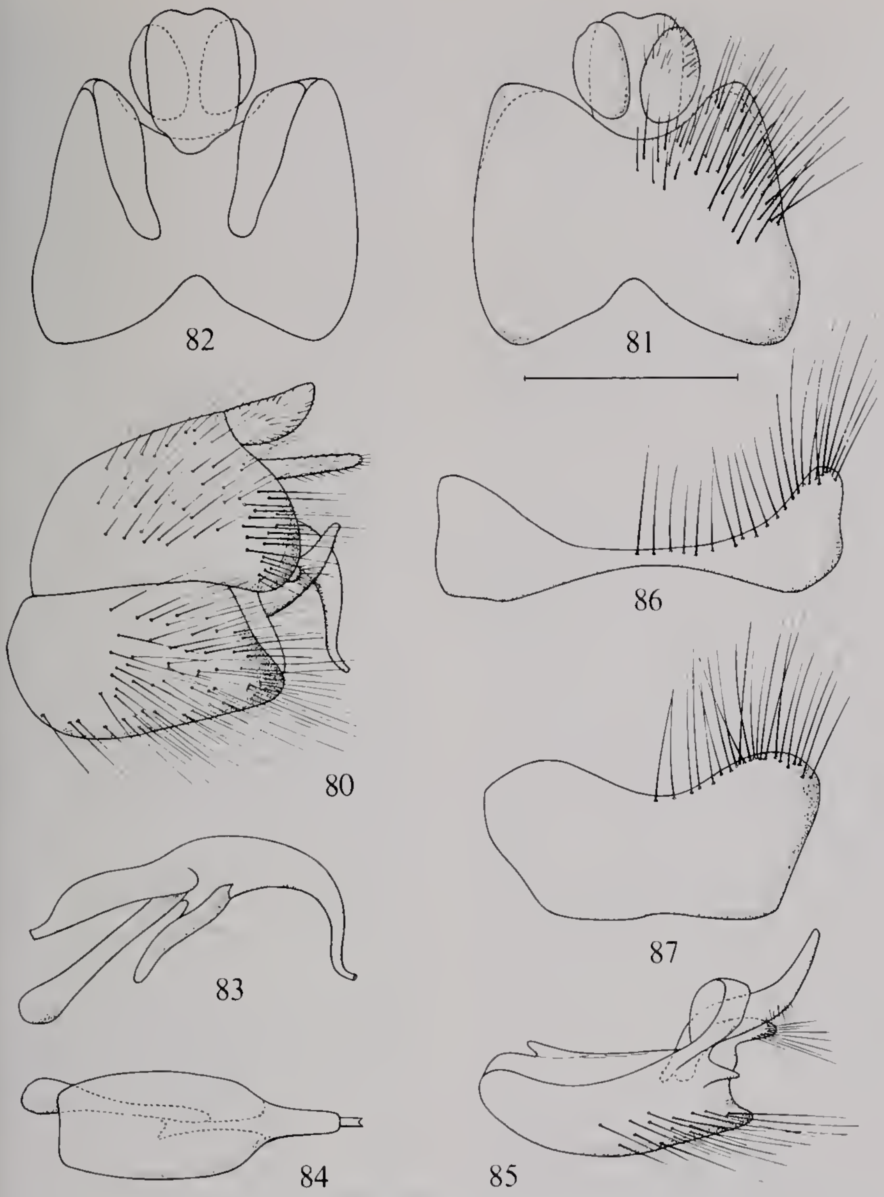

Fig. 80–87. — *Thereva plebeja* (L.) male terminalia. 80. — Genitalia in lateral view. 81. — Epandrium with appendages in dorsal view. 82. — Epandrium with appendages in ventral view. 83. — Aedeagus in lateral view. 84. — Aedeagus in dorsal view. 85. — Right gonocoxite in ventral view. 86. — Tergite 8. 87. — Sternite 8. Scale: 0.5 mm.

(1802:441). Type-locality: Northwestern Europe.

Thereua, Loew error.

Reference: Coquillett 1893*a*, Cole 1923*a*.

Diagnosis

Medium- to large-sized, heavy-bodied, usually densely pilose species.

Head. — Frons of male at its narrowest much narrower than half width of anterior ocellus; frons of female (Fig. 8) at level of anterior ocellus 2.0–3.0× as wide as ocellar tubercle; frons of female almost always has a pattern formed by differentially colored tomentum and central, shiny callosity (in some species there are two callosities on raised portions of frons); frons of male variously tomentose and pilose, only rarely with a shining callosity; head of each sex exceptionally wide; eyes of both sexes have single facet size; long, thin pile over frons (especially lower part above antennae of females), face, and genae of both sexes; gena wide in frontal view; head protrudes slightly at level of antennae; head depth 1.0–1.3× antennal length (Fig. 9); scape 0.8–1.2× as long as flagellum; flagellar style apical, two segmented, with a short, heavy terminal spine; palps one segmented.

THORAX. — np 3–5, sa 1–2, pa 1, dc 0–2, sc 2; mesonotal pile usually long, dense, erect on males; mesonotal pile of two types on female: one is short, erect, usually dark, the other is appressed, bronze colored; prosternum has long pile in and around central depression. WING. — Cell m_3 open or closed; veins R_4 and R_5 of about equal length; cell r_4 about 1.5–2.5× as long as wide at apex; color variable, from hyaline to heavily mottled, veins in some species surrounded by dark infuscation; stigma usually distinct, light to dark brown. LEGS. — Fore coxa with 2–5 (usually 4) apical setae on heavily pilose anterior surface; middle coxa has long pile on anterior and posterior surfaces; femora have setae in anteroventral position or setae lacking on fore and/or middle femora.

ABDOMEN. — Moderately broad, tapering abruptly toward apex; abdomen not telescoped; dorsum somewhat flattened in female, more convex in male; pattern variable, with tomentum entirely whitish gray (rare) to brownish in definite bands (common); abdomen of both sexes pilose, pile usually erect, denser and longer on male.

MALE TERMINALIA (Fig. 80–87). — Tergite 8 (Fig. 86) rather variable, large, and greatly constricted medially; sternite 8 (Fig. 87) variable, generally large, rectangular shaped, posterior margin often notched; epandrium (Fig. 81 and 82) wider than long along midline, posterolateral margins not extending posteriorly as far as cerci; cerci free, well sclerotized; ventral epandrial sclerite (Fig. 82) composed of a sclerotized midposterior section below cerci and 2 lateral sclerotizations attached by a membrane to posterolateral margins of epandrium, but not extending anteriorly to base of epandrium and not strongly connected to aedeagus; aedeagus (Fig. 83 and 84) rather small, simple; parameral apodeme not attached to aedeagus; distiphallus short, slightly downcurved distally, in dorsal view several times wider basally than distally; dorsal apodeme broader and projects anteriorly farther than ventral apodeme; ejaculatory apodeme simple, stick shaped; gonocoxites not united ventrally except by a thin membrane, usually broadly rounded posteriorly, often with a distinct projection; parameral process long, fingerlike, often extending to or beyond level of posterior corner of epandrium; gonostylus (Fig. 85) well developed, long, usually directed posteriorly and dorsally, thicker basally than distally, and hooklike apically; ventral lobe (Fig. 85) long, irregularly shaped, not extending posteriorly to apex of gonostylus; hypandrium present as a narrow sclerite between ventrobasal part of gonocoxites.

Habitat

Species in the genus *Thereva* seem restricted to mountainous areas and to the northern boreal and coniferous zones in North America. Irwin reared larvae from mixed montane leaf litter from the San Bernardino Mountains in southern California.

Distribution

The genus *Thereva* ranges widely over the Holarctic Region and parts of the Afrotropical Region (Lyneborg 1976; Lyneborg & Spitzer 1974), but within the Western Hemisphere it is generally confined to the boreal and mountainous areas of western, northern, and eastern North America.

Included Species

albopilosa Kröber 1912:256 ♂. Distribution. — Colorado.

aurofasciata Kröber 1912:263 ♂. Distribution. — Southern Colorado.
bakeri Cole 1923*a*:124 ♂, ♀. Distribution. — Southern California.
brunnea Cole 1923*a*:108 ♂, ♀. Distribution. — British Columbia, Canada, and Washington.
cingulata Kröber 1912:267 ♀. Distribution. — Colorado.
comata Loew 1869*a*:7 ♂. Distribution. — California.
concavifrons Kröber 1914:70 ♀. Distribution. — New Mexico.
diversa Coquillett 1894:100 ♂. Distribution. — Colorado.
duplicis Coquillett 1893*a*:198 ♂, ♀. Distribution. — South Dakota and Montana.
egressa Coquillett 1894:99 ♂. Distribution. — Colorado.
flavicauda Coquillett *in* Baker 1904: 23 ♀. Distribution. — Nevada.
flavicincta Loew 1869*b*:168 ♂. Distribution. — Northeastern United States.
  gilvipes Loew 1869*b*:168 ♀.
flavipilosa Cole 1923*a*:125 ♂. Distribution. — Fresno County, California.
flavohirta Kröber 1914:70 ♀. Distribution. — Colorado.
foxi Cole 1923*a*:112 ♂. Distribution. — Washington.
frontalis Say 1824:370 ♂, ♀. Distribution. — Northwestern United States and southwestern Canada.
fucata Loew 1872:74 ♂, ♀. Distribution. — California.
fucatoides Bromley 1937:99 ♂, ♀. Distribution. — Utah.
hirticeps Loew 1874:382 ♀. Distribution. — San Francisco Bay area, California.
johnsoni Coquillett 1893*a*:200 ♀. Distribution. — Washington.
macdunnoughi Cole 1925:87 ♂, ♀. Distribution. — Alberta, Canada.
nebulosa Kröber 1912:264 ♂. Distribution. — California.
neomexicana Cole 1923*a*:117 ♀. Distribution. — Southern Nevada.
nigripilosa Cole 1923*a*:110 ♂. Distribution. — British Columbia, Canada.
niveipennis Kröber 1914:66 ♂. Distribution. — Central coastal California.
pseudoculata Cole 1923*a*:121 ♂, ♀. Distribution. — Utah.
strigipes Loew 1869*b*:169 ♀. Distribution. — Winnipeg, Canada.
ustulata Kröber 1912:265 ♂. Distribution. — Winnipeg, Canada.
utahensis Hardy 1938:145 ♀. Distribution. — Utah.

Genus **Tabudamima** Irwin & Lyneborg, new genus (Fig. 88–93)

Feminine

Derivation of name: *Tabuda* = genus name in the Therevidae; *mimos* (Greek) or *mimus* (Latin) = imitator.

Type-species: *Thereva melanophleba* Loew 1876:112 by present designation. Type-locality: San Francisco, California.

Diagnosis

Small, moderately broad species.

HEAD. — Frons of male at its narrowest narrower than width of anterior ocellus; frons of female 1.8–2.0× as wide as ocellar tubercle; male frons entirely tomentose, with long, black pile; tomentum on frons gray; female frons entirely tomentose, often with dark transverse band and shorter pile than that of male; frons impressed; head noticeably protrudes anteriorly; facial and genal calli absent; lateral portion of face and gena has long pile, black on face, white on gena; head depth 1.0–1.1× antennal length; scape thickened, 1.3–1.5× length of flagellum; flagellar style apical, obviously one segmented, with a minute terminal spine; palps one segmented.

THORAX. — np 3, sa 1, pa 1, dc 0, sc 2; mesonotal pile in male very long, uniform, composed of white and black hairs; mesonotal pile in female of two types: the first is moderately long, scalelike, semi-appressed, white, and the other is long, erect, black; prosternum without pile in and around central depression (this may be difficult to discern because of long, dense pile on fore coxa). WING. — Cell m_3 closed or narrowly open; vein

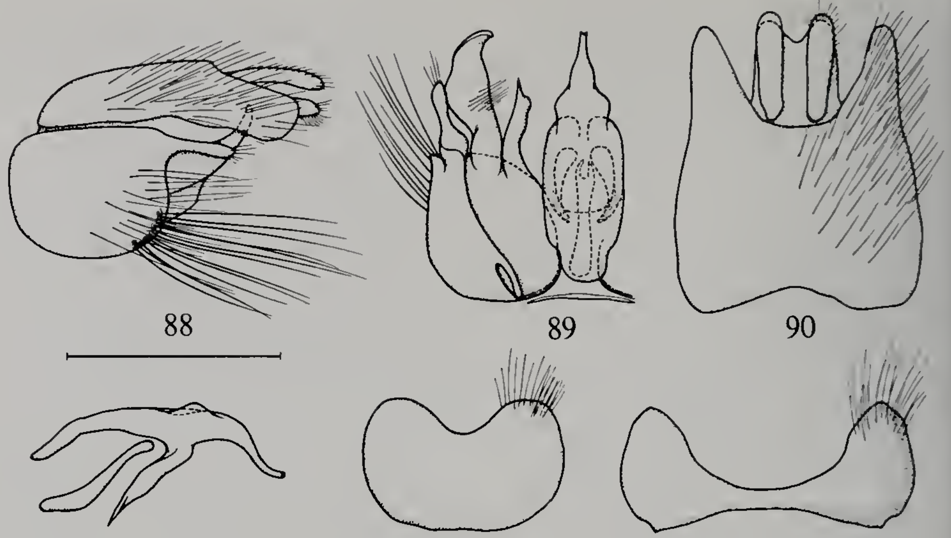

Fig. 88–93. — *Tabudamima melanophleba* (Lw.) male terminalia. 88. — Genitalia in lateral view. 89. — Right ganacoxite with appendages and aedeagus in dorsal view. 90. — Epandrium with appendages in dorsal view. 91. — Aedeagus in lateral view. 92. — Sternite 8. 93. — Tergite 8. Scale: 0.5 mm.

R_4 longer than vein R_5; cell r_4 2.1–2.2× as long as wide at apex; color grayish hyaline in male, but has more brownish tinge in female; veins very strong and dark; vein R_4 often has recurrent vein near base; stigma blackish brown. Legs. — Fore coxa has at most a single, apical seta on anterior surface; middle coxa has whitish pile on posterior surface; hind femur has 4–5 anteroventral setae.

Abdomen. — Slender, gradually tapering from segment 2 to apex; abdomen not telescoped; dorsum somewhat flattened in both sexes; dorsum of male entirely tomentose and pilose; tomentum silvery white; dorsum of female has broad, blackish anterior bands on first tergites, otherwise tomentose; tomentum gray on female dorsum.

Male Terminalia (Fig. 88–93). — Tergite 8 (Fig. 93) comparatively large and greatly constricted medially; sternite 8 (Fig. 92) large, broad oval, with semicircular incision in posterior margin; epandrium (Fig. 90) shorter in midline than wide, its posterolateral corners prominently extended, but simply rounded; cerci free, strongly sclerotized, elongate, but not extending beyond ventral epandrial sclerite; ventral epandrial sclerite only sclerotized beyond cerci, continuing anteriorly into a weak membrane reaching to about middle of epandrium, with no attachment to aedeagus; parameral apodeme without attachment to aedeagus; distiphallus (Fig. 89) gradually tapers, in lateral view (Fig. 91) short and only moderately curving; dorsal apodeme oval; ventral apodeme short and broad; ejaculatory apodeme shaped like a rod; ventral lobes of gonocoxites large, rather complex and have a membranous attachment to ventral surface of aedeagus; parameral process moderately long and slender (Fig. 89); gonocoxites not united ventrally, not even attached by a membrane; in lateral view (Fig. 88) gonocoxites nearly circular in shape; hypandrium (Fig. 89) free, forming a long, very narrow strip.

Habitat

Little is known of the habitat of these species except that several specimens were collected in coastal sand dune habitats in California.

Distribution

Species in the genus *Tabudamima* seem confined to the northwestern United States, with specimens collected from Washington, Oregon, California, and Nevada. Those from California are concentrated in the San Francisco Bay area southward along the coast to San Diego County and inland in the Sierra Nevada Mountains and in the San Bernardino and Santa Rosa mountains of southern California.

Included Species

melanophleba (Loew) 1876:317 ♂, ♀ (*Thereva*), new combination. Distribution. — San Francisco Bay area, California.

There are several closely related undescribed species in this genus.

Genus Tabuda Walker
(Fig. 6, 7, and 94–100)

Tabuda Walker 1852:197. Type-species: *Thereva fulvipes* Walker 1852:197 by original monotypy (= *T. varia* Walker 1848:221). Type-locality: Florida.

Metaphragma Coquillett 1894:97. New synonym. Type-species: *Xestomyza planiceps* Loew 1872:75 by original designation. Type-locality: California.

Diagnosis

Medium- to large-sized, robust flies.

HEAD (Fig. 6 and 7). — Frons of male at its narrowest from as wide as anterior ocellus to as wide as ocellar tubercle; frons of female at level of anterior ocellus about 2.5× as wide as ocellar tubercle; frons without distinct tomentum pattern, or at most with a pair of small, dark patches laterally; pile on lower frons moderately thick, composed of long, black hairs; upper frons bare or has thin pile laterally; head moderately to prominently protruding anteriorly, antennae thus set on a distinct protuberance; facial and genal calli absent; lateral portion of face and gena has long pile; head depth 1.0–1.3× antennal length; scape thickened, 1.7–2.0× as long as flagellum; flagellar style apical, stout, obviously one segmented, with a minute terminal spine; palps one segmented.

THORAX. — np 3–5, sa 2, pa 1, dc 1, sc 2; mesonotal pile of two types: one is moderately long, scalelike, rather dense, semi-appressed, and the other is long, erect, sparse; prosternum without pile in and around central depression. WING. — Cell m_3 open; vein R_4 longer than vein R_5; cell r_4 2.3–2.6× as long as wide at apex; color grayish brown to brown, with darker stigma or anterior margin intensively darkened, and with darker patches, especially around crossveins. LEGS. — Fore coxa with 1 or 2 apical setae on anterior surface; middle coxa with whitish pile on posterior surface; hind femur with 5–8 anteroventral setae.

ABDOMEN. — Rather broad, with sides nearly parallel from segments 1 through 3; thereafter, abdomen tapers slightly and gradually; male abdomen distinctly telescoped; abdominal tergites 6 and 7 visible only as narrow bands; dorsum of abdomen somewhat flattened; male dorsum has silver gray tomentum; female dorsum mostly subshiny to dull brown.

MALE TERMINALIA (Fig. 94–100). — Tergite 8 (Fig. 100) small and greatly constricted medially; sternite 8 (Fig. 99) small, oval, has a semicircular incision into posterior margin; epandrium (Fig. 97) shorter in midline than wide, its posterolateral corners rounded; cerci free (Fig. 97), strongly sclerotized, elongate, extending distinctly beyond ventral epandrial sclerite; ventral epandrial sclerite reaches or nearly reaches anterior margin of epandrium, but has at most a loose and weak attachment to anterior margin of aedeagus; ventral epandrial sclerite has three strongly sclerotized areas: a small semicircular area below cerci and a larger pair below epandrium; parameral apodeme and ventral lobes of gonocoxite not attached to aedeagus; distiphallus (Fig. 98) rather long, S curved; a semicircular, narrow, sclerotized ring in dorsal membrane surrounds

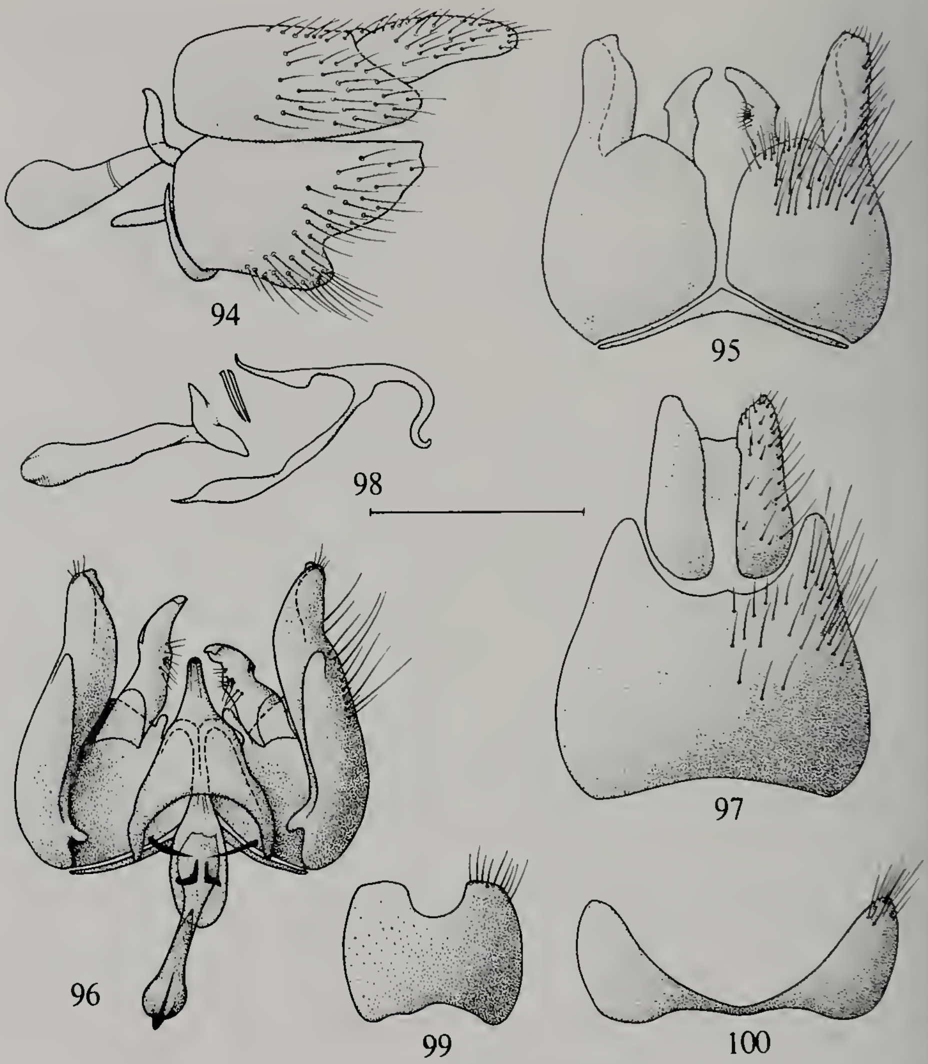

Fig. 94–100. — *Tabuda varia* Wlk. male terminalia. 94. — Genitalia in lateral view. 95. — Gonocoxites and hypandrium in ventral view. 96. — Gonocoxites with appendages and aedeagus in dorsal view. 97. — Epandrium with appendages in dorsal view. 98. — Aedeagus in lateral view. 99. — Sternite 8. 100. — Tergite 8. Scale: 0.5 mm.

proximal portion of ejaculatory apodeme; ventral apodeme large, narrowly spoon shaped distally; ejaculatory apodeme has enlarged proximal and distal sections; ventral lobes of gonocoxite (Fig. 96) small, narrow, directed upward, but not visible in ventral view; parameral process strongly united with dorsal surface of gonocoxite, at most a wartlike process present; parameral apodeme distinct but small; gonocoxites (Fig. 95) not united ventrally, short and high in lateral view (Fig. 94), project dorsally; hypandrium (Fig. 95) free, forming a long, narrow band adjoining anterior margin of gonocoxites for a long distance.

Habitat

Little is known as to the habitat that these interesting looking flies occupy. One specimen of *planiceps* was collected in sand dunes near San Francisco. Two specimens of *borealis* were collected on sand near coyote holes (Cole 1923*a*:83).

Distribution

Species of *Tabuda* appear to be confined to the western coast of North America (*T. planiceps*), eastern North America (*T. varia*), and north-central North America (*T. borealis*).

Included Species

borealis Cole 1923*a*:82 ♂, ♀. Distribution. — Saskatchewan, Canada.

planiceps (Loew) 1872:75 ♀ (*Xestomyza*), new combination. Distribution. — Western coast of North America from British Columbia, Canada, southward to southern California, United States.

varia (Walker) 1848:221 ♀ (*Thereva*), new combination. Distribution. — Eastern North America from Florida northward to Massachusetts and westward to Pennsylvania.

fulvipes Walker 1852:197 ♂, new name for *Thereva nervosa* Walker.

nervosa Walker 1848:223 ♂ (*Thereva*), not Loew 1845:28.

No undescribed species of *Tabuda* are known to us.

Note

The genus *Metaphragma* was created by Coquillett (1894:97) for *Xestomyza planiceps* Loew 1872:75. *T. planiceps* is unique in having an additional crossvein between R_5 and vein M_1 that forms a closed cell anterior to the discal cell. This additional cell is similar in shape and size to the discal cell; however, in characters such as those of the male terminalia, *planiceps* falls within the strict definition of *Tabuda*. For that reason we have synonymized *Metaphragma* Coq. with *Tabuda* Walker.

Genus Acrosathe Irwin & Lyneborg, new genus (Fig. 101–106)

Feminine

Derivation of name: *akra* (Greek) = projection; *sathe* (Greek) = phallus.

Type-species: *Bibio annulata* Fabricius 1805:68 by present designation. Type-locality: Denmark.

Diagnosis

Medium-sized, moderately thick-bodied species.

Head. — Frons of male at its narrowest narrower than width of anterior ocellus (in *bimaculata* (Cole) about 3× as wide as anterior ocellus); frons of female at level of anterior ocellus 1.3–2.4× as wide as ocellar tubercle; male frons tomentose; tomentum silvery white to gray, upper corner more or less dull black or brown (with two dull darkened areas in *bimaculata*); male frons has long, usually pale, pile; lower part of female frons tomentose and pilose, as in male, tomentum silvery gray, pile pale straw; upper part of female frons tomentose, often with dull black areas, tomentum brownish to brownish gray, pile brown or black; head distinctly protrudes anteriorly at antennal level; lateral portion of face and gena has long, pale pile; head depth 1.2–1.5× antennal length; scape slender, 0.8–1.0× as long as flagellum; flagellar style apical, two segmented, with a small terminal spine; palps one segmented.

Thorax. — np 3–4 (usually 3), sa 1–2 (usually 2), pa 1, dc 1–2, sc 2; mesonotal pile of male of some species long, erect, uniform; mesonotal pile of male of other species and of all females of two kinds: one is long to moderately long, erect, normal, and the other is shorter, semi-appressed, scalelike; prosternum has long pile in and around central depression. Wing. — Cell m_3 in most species closed and has short common vein to wing margin; cell m_3 occasionally open; vein R_4 distinctly longer than vein R_5; cell r_4 2.0–2.2× as long as wide at apex; color grayish hyaline, but a couple of species show brownish infuscations around crossveins; stigma pale brown. Legs. — Fore coxa with 2 or 3 apical setae on anterior surface; middle coxa has whitish pile on posterior surface; 6–8 rather stout anteroventral setae over entire length of hind femur.

Abdomen. — Moderately broadly built, gradually tapering from segment 2 to apex, not telescoped; dorsum somewhat flattened in both sexes; dorsum of male entirely tomentose and pilose, these being silvery white to gray; dorsum of female in most species has dark anterior bands on at least tergites 2–4, but a couple of species have tergites entirely tomentose, tomentum gray.

Male Terminalia (Fig. 101–106). — Tergite 8 (Fig. 105) large, wider than epandrium, and medially constricted for a long distance; sternite 8 (Fig. 106) trapezoidal, its lateral margins straight or concave; posterior margin of sternite 8 has semicircular incision; epandrium (Fig. 103) large, markedly convex, as long medially as, or longer than, wide; posterolateral corners of epandrium truncate in type-species (Fig. 103), more sharply pointed in North American species; cerci free, ventral epandrial sclerite well sclerotized below cerci, continuing anteriorly into a weak, narrow membrane, often loosely attached to anterior margin of aedeagus; some species have a strong, narrow attachment between lateral edge of epandrium/ventral epandrial sclerite and midsection of paramere; parameral apodeme without attachment to aedeagus; distiphallus (Fig. 102) slender, in lateral view (Fig. 104) more or

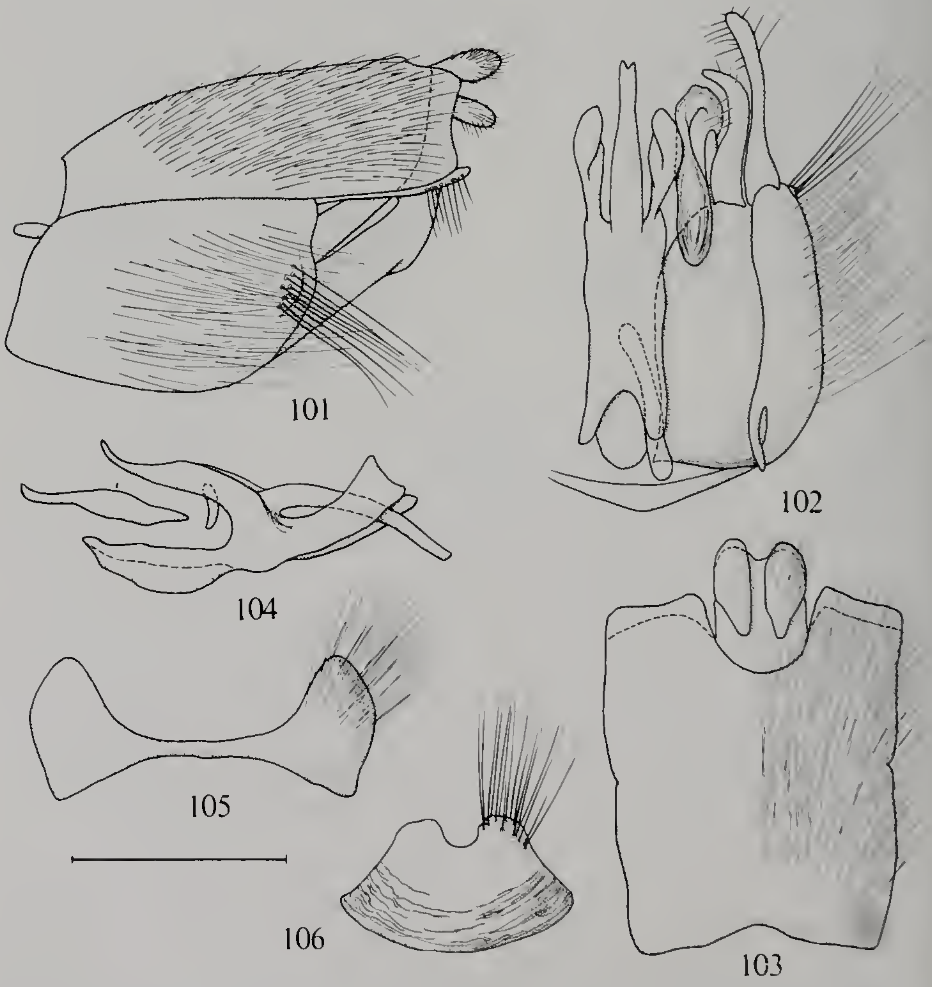

Fig. 101–106. — *Acrosathe annulata* (F.) male terminalia. 101. — Genitalia in lateral view. 102. — Left gonocoxite with appendages and aedeagus in dorsal view. 103. — Epandrium with appendages in dorsal view. 104. — Aedeagus in lateral view. 105. — Tergite 8. 106. — Sternite 8. Scale: 0.5 mm.

less downcurved; dorsal apodeme short; ventral apodeme large, forming a narrow, deep trough; 2 anterior processes arise from base of distiphallus; these processes either shorter than or as long as distiphallus; they are distinct at species level; ejaculatory apodeme simple, stick shaped; ventral lobes of gonocoxites, as in *Psilocephala* (Fig. 110), large, heavily sclerotized, and suddenly curved, forming a dorsal, anteriorly directed, distal portion strongly attached to midlateral section of aedeagus; parameral process large, free; gonocoxites free ventrally, but attached by a membrane; hypandrium (Fig. 102) narrow, comparatively large.

Habitat

The type-species is widespread in Europe, occurring mainly on coastal dunes. Most of the North American species are found in coastal dunes, but *A. vialis* inhabits mountainous areas and is often found on lake beaches.

Distribution

The genus *Acrosathe* is Holarctic, with about 10 species occurring in the Palearctic Region. Within the Nearctic Region, one species, *A. bimaculata,* is found in North Carolina; the other species are confined to western North America (British Columbia, Washington, Oregon, Idaho, California, Baja California).

Included Species

bimaculata (Cole) 1923*a*:98 ♀ (*Thereva*), new combination. Distribution. — North Carolina.

novella (Coquillett) 1893*a*:200 ♂, ♀ (*Thereva*), new combination. Distribution. — Southern California.

otiosa (Coquillett) 1893*a*:199 ♂ (*Thereva*), new combination. Distribution. — Coastal area of California.

pacifica (Cole) 1923*a*:103 ♂, ♀ (*Thereva*), new combination. Distribution. — Coastal area of central California.

vanduzeei (Cole) 1923*a*:105 ♂, ♀ (*Thereva*), new combination. Distribution. — Coastal area of north-central and northern California.

vialis (Osten Sacken) 1877:274 ♂ (*Thereva*), new combination. Distribution. — Sierra Nevada Mountains, California.

There are a number of undescribed species from the inland parts of western North America.

Genus **Psilocephala** Zetterstedt
(Fig. 10, 11, and 107–114)

Feminine

Psilocephala Zetterstedt 1838:525. Type-species: *Bibio imberbis* Fallén 1814:5; subsequent designation (Coquillett 1910:597). Type-locality: Sweden.

Diagnosis

Medium- to large-sized, thin to moderately broad species.

HEAD. — Frons of male at its narrowest distinctly narrower than half width of anterior ocellus; frons of female at level of anterior ocellus 1.8–1.9× as wide as ocellar tubercle; male frons tomentose and without pile, tomentum silvery gray; female frons tomentose anteriorly, upper three-quarters shiny blackish with a circular, depressed, wrinkled area medially, tomentum silvery gray; blackish part of frons has short, black pile; head only very slightly protrudes at antennal level; lateral portion of face without pile; gena has whitish pile similar to, but shorter than, lower occipital pile; head depth 1.3–1.6× antennal length; scape slender, 0.4–0.5× as long as flagellum; flagellar style apical, two segmented, with a small terminal spine; palps one segmented.

THORAX. — np 3, sa 2, pa 1, dc 2, sc 2; mesonotal pile of male long, erect and uniform, composed of pale and darker hairs, which are distinctly longer than width of scape; mesonotal pile of female much shorter, entirely dark, partly erect, partly semi-appressed; prosternum bare in and around central depression. WING. — Cell m_3 usually closed, rarely open, and common vein usually short; veins R_4 and R_5 about equal in length; cell r_4 about 2.5× as long as wide at apex; color hyaline with faint brownish tinge;

stigma pale brown; no other markings on wing. Legs. — Fore coxa has 2 or 3 apical setae on anterior surface; middle coxa without pile on posterior surface; hind femur has 3–4, rather slender, anteroventral setae.

Abdomen. — Rather broadly built, in male gradually tapering from segment 3 to apex; in female tapering from segment 5 to apex; abdomen not telescoped; dorsum convex in male, more flattened in female; male dorsum entirely tomen-

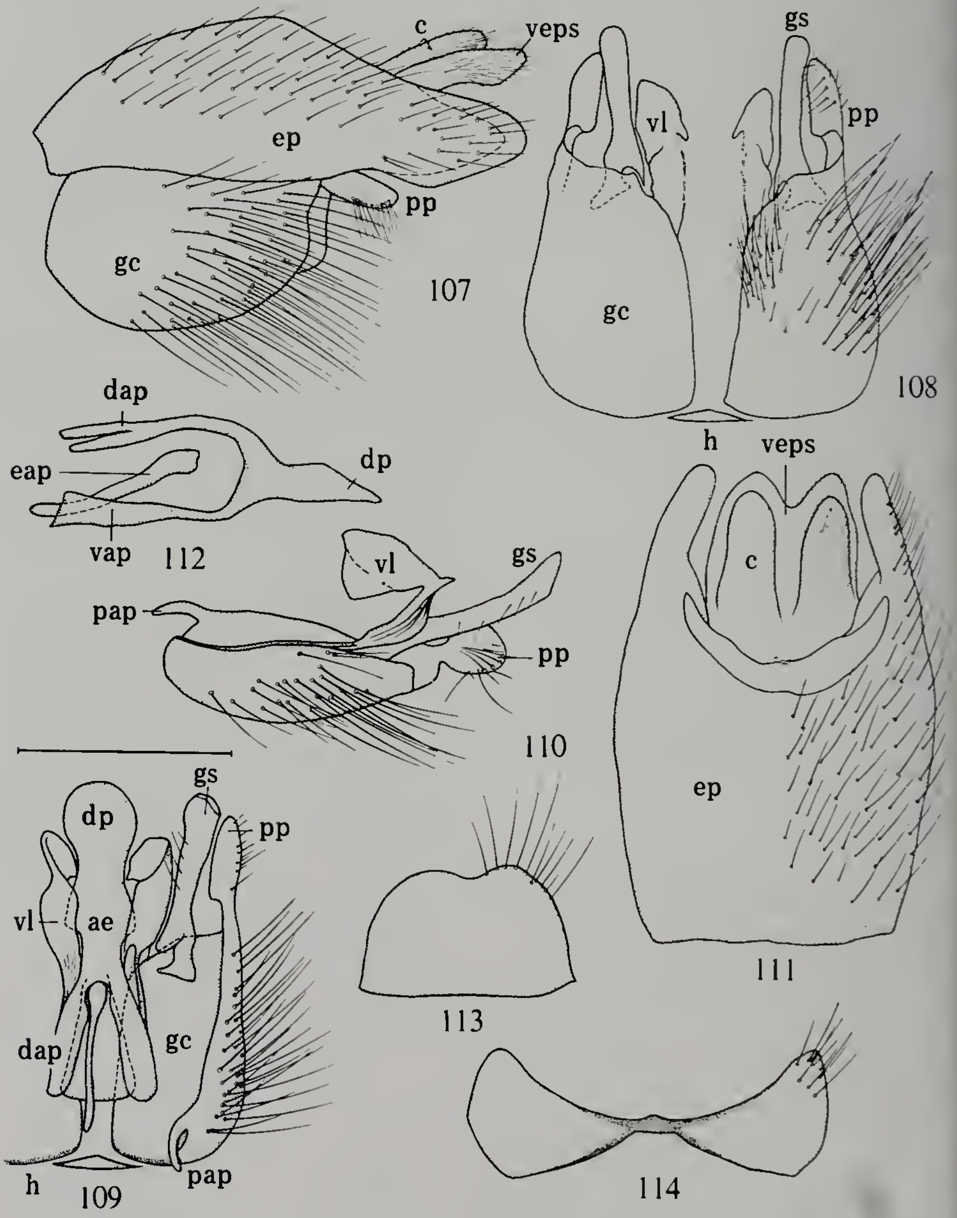

Fig. 107–114. — *Psilocephala imberbis* Fall. male terminalia. 107. — Genitalia in lateral view. 108. — Gonocoxites with appendages and hypandrium in ventral view. 109. — Left gonocoxite with appendages and aedeagus in dorsal view. 110. — Right gonocoxite with appendages in ventral view. 111. — Epandrium with appendages in dorsal view. 112. — Aedeagus in lateral view. 113. — Sternite 8. 114. — Tergite 8. Scale: 0.5 mm. List of abbreviations appears on pages 194 and 195.

tose except for polished black terminalia, tomentum silvery gray; female dorsum mostly shining black, but with marked pattern of silvery gray tomentum on segments 1–3 and 5–6.

MALE TERMINALIA (Fig. 107–114). — Tergite 8 (Fig. 114) wide, greatly constricted for a short distance medially; sternite 8 (Fig. 113) nearly semicircular, only slightly incised along posterior margin; epandrium (Fig. 107 and 111) noticeably convex, shorter in midline than wide, but has prominently projecting posterolateral corners, which are broadly lamellate; cerci free, well sclerotized, not projecting beyond ventral epandrial sclerite; ventral epandrial sclerite strongly reduced, restricted to a distinctly bilobed sclerite lying below and similar in size to cerci; apparently membrane lacking beneath epandrium; parameral apodeme without attachment to aedeagus; distiphallus (Fig. 109) in dorsal view nearly circular, in lateral view (Fig. 112) quite flat and straight; dorsal apodeme narrow proximally, but gradually wider toward apex; ejaculatory apodeme very slender; ventral lobes of gonocoxites (Fig. 110) large and strongly sclerotized, rising first in a vertical position, then suddenly curving anteriorly and terminating distally in a section firmly attached to midlateral part of aedeagus; ventral lobes not, or at most very weakly, attached along midline (Fig. 108); parameral process strongly sclerotized and rather broad; parameral apodeme long, narrow; gonocoxites not united ventrally, not even by a distinct membrane; gonocoxites truncate in lateral view (Fig. 107); hypandrium present as a small, triangular sclerite (Fig. 108).

Habitat

Specimens in this genus occupy forested zones. Very little is known of specific habitats.

Distribution

The genus *Psilocephala* is Holarctic. Within the Nearctic Region, specimens at hand are from these areas: Canada (Nova Scotia, Quebec, Ontario, Manitoba, Saskatchewan, Alberta, Yukon Territory, District of Mackenzie, and British Columbia); United States of America (Alaska, Washington, Oregon, northern California, Utah, Wyoming, Colorado, Montana, Wisconsin, Minnesota, Michigan, Pennsylvania). One male specimen is labeled from Douglas, Arizona. This specimen appears to be from outside the normal range of the genus, or it might be mislabeled.

Included Species

conspicua (Walker) 1848:223 ♀ (*Thereva*). Distribution. — Nova Scotia.

munda Loew 1869*a*:9 ♀. Distribution. — Great Lakes Region of North America.

  melanoprocta Loew 1869*a*:11 ♂, subsequent synonymy (Kröber 1912:239).

vicina (Walker) 1848:222 ♂ (*Thereva*). Distribution. — Nova Scotia.

P. conspicua (Walker) and *munda* (Loew) may well prove to be synonymous with *vicina* (Walker).

The western specimens have not been studied closely; they could represent one or more distinct, undescribed species, or they could prove to be western populations of *vicina* (Walker) or *munda* (Loew).

Genus **Penniverpa** Irwin & Lyneborg, new genus (Fig. 25 and 115–121)

Feminine

Derivation of name: *penna* (Latin) = feather; *verpa* (Latin) = penis.

Type-species: *Psilocephala festina* Coquillett 1893*b*:225 by present designation. Type-locality: Florida.

Diagnosis

Small- to medium-sized flies of very slender build.

HEAD. — Frons of male at its narrowest narrower than half width of anterior ocellus; frons of female narrow, at level of anterior ocellus 1.0–1.3× as wide as ocellar tubercle; male frons high, narrow, entirely tomentose and without pile, tomentum silvery (one species from Peru has a silvery golden tomentose frons

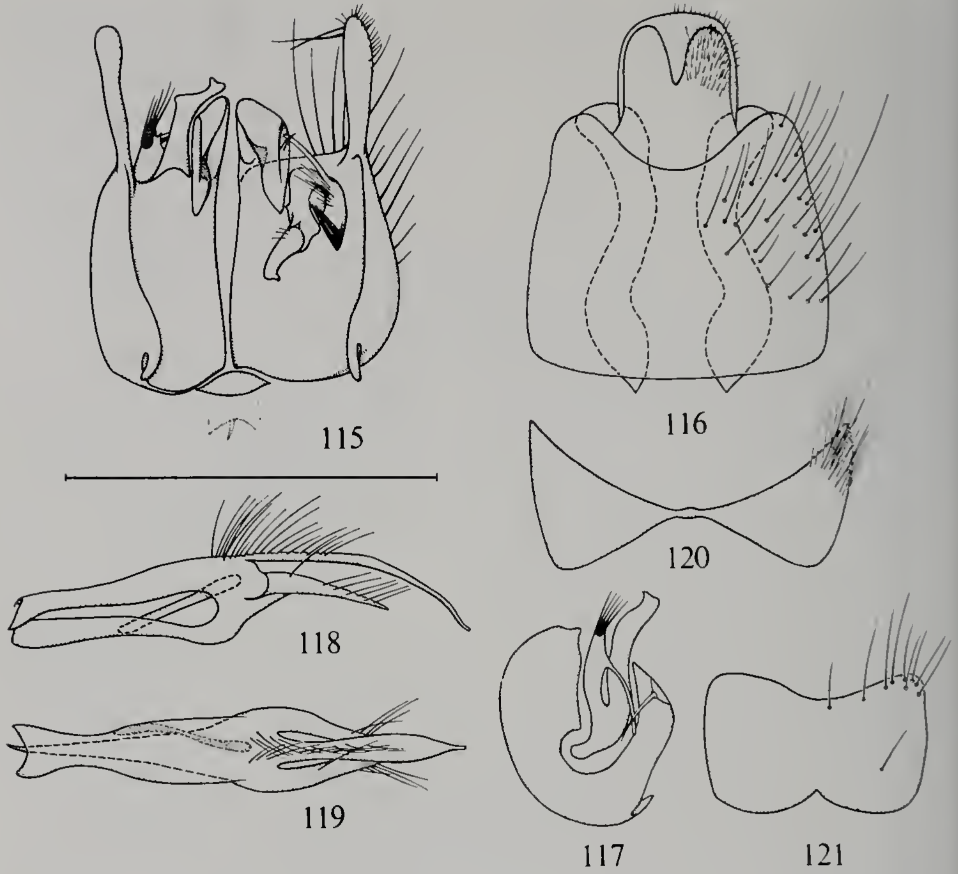

Fig. 115–121. — *Penniverpa festina* (Coq.) male terminalia. 115. — Gonocoxites with appendages and hypandrium in dorsal view; the natural positions of the anterior and posterior ends of aedeagus are shown. 116. — Epandrium with appendages in dorsal view. 117. — Left gonocoxite with ventral lobe and gonostylus in caudal view. 118. — Aedeagus in lateral view. 119. — Aedeagus in dorsal view. 120. — Tergite 8. 121. — Sternite 8. Scale: 0.5 mm.

with a few stout hairs on its lower half); female frons entirely tomentose, either uniformly silvery or upper part darker than lower part; female frons has short, sparse black pile on upper half; head moderately protrudes anteriorly; lateral portion of face without pile; gena bare or with sparse white pile; head depth 1.5–1.8× antennal length; scape slender, 0.3–0.5× as long as flagellum; flagellar style apical, two segmented, with a small terminal spine; palps one segmented.

Thorax. — np 3–4, sa 2, pa 1, dc 0, sc 1–2 (usually 1); mesonotal pile of two kinds: the first semi-appressed, pale, and the other erect, black, usually shorter than scape; mesonotal pile of male generally longer and denser than that of female; prosternum has pile in and around central depression. Wing. — Cell m_3 broadly open; vein R_4 slightly longer than R_5; cell r_4 about 2.6–2.8× as long as wide at apex; color hyaline with pale brownish stigma. Legs. — Fore coxa has 2 strong apical setae on anterior surface; middle coxa without pile on posterior surface or with a little pile in that position in one South American species; hind femur has at most 3–4 short, slender anteroventral setae. Foreleg (Fig. 25) exceptionally long.

Abdomen. — Slender in both sexes, entirely cylindrical in male, dorsum more flattened in female, tapering from segment 2 to apex; male dorsum entirely covered by silver tomentum and whitish pile; female dorsum has pattern of blackish bands and whitish tomentose areas.

MALE TERMINALIA (Fig. 115–121). — Tergite 8 (Fig. 120) about as wide as epandrium and greatly constricted medially; sternite 8 (Fig. 121) rectangular, with incisions in both anterior and posterior margins; epandrium (Fig. 116) shorter in midline than wide, its posterolateral corners broadly rounded; cerci (Fig. 116) rather weakly sclerotized and finely haired, fused along basal part; ventral epandrial sclerite projects slightly more than cerci; posterior section of ventral epandrial sclerite rounded; a setose pair of S-curved sclerites attached by membranes to posterior edge of epandrium; these sclerites not attached over midline by a distinct membrane, but their anteriormost corners are loosely attached by weak membranes to anterior margin of aedeagus; parameral apodeme without attachment to aedeagus; aedeagus (Fig. 118 and 119) long and slender; distiphallus in lateral view (Fig. 118) very flat and gently downcurved, a double row of long setae on proximal part; dorsal apodeme (Fig. 119) long and slender; ventral apodeme (Fig. 119) as long as or longer than dorsal apodeme, in dorsal view gradually tapering; 2 processes arise from midsection of aedeagus, nearly parallel to distiphallus and pointed apically; these processes converge, and the usually setose apices meet either above or below the distiphallus in lateral view; ejaculatory apodeme very slender and short, completely contained between dorsal and ventral apodemes in dorsal view; aedeagus loosely attached to ventral lobes of gonocoxites; ventral lobes (Fig. 115 and 117) complicated, rising dorsally, forming a lamellate structure, and often having a spine on exterior surface not far from the distal, dorsal edge; the gonostylus (Fig. 115 and 117) remarkably complicated, showing many modifications in several undescribed species; gonostylus more or less U shaped, composed of exterior and interior ventrally united sections; interior section relatively consistent in shape; exterior section with strong modifications, from a simple tooth, or a long process with a group of distal spines and a narrow projection stretching toward the ventral lobe (as in the type-species), to the distal spines being absent and the narrow projection being replaced by strong setae; many more modifications will certainly emerge when the numerous species are described; parameral process long, free; gonocoxites free ventrally, attached by a weak membrane; a distinct, free hypandrium present, but not always as large as illustrated (Fig. 115).

Habitat

We have only encountered a few species in nature. All have been found in very sandy areas or in dry sandy washes. A species from Lima, Peru (probably *gracilis* Kröber 1911:507) was captured abundantly in a sandy cornfield.

Distribution

Judging from the material at hand, we conclude that this genus occurs in the southern United States (Arizona, Texas, Florida, and Georgia) and southward through Mexico, the West Indies (Cuba, Jamaica, and Trinidad), Central America (Panama, Honduras, and Guatemala), and portions of South America (British Guiana, Venezuela, Brazil, Ecuador, Peru, and Bolivia).

Included Species

festina (Coquillett) 1893*b*:225 ♂, ♀ (*Psilocephala*), new combination. Distribution. — Georgia, Florida. (Other literature records probably refer to other, closely related, mostly undescribed species.)

At least four additional species, all from South America, can be placed in the genus *Penniverpa,* including *senilis* (Fabricius) (1805:68), new combination, which was reported by Lyneborg (1969: 390) probably to be from northeastern South America. Several undescribed species are mainly from the West Indies and Central and South America, but at least one undescribed species occurs in Texas, Arizona, and northeastern Mexico.

Genus Lysilinga Irwin & Lyneborg, new genus (Fig. 122–127)

Feminine

Derivation of name: *lysis* (Greek) = free, loose; *linga* (Sanskrit) = penis.

Type-species: *Psilocephala aurantiaca* Coquillett 1904*b*: 177 by present designation. Type-locality: Claremont, California.

Diagnosis

Medium-sized, slender-bodied species with little pile on body.

HEAD. — Compound eyes of male nearly touch for a considerable distance; eyes of male not divided into two distinct facet sizes. Frons of female narrow, upper half only slightly wider than ocellar tubercle, with lower half expanded to slightly more than twice width of upper half. Head about 1.2–1.4× wider than high; ratio of the distance between the lower, inner corners of compound eyes and head height 0.5–0.6; antennae rather low on head, inserted at three-fifths of head height; width of head 2.6–3.0× that of frons at antennal insertion; genae small, rounded, tomentum undifferentiated from that of face. Head hypognathous; proboscis small, fitting into subcranial cavity and not reaching antennal base; palps one segmented, slender, rodlike, usually pale colored, thinly pilose, shorter than proboscis. Head depth 1.2–1.4× antennal length; scape 0.4–0.6× as long as flagellum; flagellum laterally compressed, pear shaped, wider (dorsoventrally) than scape; flagellar style short, of apparently two segments plus terminal spine. Short, sparse, appressed pile on upper frons of female. Frons and face of male usually without pile or setae (in *L. occipitalis* occasional specimens have a few setae on lower central frons), covered with dense, silvery tomentum. Lower frons and face of female and genae and occiput of both sexes also densely tomentose, tomentum silvery. Upper frons of female usually has silvery to brown tomentum and a pair of usually large, brown velvety spots tangential to each compound eye at division of brown and silvery tomentum. (In an undescribed

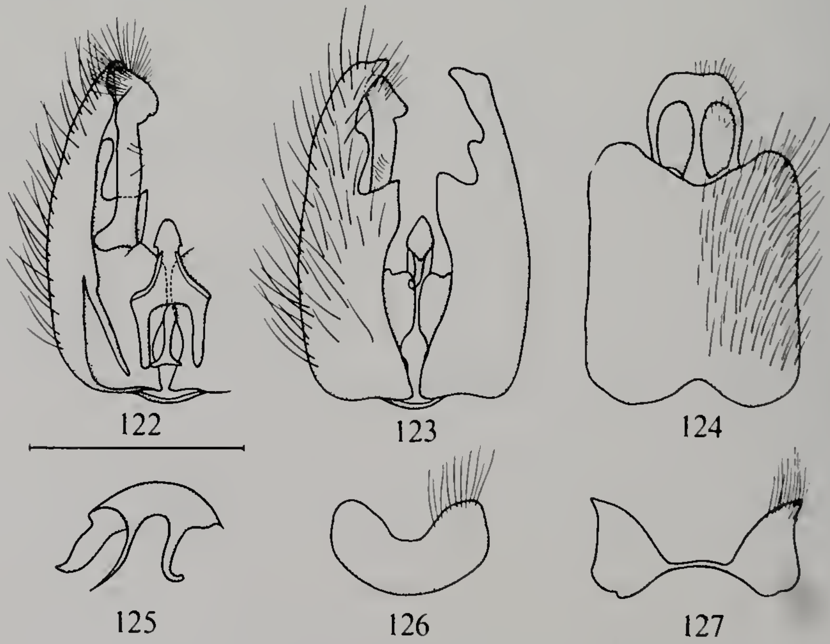

Fig. 122–127. — *Lysilinga aurantiaca* (Coq.) male terminalia. 122. — Right gonocoxite with appendages and aedeagus in dorsal view. 123. — Gonocoxites, hypondrium, and aedeagus in ventral view. 124. — Epandrium with appendages in dorsal view. 125. — Aedeagus in lateral view. 126. — Sternite 8. 127. — Tergite 8. Scale: 0.5 mm.

species from Mexico, the velvet spots are very small.) Head deeper ventrally than dorsally, giving the appearance, when viewed laterally, of a rounded isosceles triangle, the ocelli forming a point and the lengths of occiput and frons forming the long sides. The side from the antennae to the lower genae appears rounded. Ocellar tubercle has sparse, short setae in some species, lacks setae in others.

Thorax. — np 3, sa 2, pa 1, dc 0, sc 1–2; thoracic setae from dark brown to black (*L. aurantiaca,* undescribed species from Mexico) to yellowish white (*L. occipitalis, L. subrufa*). Mesonotal pile short, sparse, appressed, yellow-metallic scalelike, more abundant on males. Mesonotal tomentum grayish to brown with no discernable pattern of vittae. Prosternum has elongate white pile in and around central depression. Wing. — Cell m_3 widely to narrowly open; ratio of lengths R_4/R_5, 1.0–1.1; cell r_4 2.2–2.6× longer than wide at apex; wings hyaline with a darkened area around stigma (and cell r_1 darkened in males of an undescribed species from Mexico). Legs. — Fore coxa has 2 large setae on apical half of anterior surface; middle coxa has pale, sparse, scalelike pile on posterior surface; fore femur has a single seta in the av position; middle femur without setae; hind femur has a row of av and pv setae, av setae fewer but stouter than pv setae. All femora have scalelike pile, especially along dorsal margin.

Abdomen. — Slender, tapering toward apex, cylindrical in cross section; abdominal segments not telescoped; pile sparse, appressed, usually short. Tomentum of both sexes silvery, generally restricted to posterior margins of tergites 1, 2, 3 and often 5 and 6 (except in male of undescribed species from Mexico that has silvery tomentum covering abdomen). Ground color often red, orange, yellow, or light brown.

Male Terminalia (Fig. 122–127). — Tergite 8 elongate, bilobate at lateral margins, very thin medially (Fig. 127); sternite 8 a small bilobate sclerite (Fig. 126). Epandrium large (Fig. 124), slightly wider than long measured along midline; posterolateral margins not modified. Cerci elongate, shorter than ventral epandrial sclerite, separate from one another; ventral epandrial sclerite simple elongate, not keeled, not deeply cleft; intersegmental membrane basad of ventral epandrial sclerite weakly sclerotized laterally, connecting to sclerite and anterior margin of aedeagus (this connection not obvious because of transparent membrane); this membrane also attached to posterolateral portion of epandrium. Gonocoxites (Fig. 122 and 123) free for their entire length; hypandrium narrow, bridgelike, connecting gonocoxites; parameral process absent although gonocoxites project posteriorly and greatly enlarged; parameral apodeme attached to lateral margin of dorsal apodeme by thin, transparent membrane. Ventral lobes of moderate size, dentate, not upright, weakly attached to center of aedeagus, free from one another (Fig. 123); gonostylus elongate, reaching apex of expanded gonocoxite, twisted dorsally like a large hook; ratio of aedeagus basad of center/distad of center about 1/1; ratio of width of phallus base/width of dorsal apodeme, 4/1. Aedeagus (Fig. 122 and 125) of moderate size; distiphallus short, strongly curved, with a peculiar hoodlike appendage above and projecting posteriorly; ventral apodeme short, narrow, about as long as ejaculatory apodeme; dorsal apodeme heavily sclerotized laterally into two parallel bars; distal end of ejaculatory apodeme slightly enlarged laterally, dorsoventrally flattened.

Habitat

Little is known about the habitat of various species of *Lysilinga.* In Riverside, southern California, a malaise trap set in a small wash on a sparsely vegetated hillside yielded several specimens of *L. aurantiaca* over a period of several months.

Distribution

Lysilinga is, judging from specimens examined, confined to western North

America: southern California, Arizona, and New Mexico in the United States; Sonora, Chihuahua, Oaxaca, and Guerrero in Mexico.

Included Species

aurantiaca (Coquillett) 1904*b*:177 ♂ (*Psilocephala*), new combination. Distribution. — Southern California, Arizona, and New Mexico; Sonora, Mexico.

occipitalis (Adams) 1904:443 ♂ (*Psilocephala*), new combination. Distribution. — Southern California, Arizona, and New Mexico; Sonora and Chihuahua, Mexico.

subrufa (Cole) 1923*a*:68 ♀ (*Psilocephala*), new combination. Distribution. — Arizona and southern California. (This species may be conspecific with *L. occipitalis*.)

There is one undescribed species from Guerrero and Oaxaca in southwestern Mexico.

Genus **Brachylinga** Irwin & Lyneborg, new genus (Fig. 18 and 128–135)

Feminine

Derivation of name: *brachys* (Greek) = short; *linga* (Sanskrit) = penis.

Type-species: *Psilocephala baccata* Coquillett 1893*b*:226 by present designation. Type-locality: Los Angeles and San Bernardino counties, California.

Diagnosis

Small- to medium-sized, often slender species.

HEAD. — Compound eyes of male touch to nearly touch for a short distance; eyes of male not divided into two distinct facet sizes. Frons of female (Fig. 18) rather narrow in most species, upper half only slightly wider than ocellar tubercle, lower half expanded to 2–3× width of ocellar tubercle. In an undescribed species from San Blas, Nayarit, Mexico, female frons very wide, 2.3× width of ocellar tubercle at level of anterior ocellus, 4× width at antennal insertion. Head squat, 1.2–1.6× wider than high; distance between lower, inner corners of compound eyes 0.6–0.8× head height; antennae about midway or slightly lower on head, between 40 and 70 percent of head height above antennal insertion; genae small, rounded, tomentum usually undifferentiated from that of face (small group of species along Pacific Coast from Sonora, Mexico, to Panama has differentiated tomentum on genae). Head slightly prognathous in most species, hypognathous in others; proboscis relatively large, reaching to or slightly beyond base of antennae in most species; palps ½–¾ length of proboscis, often yellowish to yellowish-brown. Head depth 1.2–1.4× antennal length; scape 0.5–0.8× as long as flagellum; first flagellomere pear shaped to elongate; dorsal portion of scape sparsely to densely covered with thickened, dark setae; antennae covered with a fine tomentum; flagellar style short, of apparently two segments plus terminal spine. Pile on frons of male variable, from absent to abundant, from erect to appressed, from short to long; pile on female also variable although never entirely absent. Frons, face, genae, and occiput clothed in coarse to fine pruinose tomentum, often brown, gray, or silvery; upper and lower frons not differentiated by pattern or color of tomentum; frons of female (Fig. 18) often has a velvety brown spot tangential to each compound eye; this spot large and round or small and flattened against eye margin; in some species no spot is evident. Frons of male either with or without small spot; if spots exist, they are flattened against each compound eye. Ocellar tubercle has few to several setae.

THORAX. — np 3, sa 1–2 (usually 2), pa 1, dc 0–2 (usually 2), sc 2; thoracic setae dark brown to black. Mesonotal pile generally sparse, thin, erect, with scalelike, bronze-colored appressed pile; pile generally denser on males than on females. Mesonotal tomentum usually grayish to brown without discernible pattern of vittae. WING. — Cell m_3 from widely open to closed; ratio of lengths R_4/R_5 about 1.0–1.1; cell r_4 2.0–3.2× longer than wide at apex; wings hyaline

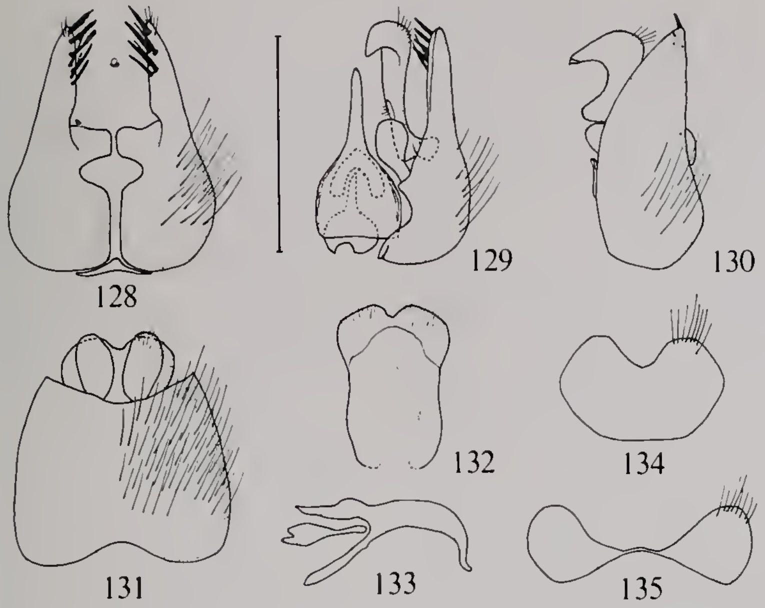

Fig. 128–135.— *Brachylinga baccata* (Caq.) male terminalia. 128. — Gonocoxites and hypandrium in ventral view. 129. — Left gonocoxite with appendages and aedeagus in dorsal view. 130. — Left gonocoxite and gonostylus in lateral view. 131. — Epandrium with appendages in dorsal view. 132. — Ventral epandrial sclerite. 133. — Aedeagus in lateral view. 134. — Sternite 8. 135. — Tergite 8. Scale: 0.5 mm.

with a darkened area around stigma in some species and darkened areas surrounding the veins in a few species. Legs. — Fore femur has 0–1 av setae (usually 1); middle femur has no setae; hind femur has a sparse row of av and pv setae; scalelike, appressed as well as thin, erect pile on all femora.

Abdomen. — Slender (especially in male), tapering toward apex, cylindrical in cross section; pile sparse, semi-appressed in most species; tomentum sparse, usually silvery along sides of females, covering all of dorsum in males of most species (*B. pavida* males lack this feature). Ground color often dark brown or black.

Male Terminalia (Fig. 128–135). — Segment 8 from slightly to greatly reduced; sternite 8 (Fig. 134) a rounded sclerite, notched on the posterior margin; tergite 8 from narrowly constricted (as in *B. pavida*) to broadly constricted (as in *B. baccata* (Fig. 135) and *B. abdominalis*). Epandrium (Fig. 131) of moderate size, usually wider than long, ratio of length/width along midlines from 0.7 to 1.0; posterolateral margins not modified; cerci as long as to considerably shorter than ventral epandrial sclerite and usually free from one another; ventral epandrial sclerite (Fig. 132) simple, often notched apically, usually relatively large with respect to cerci; intersegmental membrane basad of ventral epandrial sclerite weakly sclerotized, with small, lateral shields fitted into posteroventral portion of epandrium in some species and not, or at most very weakly, connected to anterior margin of aedeagus. Gonocoxites (Fig. 128) free over entire length, usually simple in form, but in some species elongate posteriorly; hypandrium small, thin, free, bridgelike, attached to both gonocoxites by membranes; aedeagus attached to ventral lobes of gonocoxites; parameral process absent or very minute; parameral apodeme attached to lateral margin of aedeagus by a thin, transparent membrane; ventral lobes of moderate size (small in a few West Indian species), weakly attached to center of aedeagus; gonostylus usually elongate, curved dorsad, and with a tuft of setae on extreme posteroventral portion in a few species; gonostylus reaches beyond (posteriorly) distiphallus and, in most species, beyond gonocoxite extensions; ratio of aedeagus basad of center/distad of center, usually 0.67–0.80, in a few cases 1.0–1.4 (e.g., *B. abdominalis*); ratio of width of phallus base/width of dorsal apodeme, 0.15–0.44, most North American species ranging between 0.3 and 0.4. Aedeagus variable, usually of moderate size; distiphallus short (as in *B. abdominalis*) to long [as in *B. sericeifrons* (Kröber 1928*a*:34) from Chile], with those of most North American species of moderate length; distiphallus simple, downcurved apically; ventral apodeme short, broader at base than at apex, shorter than dorsal apodeme, and usually shorter than ejaculatory apodeme, in *B. abdominalis* very broad and forked apically; dorsal apodeme shieldlike, broader apically than basally, generally more heavily sclerotized along lateral margins; distal end of ejaculatory apodeme club shaped, in *B. abdominalis* very large, triangular.

Habitat

Many of the species inhabit dry canyons in Mediterranean zone vegetation; others are found along beach areas in and amongst dune vegetation. Species of *Brachylinga* are not found in extreme deserts but are often associated with marginal desert habitats.

Distribution

Brachylinga occurs throughout much of the drier zones of the Nearctic and Neotropical regions. One group is found in the southwestern USA and western Mexico, another in Chile, Peru, and Ecuador; yet another is found in the West Indies and Florida.

Included Species

- *abdominalis* (Fabricius) 1805:12 (*Bibio*), new combination. Distribution. — Puerto Rico, West Indies.
  - *vexans* (Curran) 1926:2 ♂, ♀ (*Psilocephala*), new synonym.
- *baccata* (Coquillett) 1893*b*:226 ♂, ♀ (*Psilocephala*), new combination. Distribution. — California.
- *cinerea* (Cole) 1923*a*:65 ♂, ♀ (*Psilocephala*), new combination. Distribution. — New Mexico.
- *monensis* (Curran) 1926:2 ♀ (*Psilocephala*), new combination. Distribution. — Mona Island, West Indies.
- *morata* (Coquillett) 1893*b*:225 ♂, ♀ (*Psilocephala*), new combination. Distribution. — New York, New Jersey, Florida.
- *obscura* (Coquillett) 1893*b*:229 ♀ (*Psilocephala*), new combination. Distribution. — Jamaica, West Indies.
- *pavida* (Coquillett) 1893*b*:226 ♂ (*Psilocephala*), new combination. Distribution. — Arizona, California; Baja California, Mexico.
- *pilosa* (Kröber) 1914:47 ♂ (*Psilocephala*), new combination. Distribution. — Arizona.
- *platycera* (Loew) 1872:114 ♀ (*Psilocephala*), new combination. Distribution. — Cuba, West Indies.
  - *laticornis* (Loew) 1869*a*:10 ♀ (*Psilocephala*), not Loew 1856.
- ? *slossonae* (Coquillett) 1893*b*:227 ♀ (*Psilocephala slossoni*) emendation, new combination. Distribution. — New Hampshire.
  - *slossoni* (Coquillett), improper original spelling.
- *squamosa* (Hardy) 1943:24 ♂, ♀ (*Psilocephala*), new combination. Distribution. — Key West, Florida.
- *tepocae* (Cole) 1923*b*:461 ♀ (*Psilocephala*), new combination. Distribution. — Sonora, Mexico.

More than 10 species of *Brachylinga* are undescribed, and several species are described from South America.

Genus **Litolinga** Irwin & Lyneborg, new genus (Fig. 16, 17, and 136–141)

Feminine

Derivation of name: *litos* (Greek) = simple; *linga* (Sanskrit) = penis.

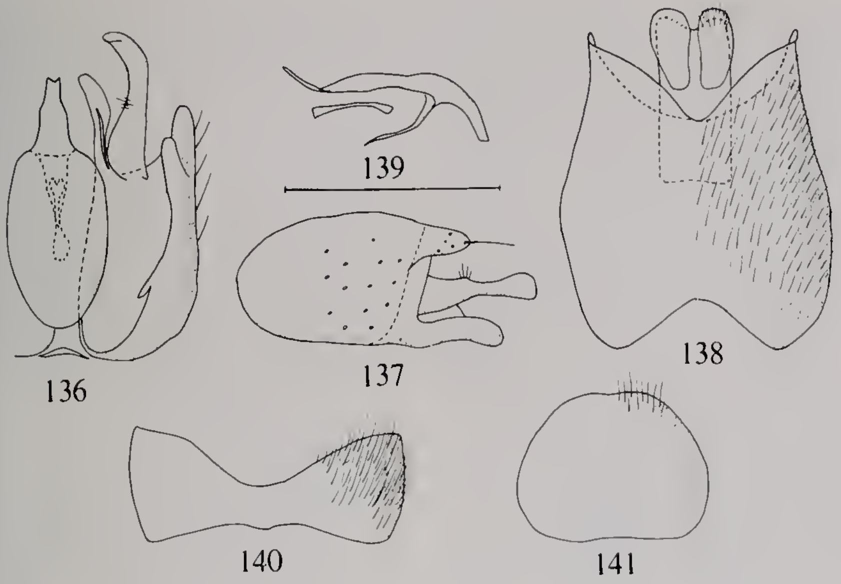

Fig. 136–141. — *Litolinga acuta* (Adams) male terminalia. 136. — Left gonocoxite with appendages and aedeagus in dorsal view. 137. — Left gonocoxite with appendages in ventrolateral view. 138. — Epandrium with appendages in dorsal view. 139. — Aedeagus in lateral view. 140. — Tergite 8. 141. — Sternite 8. Scale: 0.5 mm.

Type-species: *Psilocephala acuta* Adams 1903:222 by present designation. Type-locality: Englewood, Clark County, Kansas.

Diagnosis

Small- to medium-sized, usually slender species.

Head. — Compound eyes of male almost touching for a considerable distance; eyes of male of two distinct facet sizes, with a linear indentation on eye surface where different facet sizes meet. Frons of female (Fig. 17) extremely wide, more than 3× width of ocellar tubercle at level of antennal insertion and more than 2× width of ocellar tubercle at vertex. Frons of male has light to dark brown velvety patch contiguous with each compound eye; frons of female usually has distinct rounded, dark brown velvety spot contiguous with each compound eye (one undescribed species from Texas has minute crescent-shaped velvety patches). Frons and face of both sexes completely tomentose; tomentum buff to brown; frons and upper face of male without pile or setae; frons of female has scattered, sparse, short setae above velvety spots, otherwise upper face and frons without pile or setae. Genae protrude as lobes below compound eyes (Fig. 16), always with a patch of darker brown tomentum running to subcranial cavity. Head triangular in shape when viewed from side, with ocelli forming upper point, base of genae a second and antennal insertion a third, with antennae placed very low on head. Ocellar tubercle has many short setae angled forward, originating mainly from posterior portion. Head 0.6–0.8× as deep as antennal length; scape of male 0.4–0.5× as long as flagellum; scape of female 0.5–0.6× as long as flagellum. Scape stout; first flagellomere exaggeratedly pear shaped with a longer terminal style composed of a single segment plus a blunted apical spine. Palps one segmented although on some specimens they may appear to be two segmented.

Thorax. — np 3, sa 1–2 (usually 2), pa 1, dc 0, sc 1–2; all thoracic setae dark brown to black; mesonotal pile of both sexes pale, mostly silvery, appressed, sparse in general; prosternum with elongate white pile in and around central depression. Wing. — Cell m_3 widely open; ratio of lengths R_4/R_5 0.93–1.05; cell r_4 2.0–2.8× longer than wide at apex; wings generally have mottled brown patches between veins, amount of darkened area differs between species. Legs. — Fore coxa has 2 large, black setae on anterior surface, 1 apical, the other about midway between apex and base of coxa; hind femur has 3–7 anteroventral setae.

Abdomen. — Rather slender, gradually tapering from segment 2 toward apex; abdominal segments not telescoped; male dorsum flattened, most species have a patina of fine silvery tomentum; ground color dark to light brown.

Male Terminalia (Fig. 136–141). — Tergite 8 only moderately constricted in middle (Fig. 140); sternite 8 a small, nearly circular sclerite (Fig. 141). Epandrium (Fig. 138) about ⅔ as long as wide along midline, with sharp posterolateral corners extending nearly to level of posterior margin of ventral epandrial sclerite; cerci extend slightly beyond ventral epandrial sclerite; ventral epandrial sclerite simple, about 2× as long as cerci, posterior margin incised in several species; sclerotization of intersegmental membrane anterior of ventral epandrial sclerite weak, connecting this sclerite with anterior margin of aedeagus; sclerotization of intersegmental membrane does not reach posterolateral portion of epandrium. Gonocoxites (Fig. 136) free for their entire distance; hypandrium free, small, bridgelike, connecting gonocoxites; parameral process present as a short finger; parameral apodeme weak, not attached to aedeagus; ventral lobes of gonocoxites relatively large, lightly sclerotized, and weakly attached to ventral center of aedeagus; gonostylus elongate, twisted toward distiphallus, usually blunt; ratio of aedeagus basad of center/distad of center about 2/1; ratio of width of phallus base/width of dorsal apodeme 1/4. Aedeagus (Fig. 136 and 139) large, distiphallus simple, short, downward curved; ventral apodeme thin, short, bladelike, about ⅔ as long as dorsal apodeme, not entirely covering ejaculatory apodeme; dorsal apodeme generally covers ejaculatory apodeme; anterior end of ejaculatory apodeme clublike, enlarged, though dorsoventrally flattened.

Habitat

Specimens of *Litolinga* have been collected in the beach sands of the Gulf of Mexico and inland in sand dunes of Kansas and Texas. Larvae of one species, *L. acuta* (Adams), are known predators of *Elasmopalpus lignosellus* (Zeller), the lesser corn stalk borer, on peanuts in Texas (Johnson 1978).

Distribution

Litolinga is restricted to the southeastern and south-central United States (Florida, Kansas, Texas) and along the eastern coast of Mexico (Tamaulipas. Vera Cruz).

Included Species

acuta (Adams) 1903:222 ♂, ♀ (*Psilocephala*), new combination. Distribution. — Kansas, Texas.
 pallida (Kröber) 1914:45 ♂ (*Psilocephala*), new combination, new synonym.
? *bolbocera* (Osten Sacken) 1887:162 ♀ (*Thereva*), new combination. Distribution. — Presidio, Mexico. (From the description, the species seems to belong within *Litolinga*.)
 bolbocceras, Kröber 1914:64, error in spelling.
tergisa (Say) 1823:39 ♂ (*Thereva*), new combination. Distribution. — Florida.
 tergissa, LeConte 1859:57, unjustified emendation.
 corusca (Wiedemann) 1828:232 ♂ (*Thereva*) Cole 1923*a*:71.

There are about three undescribed species.

Genus **Rhagioforma** Irwin & Lyneborg, new genus (Fig. 23 and 142–147)

Feminine

Derivation of name: *Rhagio*, a genus of flies; *forma* (Latin) = shape, form.

Type-species: *Psilocephala maculipennis*

Kröber 1914:45 by present designation. Type-locality: San José del Cabo, Baja California, Mexico.

Diagnosis

Moderately large-sized, slender species.

Head. — Frons of male at its narrowest much narrower than half width of anterior ocellus; frons of female at level of anterior ocellus 2.0–2.2× as wide as ocellar tubercle; male frons raised, with brownish-gray tomentum and long, black pile over entire surface; female frons has brownish-gray tomentum, unpatterned, slightly concave in middle, and has short, appressed pile on upper two-thirds; head rather prominently protrudes anteriorly at antennal level; head depth 1.2–1.4× antennal length (Fig. 23); scape slender, 0.6–0.8× as long as flagellum; first flagellomere constricted at base; flagellar style long, slender, two segmented, with a distinct, terminal spine; palps one segmented.

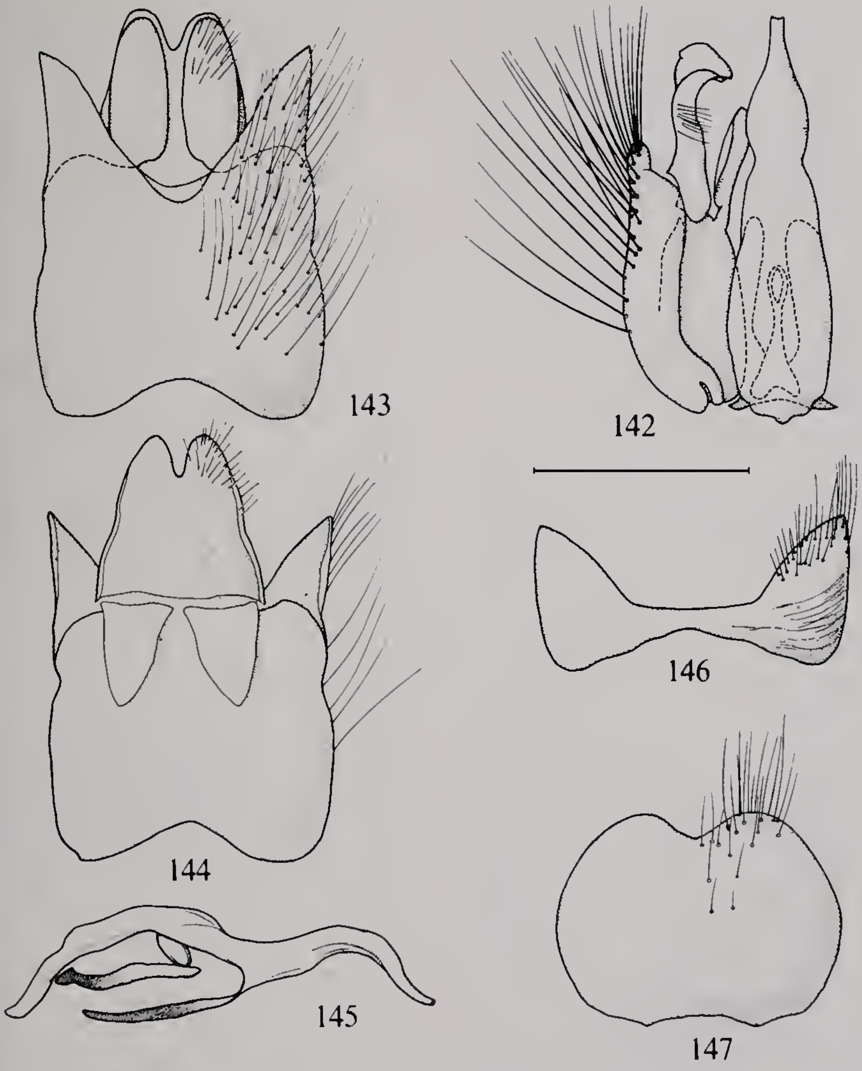

Fig. 142–147. — *Rhagioforma maculipennis* (Kröb.) male terminalia. 142. — Right gonocoxite with appendages and aedeagus in dorsal view. 143. — Epandrium with appendages in dorsal view. 144. — Epandrium with appendages in ventral view. 145. — Aedeagus in lateral view. 146. — Tergite 8. 147. — Sternite 8. Scale: 0.5 mm.

Thorax. — np 3–4, sa 2, pa 1, dc 2, sc 2; mesonotal pile of male long, dense, erect, that of female much shorter and more appressed; prosternum has long pale pile in and around central depression. Wing. — Cell m_3 open or closed at wing margin; vein R_4 much longer than vein R_5; cell r_4 about 2× longer than wide at apex; wing grayish-brown with pattern formed by dark shadows around crossvein and distal portion of longitudinal veins; stigma dark brown. Legs. — Fore coxa has 2 strong black setae: 1 apical on anterior surface and 1 subapical on exteroanterior margin; hind femur has 5–7 anteroventral setae, a few posteroventral setae.

Abdomen. — Rather slender and gradually tapering from base toward apex; dorsum noticeably convex in both sexes; dorsum of male entirely tomentose and pilose; tomentum silvery gray, pile white; dorsum of female yellowish brown, with black spots in midline, pile sparse and very short, strongly resembling the abdominal pattern found in many species of *Rhagio* F.

Male Terminalia (Fig. 142–147). — Tergite 8 (Fig. 146) large and strongly constricted along middle; sternite 8 (Fig. 147) very large, broadly oval, with semicircular incision posteriorly; epandrium (Fig. 143) shorter in midline than wide, with pointed, projecting, posterolateral corners; cerci free (Fig. 143), well separated and sclerotized, sparsely haired, large; ventral epandrial sclerite (Fig. 144) extends slightly beyond cerci, posterior margin cleft, anteriorly reaching only to level of middle of epandrium, the anterior part separated along midline and from part below cerci; parameral apodeme without attachment to aedeagus; distiphallus (Fig. 142) wide proximally and gradually tapering, in lateral view (Fig. 145) only slightly curved; dorsal apodeme (Fig. 142) long, oval; ventral apodeme shaped like a very narrow spoon; ejaculatory apodeme (Fig. 142) small, with distal part expanded; ventral lobes of gonocoxite (Fig. 142) large, lamellate, loosely attached to ventral surface of aedeagus; parameral process absent, but parameral apodeme well developed, short and thick; gonocoxites not united ventrally, only attached by a weak membrane anteriorly; hypandrium (Fig. 142) present, free.

Habitat

Unknown. One female was taken drinking from a small stream in an otherwise dry area in northern Baja California.

Distribution

The genus *Rhagioforma* is apparently restricted to Baja California, Mexico.

Included Species

maculipennis (Kröber) 1914:45 ♂ (*Psilocephala*), new combination. Distribution. — Baja California, Mexico.

No undescribed species of this genus are known.

Genus Arenigena Irwin & Lyneborg, new genus (Fig. 19, 21, and 148–156)

Feminine

Derivation of name: *arena* (Latin) = sand; *gena* (Latin) = born in.

Type-species: *Thereva semitaria* Coquillett 1893*a*:198 by present designation. Type-locality: Southern California.

Diagnosis

Medium-sized, slender to moderately broad species.

Head. — Eyes in male (Fig. 19) absolutely touch for a rather long distance; frons of female at level of anterior ocellus about twice as wide as ocellar tubercle and only slightly widens toward bottom of eyes; frons in both sexes entirely tomentose, not patterned, with at most a few hairs on the upper frons of female; head only very slightly protrudes anteriorly; gena has very short, pale pile; head depth 1.5–1.7× antennal length (Fig. 21); scape slender, 0.5–0.9× as long as flagellum; flagellar style two segmented, with a distinct terminal spine; palps one segmented.

Thorax. — np 3, sa 2, pa 1, dc 1–2, sc 2; all thoracic setae pale; mesonotal pile in both sexes of two types: one is long, appressed, pale, scalelike, and the other is short, erect and pale or dark; prosternum has long, whitish pile in and around central depression. Wing. — Cell m$_3$ closed; veins R$_4$ and R$_5$ equal in length; cell r$_4$ 1.9–2.1× as long as wide at apex. Legs. — Fore coxa usually has 3 setae on anterior surface: 2 on apical half and 1 on basal half of anteroexterior margin, the latter rarely missing; hind femur has 6–8 anteroventral setae.

Abdomen. — Rather slender, gradually tapering posteriorly from segment 2; male dorsum convex or somewhat flattened, densely covered with whitish-gray tomentum and whitish pile; female dorsum yellowish, subshiny, frequently with

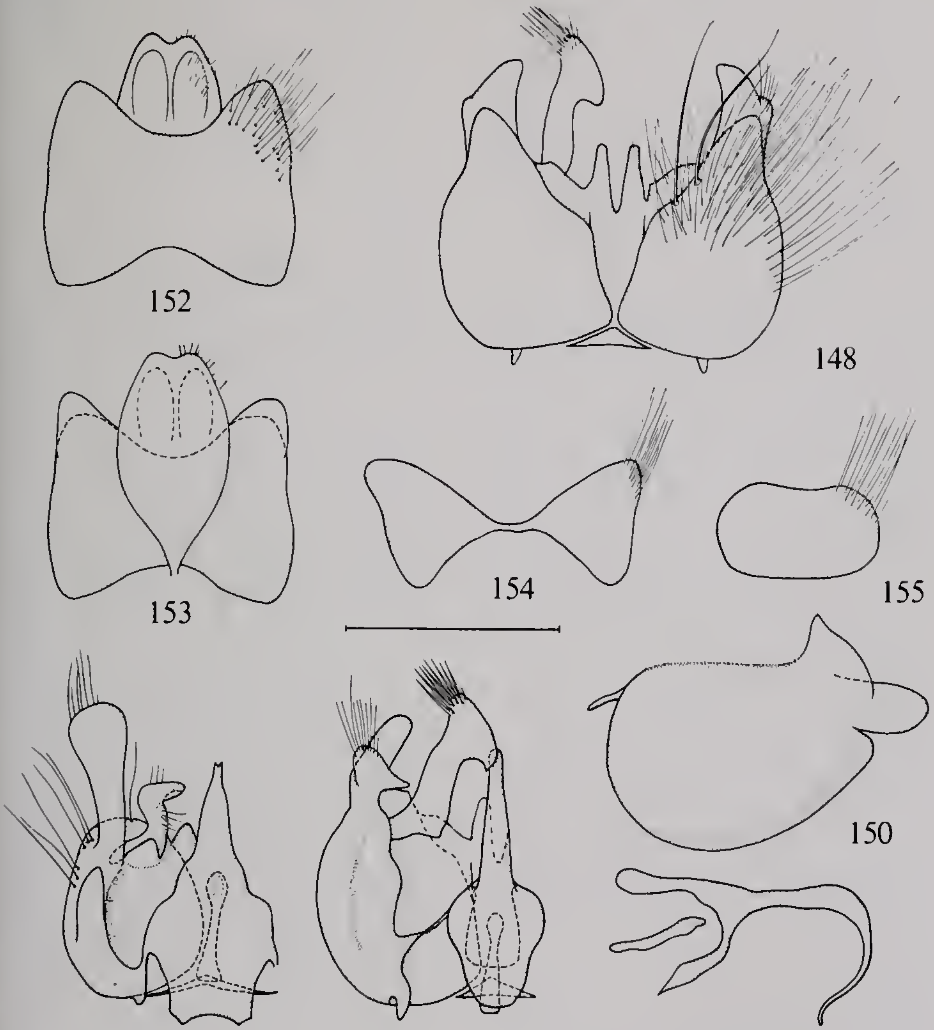

Fig. 148–156. — *Arenigena* spp. 148–155. — *A. semitaria* (Coq.) male terminalia. 148. — Gonocoxites with appendages (left gonostylus omitted) and hypandrium in ventral view. 149. — Right gonocoxite with appendages and aedeagus in dorsal view. 150. — Left gonocoxite in lateral view. 151. — Aedeagus in lateral view. 152. — Epandrium with appendages in dorsal view. 153. — Epandrium with appendages in ventral view. 154. — Tergite 8. 155. — Sternite 8. 156. — *A. morcida*-group right gonocoxite with appendages and aedeagus in dorsal view. Scale: 0.5 mm.

grayish to grayish-brown anterior bands on anterior segments.

MALE TERMINALIA (Fig. 148–156). — Tergite 8 (Fig. 154) comparatively large and constricted for rather a short distance in middle; sternite 8 (Fig. 155) also rather large, oval, in some species with a low, wide incision along midpoint of posterior margin; epandrium (Fig. 152) shorter in midline than wide, with short, rounded posterolateral corners; cerci free, rather weakly sclerotized; ventral epandrial sclerite (Fig. 153) large, often extending beyond cerci, tapering anteriorly and reaching to anterior margin of epandrium, where folded 180° and attached to anterior margin of aedeagus, this attachment markedly well sclerotized; parameral apodeme has a weak, membranous attachment to aedeagus in *semitaria* (Fig. 149), a more sclerotized attachment in the *marcida* group (Fig. 156); aedeagus (Fig. 151) has gradually tapering, curving distiphallus, broad, rectangular to ovoid dorsal apodeme, short, simple ventral apodeme, and short ejaculatory apodeme that widens slightly distally; ventral lobes of gonocoxites (Fig. 148) weakly sclerotized, without a distinct attachment to ventral surface of aedeagus; parameral process (Fig. 149 and 156) present and variously modified distally; parameral apodeme short; gonostylus hook shaped, sometimes with an apical comb of setae; gonocoxites (Fig. 148) in ventral view attached by a rather wide membrane in midline, this membrane continuing posteriorly into weakly sclerotized ventral lobes, each gonocoxite being clearly demarcated; hypandrium (Fig. 148) free as a narrow, well-marked sclerite along the anteroventral corners of the gonocoxites.

Habitat

Species of *Arenigena* are found in desert habitats with sparse vegetation and sandy substrates; specimens have been taken from desert washes.

Distribution

Arenigena is a desert genus, found from Idaho into Mexico and from California eastward to Colorado, New Mexico, and Texas.

Included Species

brunnea (Kröber) 1914:46 ♀ (*Psilocephala*), new combination. Distribution. — Arizona.

marcida (Coquillett) 1893*b*:228 ♂ (*Psilocephala*), new combination. Distribution. — Southern California.

semitaria (Coquillett) 1893*a*:198 ♂, ♀ (*Thereva*), new combination. Distribution. — Southern California.

Several undescribed species occur in this genus.

Genus Ammonaios Irwin & Lyneborg, new genus (Fig. 20, 22, and 157–161)

Masculine

Derivation of name: *ammos* (Greek) = sand; *naio* (Greek) = to dwell.

Type-species: *Thereva nivea* Kröber 1914:64 by present designation. Type-locality: Mesilla Valley, New Mexico.

Diagnosis

Moderately large, heavy-bodied species.

HEAD. — Frons of male (Fig. 20) at its narrowest distinctly narrower than half width of anterior ocellus; frons of female at level of anterior ocellus 2.1–2.4× as wide as ocellar tubercle; male frons has whitish tomentum and whitish, scaly pile; female frons has entirely pale tomentum, not markedly patterned, and like male has appressed, pale, scaly pile; head only slightly protrudes at antennal level; lateral portion of face and gena has scaly pile; facial and genal calli absent; head depth 1.4–1.8× antennal length (Fig. 22); scape slender, 0.3–0.6× as long as flagellum; flagellar style apical, two segmented, with a distinct terminal spine; palps one segmented.

THORAX. — np 3–5, sa 1–2, pa 1, dc 1–2, sc 2; all setae slender and pale; mesonotal pile in both sexes dense, uniform, pale, mostly scaly, and semi-appressed to appressed; prosternum has long, whitish pile in and around central depression. WING. — Cell m_3 closed; vein

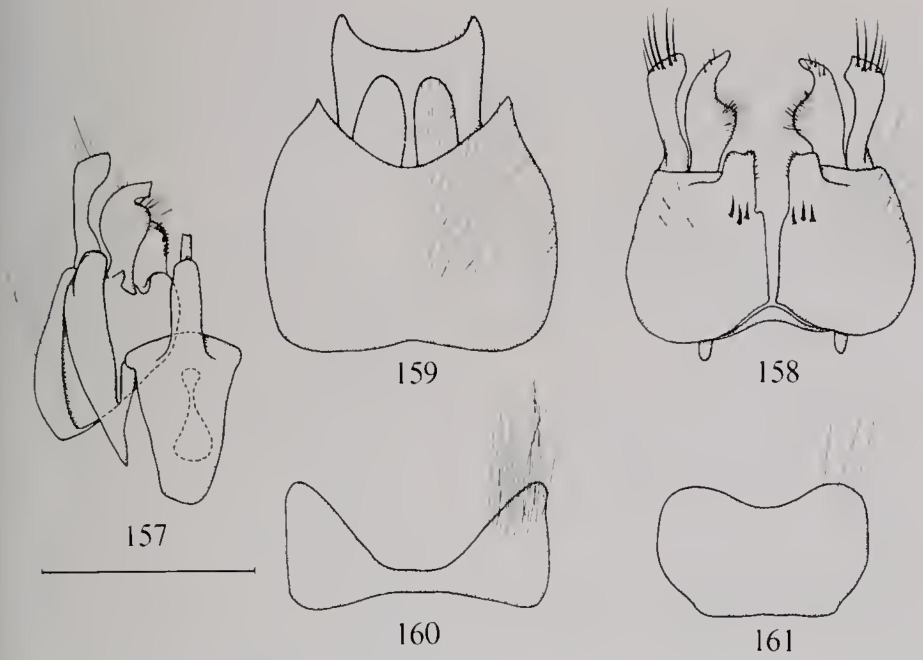

Fig. 157–161. — *Ammanaias niveus* (Kräb.) male terminalia. 157. — Right gonocoxite with appendages and aedeagus in dorsal view. 158. — Ganocaxites with appendages and hypandrium in ventral view. 159. — Epandrium with appendages in dorsal view. 160. — Tergite 8. 161. — Sternite 8. Scale: 0.5 mm.

R_4 longer than vein R_5; cell r_4 1.9–2.0× as long as wide at apex; color uniformly hyaline, pale brownish, or with a whitish tinge; stigma pale or dark brownish, or costal margin more extensively darkened. Legs. — Fore coxa with 2 pale, slender apical setae on anterior surface, sometimes an additional seta more basally; middle coxa has whitish scaly pile on posterior surface; hind femur has 2–8 pale to dark anteroventral setae.

Abdomen. — Rather broadly built, in both sexes gradually tapering from segment 3 to apex; dorsum flattened in both sexes; male dorsum entirely covered with thick, long, appressed, scaly whitish pile that completely covers integumental surface; female dorsum yellowish brown to grayish yellow, with ill-defined, darker anterior bands on anterior segments; pile much sparser and shorter than on male.

Male Terminalia (Fig. 157–161). — Tergite 8 (Fig. 160) and sternite 8 (Fig. 161) large. Epandrium (Fig. 159) shorter in midline than wide, posterolateral corners rather sharply pointed; cerci free, rather weakly sclerotized, never extending beyond ventral epandrial sclerite; ventral epandrial sclerite (Fig. 159) very wide, more or less strongly extending beyond cerci, and more or less ventrally directed; ventral epandrial sclerite reaches anterior margin of epandrium and has a membranous attachment to aedeagus; parameral apodeme has a more or less distinctly sclerotized bridge to dorsal apodeme of aedeagus; aedeagus has a long, narrow, downcurved distiphallus; dorsal apodeme tapers distally; ventral and ejaculatory apodemes small; ventral lobes of gonocoxites short and weak, not attached to aedeagus; parameral process large and stout, often slightly spoon shaped; parameral apodeme stout; gonostylus variously shaped; gonocoxites short, truncate distally, ventrally (Fig. 158) attached by a membrane; hypandrium narrow and laterally fused to gonocoxites.

Habitat

Species in the genus *Ammonaios* are inhabitants of very xeric zones and can be found as adults on and near shifting sand dunes. Larvae have been reared from sand taken from areas near vegetation in shifting dunes. This genus is not known to occur in coastal areas and seems restricted to inland dune systems.

Distribution

Southwestern United States (Oregon, California, Idaho, Utah, Nevada, Arizona, New Mexico, Texas) and northern Mexico (Baja California, Sonora, Chihuahua, Coahuila).

Included Species

niveus (Kröber) 1914:64 ♂ (*Thereva nivea*), new combination. Distribution. — New Mexico.

At least four additional, unnamed species are at hand.

Genus **Megalinga** Irwin & Lyneborg, new genus (Fig. 3 and 162–168)

Feminine

Derivation of name: *megas* (Greek) = large; *linga* (Sanskrit) = penis.

Type-species: *Megalinga insignata* Irwin & Lyneborg, herein described, by present designation. Type-locality: Death Valley, California.

Diagnosis

Medium- to large-sized, slender to moderately broad species.

HEAD. — Frons of male at its narrowest narrower than half width of anterior ocellus, or eyes tangential; frons of female at level of anterior ocellus from 2 to nearly 3× as wide as ocellar tubercle, gradually widening downward to bottom of eyes; frons has entirely grayish tomentum, either without distinct pattern or with two small, dark tomentose, circular areas on lower frons at eye margin; male frons without pile; female frons has sparse, short, black, semi-appressed pile on upper two-thirds; head moderately protrudes anteriorly; face without pile; genae ridge shaped, with darker tomentum than rest of head and short, black pile; head depth 1.4–1.7× antennal length; scape slender, 0.4–0.6× as long as flagellum; flagellar style two segmented with a distinct terminal spine; palps one segmented.

THORAX. — np 3, sa 2, pa 1, dc 1–3, sc 2; mesonotal pile mostly short, semi-appressed to appressed, pale; additional sparse pile of very short, black, erect hairs sometimes occurs on midanterior portion; prosternum has long whitish pile in and around central depression; each cervical lobe anterior to prosternum has a strong, black seta (Fig. 3). WING. — Cell m_3 open; vein R_{2+3} has a deep curve apically; vein R_4 longer than vein R_5; cell r_4 1.6–1.8× as long as wide at apex; whitish-hyaline, with strongly marked pattern of dark brownish patches. LEGS. — Fore coxa has 2 stout setae on apical half of anterior surface and an additional stout seta near base on anteroexterior margin; hind femur has 5–6 anteroventral setae, some shorter posteroventral setae, often arranged in a close group near apex.

ABDOMEN. — Rather narrow, gradually tapering from base to apex; dorsum convex, especially in male; dorsum of male has pale grayish tomentum; dorsum of female yellowish to brownish, due to thinner tomentum, and not distinctly patterned.

MALE TERMINALIA (Fig. 162–168). — Tergite 8 (Fig. 167) about as wide as epandrium and greatly constricted in middle; sternite 8 (Fig. 168) rather large, with broad incision in posterior margin; epandrium (Fig. 162) shorter in midline than wide, its posterolateral corners broadly rounded, with a broad, infolded margin; cerci (Fig. 162) free, strongly sclerotized, not extending beyond ventral epandrial sclerite; this sclerite large, reaching to anterior margin of epandrium, not attached to anterior margin of aedeagus, entirely membranous, only a horseshoe shaped sclerotized area (Fig. 166) below cerci; aedeagus has two attachments (Fig. 164) to parameres and gonocoxites: a long, weak, membranous bridge stretching from distal corners of dorsal apodeme to midsection of paramere, and a stronger attachment between ventral lobes of gonocoxites and ventral surface of aedeagus; aedeagus (Fig. 164 and 165) of a very remarkable shape; distiphallus forms a right angle with the heavily sclerotized, rectangular dorsal apodeme and curves downward for about 270°, its apex being deeply cleft; ventral apodeme arises at a right angle from base of distiphallus, extending parallel to dorsal apodeme, but much narrower and shorter; ejaculatory apodeme about as

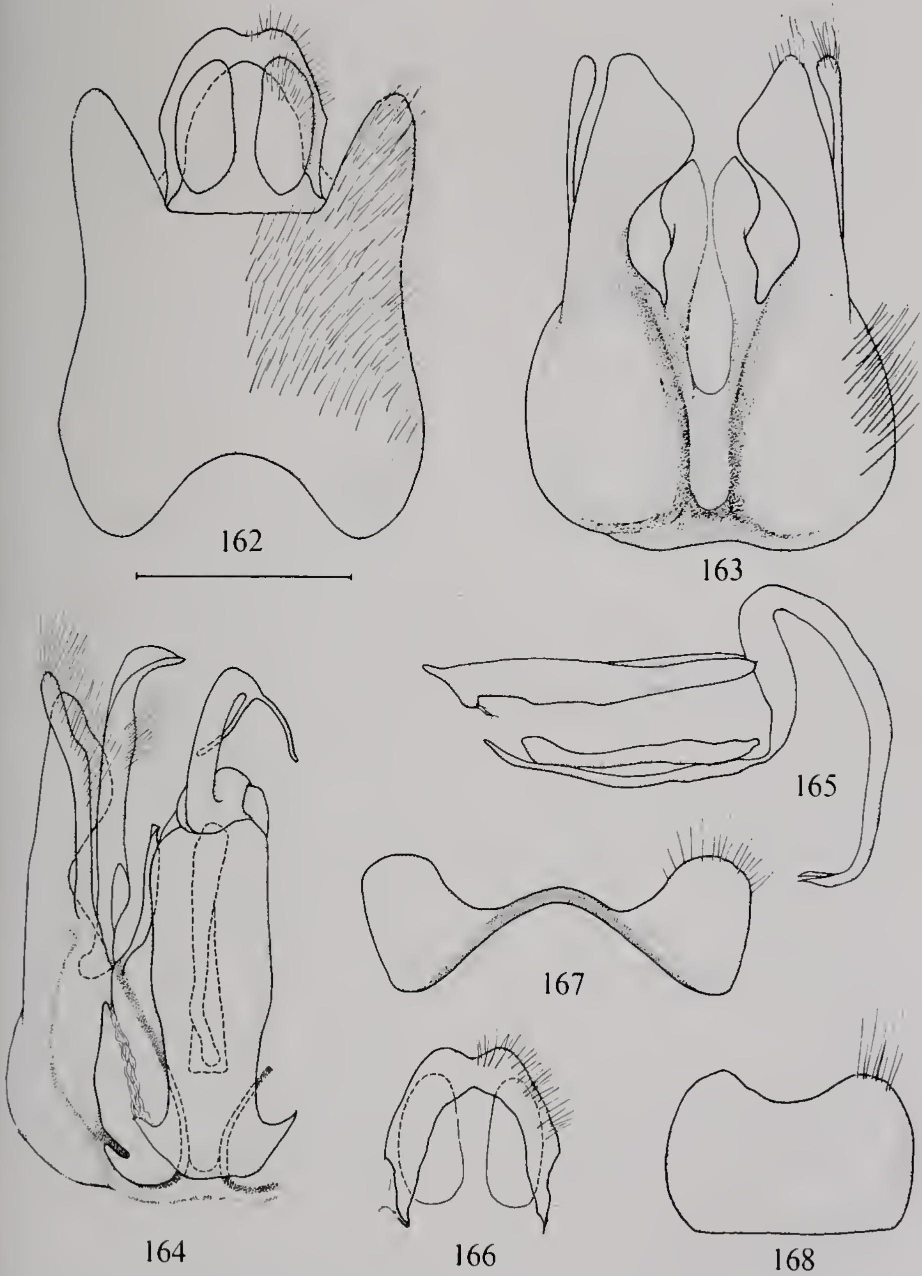

Fig. 162–168. — *Megalinga insignata* Irw. & Lyn. male terminalia. 162. — Epandrium with appendages in dorsal view. 163. — Gonocoxites with appendages in ventral view. 164. — Right gonocoxite with appendages and aedeagus in dorsal view. 165. — Aedeagus in lateral view. 166. — Ventral epandrial sclerite and cerci in ventral view. 167. — Tergite 8. 168. — Sternite 8. Scale: 0.5 mm.

long as ventral apodeme and very slender. Ventral lobes of gonocoxites (Fig. 163) very large, attached in midline for a long distance, and also attached to body of aedeagus; parameral process very long and slender, but its apodeme very reduced; gonocoxites (Fig. 163) in ventral view attached by a strong membrane over midline but a ventral synsclerite is not formed, as each gonocoxite is clearly demarcated by a strongly sclerotized and pigmented inner margin; a similar strong membrane attaches the ventral lobes for a long distance; a free hypandrium is not present, but a hypandrial element may enter into the fusion of the anteroventral corners of the gonocoxites.

Habitat

The two species listed below occupy distinct habitats, one in the deserts of the southwestern United States, the other in the coastal dunes and beaches of southern Mexico, Guatemala, and El Salvador along the Pacific Ocean.

Distribution

This genus is apparently restricted to the deserts of the southwestern United States and the coastline of Sinaloa, Mexico, southward to El Salvador.

Included Species

insignata Irwin & Lyneborg, described below. Distribution.—Southern California, Arizona, and northern Baja California.

One undescribed species of *Megalinga* is known from Sinaloa, Nayarit, and Guerrero, Mexico, and Ahuachapan, El Salvador.

Megalinga insignata Irwin & Lyneborg, new species

Derivation of name: *in* (Latin) = not; *signatus* (Latin) = mark.

Description

See Table 1 for selected measurements of the holotype and most paratype material.

Male, holotype, specimen number *5144*[1], 8.96 mm in length, excluding antennae. Ground color pale tan overall; pile generally short, but longer on genae, lower occiput, and laterally on abdomen; all pile whitish to pale yellow; tomentum silver to golden, moderately dense.

HEAD. — Frons narrow, the eyes large, diverging only slightly from middle of frons toward genae; eyes at their closest separated by about half the width of the anterior ocellus. Pile lacking on frons and face, long on occiput and rather dense on lower occiput; genae flanged, enlarged, with short dark brown hairs on ventral surface. Ocellar triangle prominent, with about 12 short, blackish bristles; occiput has a single row of postocular setae, 11 on each hemisphere. Tomentum very fine, brownish golden centrally and grayish silver laterally on frons and face; genae have dark brown tomentum; occiput has white tomentum; frons has two minute, crescent shaped marks of brown tomentum, one tangential to each eye. Antennae tan to yellowish-tan; scape has a single large black seta projecting anterodorsally from dorsal surface and 2 such setae projecting anteroventrally from ventral surface; pile whitish, rather short on scape and pedicel, black, very short on basal third of flagellum; tomentum fine, whitish on scape and pedicel, thinner on flagellum; scape slightly longer than wide; pedicel about half as long as wide: flagellum about 2.5× longer than wide, exaggeratedly pear shaped; style composed of two subsegments plus terminal spine, basal subsegment short, apical subsegment about 2× as long as basal subsegment, terminal spine short, blunt. Proboscis brown, large, reaching almost to base of antennae; palps yellowish, reach about three-fourths distance to apex of proboscis, one segmented though with a deep constriction about one-fourth distance from base to apex.

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[1] Each specimen has been assigned a unique number to facilitate the association of data. This number appears below the specimen on a separate yellow label bearing, besides the number, the words, THEREVIDAE/M.E. IRWIN/SPECIMEN #.

Table 1. — Measurements (in mm) of various morphological attributes of *Megolinga insignata* Irwin & Lyneborg, new species.

Morphological Attribute	Sex Specimen No.[a] Type	♂ 5144 Holo	♂ 5134 Para	♂ 5143 Para	♂ 5148 Para	♂ 5150 Para	♀ 5137 Para	♀ 5140 Para	♀ 5141 Para	♀ 5145 Para	♀ 5151 Para	Mean ± Standard Deviation Males	 Females
Total length (excluding antennae)		8.96	9.30	9.55	8.72	9.13	11.79	9.79	10.87	11.54	12.53	9.13 ± 0.28	11.30 ± 0.92**[b]
Head width		2.04	1.98	2.06	2.00	2.08	2.22	2.04	2.20	2.34	2.32	2.03 ± 0.04	2.22 ± 0.11**
Head height		1.58	1.58	1.60	1.50	1.60	1.68	1.54	1.66	1.74	1.78	1.57 ± 0.04	1.68 ± 0.08*
Head depth		1.14	1.10	1.16	1.12	1.12	1.28	1.14	1.20	1.30	1.32	1.13 ± 0.02	1.25 ± 0.07**
Distance between eyes at vertex		0.26	0.24	0.26	0.24	0.22	0.42	0.36	0.36	0.40	0.42	0.24 ± 0.02	0.39 ± 0.03**
Frontal width at anterior ocellus		0.14	0.14	0.14	0.16	0.14	0.50	0.42	0.44	0.50	0.48	0.14 ± 0.01	0.47 ± 0.03**
Frontal width at antennae		0.68	0.68	0.70	0.68	0.72	0.90	0.82	0.90	0.96	0.96	0.69 ± 0.02	0.91 ± 0.05**
Facial width at lower eye margin		0.86	0.92	0.90	0.90	0.88	1.06	0.94	1.10	1.12	1.10	0.89 ± 0.02	1.06 ± 0.07**
Eye height		1.44	1.40	1.46	1.38	1.50	1.50	1.38	1.48	1.50	1.56	1.44 ± 0.04	1.48 ± 0.06
Eye depth		0.86	0.80	0.84	0.86	0.82	0.90	0.78	0.80	0.86	0.98	0.84 ± 0.02	0.86 ± 0.07
Frontal protuberance depth		0.10	0.10	0.12	0.12	0.10	0.14	0.10	0.10	0.10	0.14	0.11 ± 0.01	0.12 ± 0.02
Antennal scape length		0.18	0.18	0.20	0.20	0.20	0.22	0.18	0.20	0.22	0.22	0.19 ± 0.01	0.21 ± 0.02
Antennal flagellum length		0.50	0.42	. . .	0.50	0.44	0.52	0.48	0.48	0.56	0.54	0.47 ± 0.04	0.52 ± 0.03
Wing length (humeral crossvein to apex)		5.81	5.81	6.06	5.81	6.06	6.56	5.98	6.39	6.81	6.81	5.91 ± 0.12	6.51 ± 0.31**
Wing width, maximum		2.68	2.36	2.56	2.64	2.70	2.70	2.44	2.64	2.64	2.76	2.59 ± 0.12	2.64 ± 0.11
Distance fork R_{4+5} to outrun R_4		1.46	1.36	1.60	1.54	1.56	1.60	1.62	1.56	1.74	1.52	1.50 ± 0.09	1.61 ± 0.07
Distance fork R_{4+5} to outrun R_5		1.34	1.22	1.42	1.28	1.40	1.54	1.48	1.40	1.52	1.48	1.33 ± 0.07	1.48 ± 0.05**
Distance outruns R_4 to R_5		0.96	0.94	0.90	1.04	0.98	1.20	1.00	1.14	1.16	1.18	0.96 ± 0.05	1.14 ± 0.07**
Distance fork R_{4+5} to apex		1.72	1.60	1.84	1.76	1.78	1.90	1.84	1.74	1.94	1.88	1.74 ± 0.08	1.86 ± 0.07
Fore tibia length		1.84	1.90	2.00	1.84	1.94	2.28	1.94	2.22	2.24	2.22	1.92 ± 0.05	2.18 ± 0.12**
Hind tibia length		2.90	2.96	3.04	3.00	3.02	3.60	3.12	3.50	3.66	3.50	2.98 ± 0.05	3.48 ± 0.19**
Fore basitarsus length		0.90	0.90	1.00	0.90	0.94	1.06	0.96	1.18	1.16	1.16	0.93 ± 0.04	1.10 ± 0.08**
Hind basitarsus length		1.28	1.22	1.24	1.24	1.26	1.50	1.26	1.48	1.60	1.50	1.25 ± 0.02	1.47 ± 0.11**

[a] Each specimen has been assigned a unique number to facilitate the association of data. The number appears below the specimen on a separate yellow label, bearing, besides the number, the words, THEREVIDAE/M.E. IRWIN/SPECIMEN #.

[b] Means of males and females significantly different from one another at the 5-percent (*) or 1-percent (**) levels, analysis of variance, completely randomized design.

Thorax. — Mesonotal vittae rather indistinct; tomentum silver grayish, rather dense, covering all of mesonotum, scutellum, and pleural areas; pile short, appressed, dense on and near scutellum, white with a few golden tan patches along anterior part of faint narrow vittae on mesonotum. Mesonotal macrosetal pattern: np 3, sa 2, pa 1, dc 2, sc 2, black. Pile thin, white, elongate, confined for the most part to anepisternum, pleurotergite, and coxae. Wing. — Veins yellowish brown with darker patches in several areas: at fork R_{4+5}, along veins R_4 and R_5, near tip of R_{2+3}, along vein R_{2+3} below darkened stigma, along most crossveins (not humeral crossvein), and thinly along veins M_1, M_2, and M_3. Veins M_3 and M_4 do not meet, distance between them at wing margin 0.16 mm; vein R_{2+3} curves dorsally at tip; vein R_4 exaggeratedly sinuate; halter very pale tan overall. Legs. — Legs yellowish brown; femora have white, mostly appressed pile, scalelike dorsally; femoral setal pattern: f_1 3 av; f_2 2 av, 1 pv; f_3 4 av, 11pv. Tibial setal pattern: t_1 3 ad, 4 pd, 4 pv; t_2 2 ad, 4 av, 3 pd, 3 pv; t_3 7 ad, 6 av, 4 pd, 4 pv. Fore coxa has 3 prominent, black setae, 1 basal and 2 apical.

Abdomen. — Yellowish brown with silver gray tomentum and white pile; fascia slightly differentiated by a more tanish tomentum.

Male Terminalia. — Very large, darker brown than abdomen. See generic description for description of male terminalia.

Variation of Males in Paratype Series. — Mean length, excluding antennae, 9.13 mm ± standard deviation of 0.28 mm. Measurement differences are presented in Table 1. Femoral setal pattern: f_1 av 3–4, pv 0–1; f_2 av 1–4, pv 1–3; f_3 av 4–6, pv 7–11. Tibial setal pattern: t_1 ad 3–5, av 0, pd 3–4, pv 2–4; t_2 ad 2–4, av 2–4, pd 3–4, pv 3–5; t_3 ad 4–9, av 4–8, pd 3–8, pv 2–6.

Variation of Females in Paratype Series. — Mean length, excluding antennae, is 11.30 mm ± standard deviation of 0.92 mm. Females are significantly (at 1-percent level) larger than males. Table 1 presents selective measurements of female paratypes. Females are similar to males except as follows: females have less dense tomentum and less dense pile overall. Frontal differences are great, as can be seen from Table 1; upper frons has sparse, short, black setae; a pair of small half crescent dark brown spots, one tangential to each eye, occur at the junction of upper and lower frons; a slightly darker tan strip of tomentum connects eye margin and antennal insertion. Femoral setal pattern: f_1 av 2–6, pv 0–2 (*5151* has pd 1); f_2 av 3–5, pv 2–5; f_3 av 4–8, pv 6–9. Tibial setal pattern: t_1 ad 3–4, av 0, pd 2–5, pv 4; t_2 ad 3–4, av 2–3, pd 3–4, pv 3–4; t_3 ad 6–10, av 6–9, pd 4–7, pv 4–7.

Female Terminalia. — Tergite 8 rather large, squarish, with a transverse band of black setae about midway from anterior to posterior ends; sternite 8 elongate, a similar band of black setae about one-third distance from base to apex, with a small central hump covered with small setae centrally along posterior margin, without any incisions on posterior margin; vaginal apodeme (sternite 9) a complete sclerotized, elongate ring, taking up most of space above sternite 8, with a thin sclerotized connection posteriorly to tergite 9 and an extraordinary sclerotized structure involving the sclerotization of the spermathecal duct and a triangular sclerotized apparent apex of the duct that might represent a united spermathecae (Irwin 1976); intersegmental membrane connecting sternite 8 and vaginal apodeme heavily sclerotized, containing 2 sclerites united along midline of sternite 8 and connected to lateral portion of sclerotized ring of vaginal apodeme. Tergite 10 has about 8 thickened spines in the posterodorsal position, and tergite 9 has about 6 thinner, longer spines in the posteroventral position; some finer setae anterior of posterodorsal spines on tergite 10; cerci widely separated, have a dense patch of black setae, connected to one another by a transparent membrane; subanal plate pointed apically, fitted beneath tergites 9 and 10 and does not extend posteriorly beyond cerci.

Specimens Examined

Holotype: ♂, *5144,* California Academy of Sciences type number *13670;* Bennetts Well, Inyo County, California; 30 March 1952; on indefinite loan from the California Insect Survey, University of California, Berkeley; A. E. Michelbacher, collector. Paratypes: 5 males, 12 females from these localities:

MEXICO: Baja California Norte: Bahia de los Angeles, 1 April 1973, J. T. Doyen & J. A. Powell, ♀, *5151* (CIS to CIS).[1]

UNITED STATES: Arizona: Maricopa County: Tempe, 8 May 1964, F. F. Hasbrouch, ♂, *5150* (ASU to ASU). California: Imperial County: Brawley, 14 April 1959, E. I. Schlinger, ♀, *5146* (EIS to UCR). Riverside County: Coachella, 25 May 1938, E. C. VanDyke, ♀, *5147* (CAS to CAS). San Bernardino County: Needles, 3 May 1964, P. Torchio & G. Bohart, ♂, *5149* (USU to USU); 9 air miles south of Baker at Zzyzx Springs, 24 April 1977, C. T. Kitayama (malaise trap), ♂, *5134* (CIS to MEI), ♀, *5135* (CIS to CIS), *5136* (CIS to UCD); same data, 25 April 1977, ♀, *5137* (CIS to MEI); same data as last except, G. W. Ulrich, ♀, *5138* (CIS to USNM); same data, 26 April 1977, M. E. Buegler (hand netted), ♀, *5139* (CIS to CNC); same data, 27 April 1977, ♀, *5140* (CIS to INHS). Inyo County: Furnace Creek, Death Valley, 27 March 1961, M. E. Irwin, ♀, *5141* (MEI to ZMC); same data, D. R. Miller, ♀, *5142* (UCD to MEI); same data, 8 April 1939, E. G. Linsley, ♂, *5143* (CIS to CIS); Bennetts Well, Death Valley National Monument, 15 April 1968, J. Bigelow & M. A. Cazier, ♀, *5145* (ASU to ASU); Tecopa, 30 May 1955, J. Belkin, ♂, *5148* (UCR to UCR).

Genus Breviperna Irwin
(Fig. 169–175)

Feminine

Breviperna Irwin 1977*b*:288. Type-species: *Psilocephala placida* Coquillett 1894:99 by original designation. Type-locality: Listed as "Florida," apparently in error (Irwin 1977*b*:293).

Reference: Irwin 1977*b*.

Diagnosis

Large, robust species.

Head. — Frons of male at its narrowest about as wide as anterior ocellus; frons of female at level of anterior ocellus nearly twice as wide as ocellar tubercle; frons without distinct pattern of tomentum; pile on lower frons moderately dense, sparse on upper frons, composed of rather long, black hairs; antennae set on low protuberance; facial and genal calli absent; lateral portion of face and gena bare; antennae 0.6–0.8× as long as depth of head; scape 0.8–0.9× as long as flagellum; flagellar style apical with two segments and a terminal spine; palps one segmented.

Thorax.— np 3–5 (usually 4), sa 2, pa 1–2 (usually 1), dc 0–1, sc 1–3 (usually 2); mesonotal pile of two types: one is long, scalelike, sparse, semi-appressed, and the other is short, thin, erect, sparse; prosternum has pile in and around central depression. Wing. — Cell m_3 open or closed; vein R_4 longer than vein R_5; cell r_4 about 2× as long as wide

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[1] Specimen loan institutions and depositories (abbreviations in parentheses): Arizona State University, Tempe (ASU); California Academy of Sciences, San Francisco (CAS); California Insect Survey, University of California, Berkeley (CIS); Canadian National Collection, Ottawa (CNC); Illinois Natural History Survey, Urbana (INHS); M. E. Irwin Collection (MEI); Evert I. Schlinger Collection (EIS); University of California, Davis (UCD); University of California, Riverside (UCR); United States National Museum of Natural History, Washington, D.C. (USNM); Utah State University, Provo (USU); Zoological Museum, Copenhagen, Denmark (ZMC).

at apex; color hyaline with dark brown stigma. Legs. — Fore coxa has 2 apical setae on anterior surface; middle coxa without pile posteriorly; hind femur has 7–9 anteroventral setae.

Abdomen. — Broad, nearly parallel sided from segments 1 through 3, thereafter, abdomen tapers sharply to apex; segments 5–8 telescoped within segments 3–4 in males; female segments not telescoped; dorsum of abdomen flattened, more so in males than in females; male dorsum densely clothed in silver tomentum; female dorsum lacks silver tomentum.

Male Terminalia. — Tergite 8 (Fig. 175) small and narrowly constricted medially; sternite 8 (Fig. 174) small and broadly bilobate; epandrium (Fig. 172) large, covering most of terminalia, distinctly shorter than wide, with posterolateral margins bidentate; cerci free, extending slightly beyond ventral epandrial sclerites; ventral epandrial sclerite (Fig. 172) not keeled, not united to anterior margin of aedeagus; parameral apodeme attached by a thickened, wide, nonsclerotized membrane to dorsal apodeme of aedeagus and ventral lobes broadly attached by a nonsclerotized membrane to

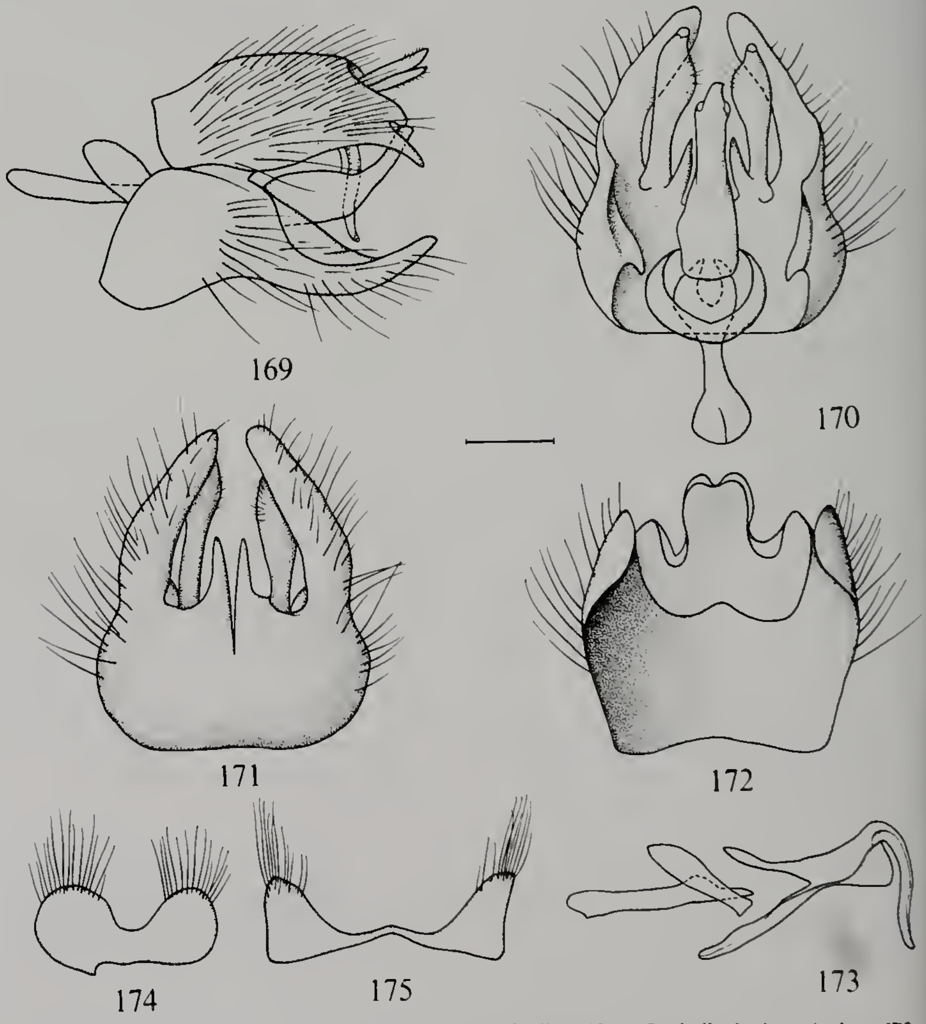

Fig. 169–175. — *Breviperna placida* (Caq.) male terminalia. 169. — Genitalia in lateral view. 170. — Gonocoxites with appendages and aedeagus in dorsal view. 171. — Gonocoxites with appendages in ventral view. 172. — Epandrium with appendages in ventral view. 173. — Aedeagus in lateral view. 174. — Sternite 8. 175. — Tergite 8. Scale: 0.5 mm.

center of aedeagus; distiphallus (Fig. 173) elongate, slender, with an asymetrically twisted tip; a nearly closed, sclerotized ring surrounding proximal portion of ejaculatory apodeme is loosely attached to ventral lobe; ventral apodeme short and narrow; ventral lobes fused basally, elongate, forming a posteriorly directed continuation to central portion of gonocoxites; distal parameral process reduced, only a basal apodeme existing; gonocoxites (Fig. 171) broadly fused ventrally and flattened; hypandrium absent or completely fused with gonocoxites, not identifiable.

Habitat

Breviperna placida inhabits forested mountainous zones, but specific habitats are unknown.

Distribution

The genus *Breviperna* is found predominantly in southeastern Arizona.

Included Species

placida (Coquillett) 1894:99 ♀ (*Psilocephala*). Distribution. — Southeastern Arizona.

No undescribed species are known to us. *Breviperna milleri* Irwin (1977*b*:294, ♀) was found to belong to the genus *Ozodiceromya* Bigot, based on subsequent material containing a male.

Genus **Nebritus** Coquillett
(Fig. 2 and 176–181)

Nebritus Coquillett 1894:98. Type-species: *N. pellucidus* Coquillett 1894:98 by original monotypy. Type-locality: Southern California.

Zionea Hardy 1938:144 new synonym. Type-species: *Z. tanneri* Hardy 1938: 144 by original monotypy. Type-locality: North Fork, Provo Canyon, Utah.

Diagnosis

Large- to medium-sized, slender bodied species.

Head (Fig. 2). — Frons of male wide, at level of anterior ocellus 1.6–2.0× as wide as width of ocellar tubercle; frons of female at level of anterior ocellus 2.5–3.0× as wide as width of ocellar tubercle; frons strongly patterned: lower part raised, forming a polished black callus, upper part with brownish to brownish-gray tomentum surrounding the polished black ocellar tubercle; frontal pile very long and erect, extending below level of antennal bases; head prominently protruding anteriorly; antennae set on distinct protuberance; lower frontal callus extends between antennal bases and forms an upper midfacial callus below antennae; a polished black callus also located ventrally on face; upper postocular margin thickened and polished black; lateral portion of face without pile; gena has long pile; antennae 1.0–1.3× as long as depth of head; scape 1.2–1.5× as long as flagellum, slender or thickened; flagellar style subapical, placed in a groove on exterior surface of first flagellomere a considerable distance basad of apex; number of segments in flagellar style not discernable without dissection; palps one segmented.

Thorax.— np 3–4, sa 2, pa 1, dc 0–1, sc 2; mesonotal pile in both sexes of two types: one is long, erect, black, rich, and the other is moderately long, semi-appressed to appressed, pale, rich, but largely restricted to lateral parts of mesonotum and to two bands on middorsum; prosternum has long pile in and around central depression. Wing. — Cell m_3 open; veins R_4 and R_5 about equal in length or R_5 slightly longer; cell r_4 2.5–3.2× as long as wide at apex; grayish brown to brown, frequently most intensively pigmented along anterior margin or pigment arranged in broad streaks along veins; veins coarse; stigma distinct. Legs. — Fore coxa has 2–3 apical setae on anterior surface; middle coxa has whitish pile on posterior surface; hind femur has 4–12 anteroventral setae.

Abdomen. — Broad at base, gradually tapering from base or from segment 2 to apex, not telescoped; dorsum flattened, in both sexes dull, with grayish to brownish tomentum, or dorsum subshiny, without any marked pattern.

Male Terminalia (Fig. 176–181). — Tergite 8 variable, in the type-species

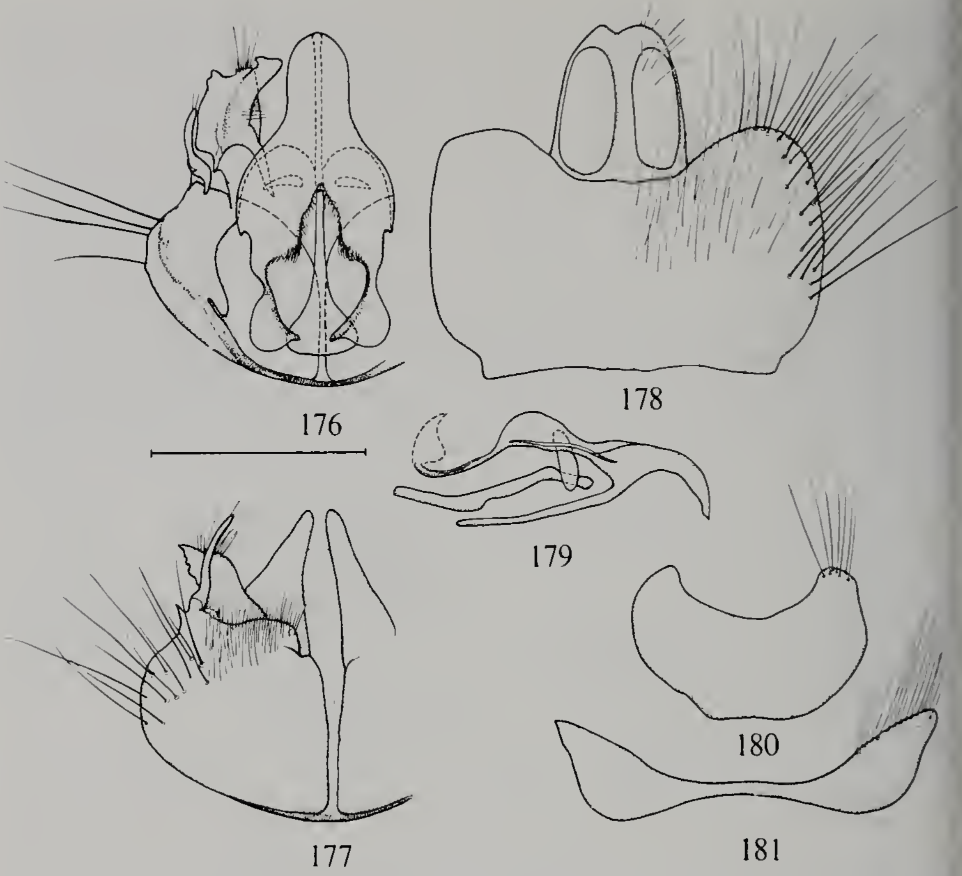

Fig. 176–181. — *Nebritus pellucidus* Coq. male terminalia. 176. — Right gonocoxite with appendages and aedeagus in dorsal view. 177. — Gonocoxites with appendages in ventral view. 178. — Epandrium with appendages in dorsal view. 179. — Aedeagus in lateral view. 180. — Sternite 8. 181. — Tergite 8. Scale: 0.5 mm.

(Fig. 181) small and strongly constricted medially; sternite 8 (Fig. 180) rectangular to bilobate; epandrium (Fig. 178) only about half as long medially as wide, its posterolateral corners infolded; cerci rather large, free, well sclerotized, not extending beyond level of ventral epandrial sclerite; ventral epandrial sclerite large, extending to or nearly to anterior margin of epandrium, with a membranous attachment to anterior margin of aedeagus; ventral epandrial sclerite as a whole well sclerotized, keel shaped apically below cerci; parameral apodeme not attached to aedeagus; distiphallus rather long compared with rest of aedeagus, downcurved; dorsal apodeme semicircular, its distal margin with two lateral projections; ventral and ejaculatory apodemes small, weakly sclerotized; ventral lobes of gonocoxites large, spoon shaped, directed obliquely upward, with distinct attachment to ventral surface of aedeagus; parameral process long and slender, noticeably projecting beyond posterior margin of gonocoxite; parameral apodeme short; gonocoxites (Fig. 177) not united ventrally except by a membrane; gonocoxite in lateral view broadly rounded posteriorly; hypandrium broad throughout, united with anterior margin of gonocoxites for a rather long distance.

Habitat

The two described species are found in montane habitats; the one undescribed species seems confined to coastal sand dunes.

Distribution

Western North America.

Included Species

pellucidus Coquillett 1894:98 ♂, ♀. Distribution. — Southern California (Monterey, San Luis Obispo, Kern, San Bernardino, Riverside, Los Angeles, and San Diego counties) and Mexico (Baja California Norte).

tanneri (Hardy) 1938:144 ♀ (*Zionea*), new combination. Distribution. — Western United States (Utah, Nevada, and California) and northwestern Mexico (Baja California Norte).

One undescribed species is at hand from the coastal dunes of California (Monterey, San Luis Obispo, Ventura counties).

Note

In all basic respects of male terminalia and other obvious synapomorphies, *tanneri* conforms to the ground plan of *pellucidus*. These two species are, in our judgment, closely related. Therefore, we have synonymized *Zionea* with *Nebritus*.

Genus **Cyclotelus** Walker
(Fig. 24, 26, 27, 30, and 182–187)

Masculine

Cyclotelus Walker 1850:4. Type-species: *pruinosus* Walker; subsequent designation (Becker 1912:315). Type-locality: South America.

Furcifera Kröber 1911:524, new synonym. Type-species: *fascipennis* (Cole) by subsequent designation (Cole 1960*a*: 165) (= *Cyclotelus socius* Walker 1850: 6, new synonym). Type-locality: Brazil.

Epomyia Cole 1923*a*:26. Type-species: *Thereva pictipennis* Wiedemann by original designation. Type-locality: Savannah, Georgia.

Reference: Cole 1960*a* (as *Furcifera*).

Diagnosis

Small to rather large species (4.5–13 mm), moderately slender.

HEAD. — Frons of male at its narrowest much less than half width of anterior ocellus; female frons (Fig. 30) at level of anterior ocellus 1.5× as wide as ocellar tubercle; head 0.6–0.9× as high as wide, slightly more circular in males; compound eyes of female of uniform facet size, of male divided (e.g., *pictipennis* (Wied.) and *rufiventris* (Loew)) or at least with smaller facets ventrally; antennal insertion 0.6–0.7× distance from vertex to genae; frons at antennal insertion 0.3–0.4× (females) or 0.2–0.3× (males) as wide as head; genae slightly flanged, dark tomentum contrasting with silvery tomentum of lower face; head hypognathous; proboscis does not reach antennal base; palps one segmented, 0.7–1.0× as long as proboscis, thin basally, thicker distally, incurved toward tip, densely covered with thick hairs, especially basodorsally and distoventrally; head 0.5–1.1× as deep as antennal length (Fig. 26 and 27) (North American species tend to have antennal length about equal to head depth); scape 0.5–2.0× as long as flagellum (though in the North American species the range is 0.5–0.7×), 0.1–0.4× as wide as long (range 0.3–0.4× in North American species); scape sparsely covered with thin to mediumly thick hairs; dorsobasal surface of first flagellomere has a few short hairs, basal third more or less constricted, more so in South American species; flagellar style often not entirely terminal, either subterminal (i.e., set on outer lateral portion of apex — usually the North American species) or distinctly aterminal (Fig. 26) (i.e., set on outer lateral portion about two-thirds from base of first flagellomere — usually South American species including the type-species); style of 1–2 visible segments plus spine, approximately one-tenth as long as first flagellomere; frons lacks (male) or at most has a few short, inconspicuous setae on upper portion (females); 10–25 stout, usually darkly colored occipital setae per side in a single row paralleling eye margin from vertex to about one-third distance to bottom of eye, then incurving sharply around a stripe of silvery tomentum tangential to lower eye margin, and then downcurving for a short distance; pile lacking on frons, face, lateral areas of face and genae, moderately dense, elongate on ventral occiput, generally absent on ventral occipital tomentose stripe tangential to eye margin; tomentum fine, powdery, covering most of frons (male) or mainly lower part of frons (female) (Fig. 30), entire face and ventral occiput; gena has dark tomentum; upper frons of male has triangle of dark, velvety tomentum; frons of female has a well-defined central patch and often two smaller patches tangential to compound eyes of dark, velvety tomentum; usually area between female velvety tomentose patch and ocellar tubercle shiny, lacks tomentum.

Thorax. — np 2–4 (usually 3), sa usually 2 (North American species) or 1 (South American species), pa 1, dc 0, sc usually 2 (North American species) or 1–3 (usually 1, South American species); mesonotal pile sparse, moderately short (male) or very short (female), erect,

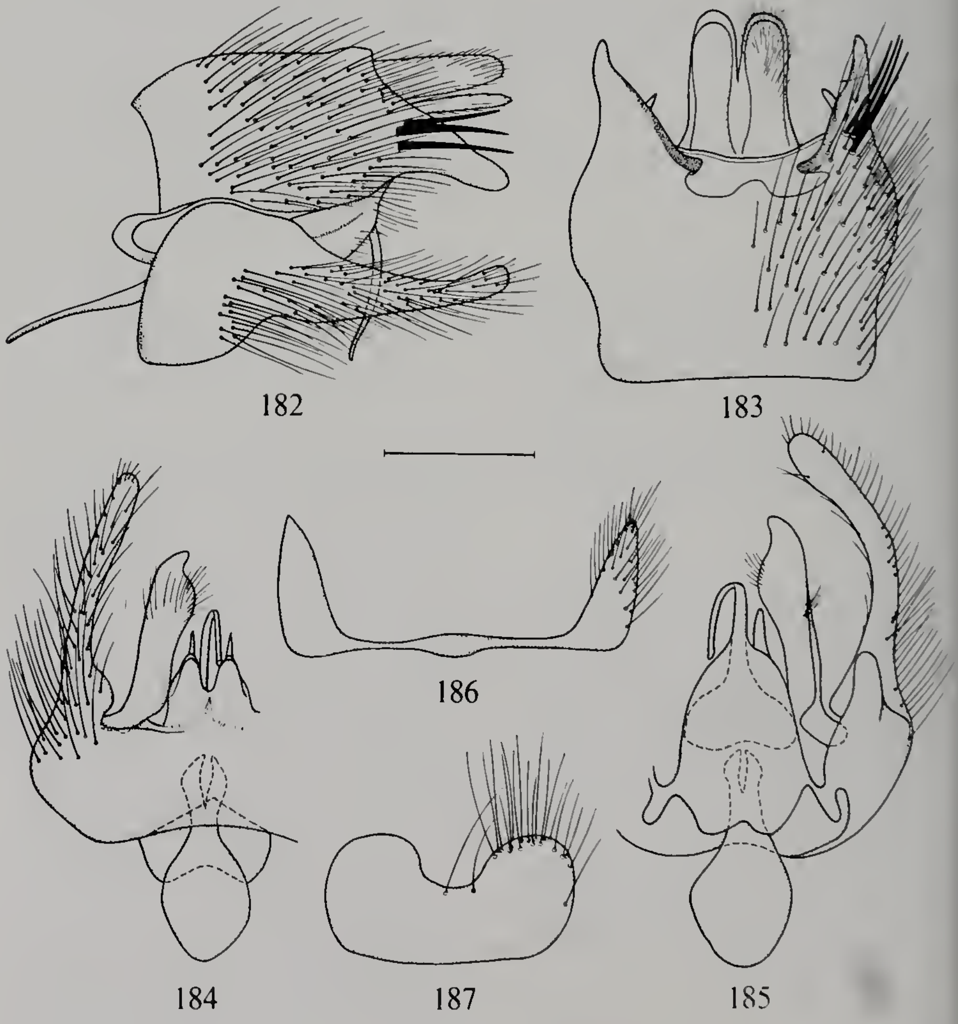

Fig. 182–187. — *Cyclotelus pruinosus* Wlk. male terminalia, holotype. 182. — Genitalia in lateral view. 183. — Epandrium with appendages in dorsal view. 184. — Gonocoxites with appendages and aedeagal parts in ventral view. 185. — Left gonocoxite with appendages and aedeagus in dorsal view. 186. — Tergite 8. 187. — Sternite 8. Scale: 0.5 mm.

occurring over entire surface except scutellum; mesonotal tomentum of two types: one is long, scalelike, semi-appressed, sparse, and the other is pollinose, dense, forming vittae and patterns; scutellum has velvety tomentum and often a marginal row of dense, enlarged scalelike tomentum — or pile — in an erect, vertical position; scutellar setae also assume erect position; pile lacking on most of pleurae, sparse on anepisternum and upper, lateral portions of prosternum, dense in a longitudinal row on pleurotergite; pollinose tomentum relatively sparsely covers most of pleural region, lacking on anepimeron. WING. — Hyaline to infuscate with various, usually transverse, patterns in browns, yellows, and/or grays; vein R_4 shallowly S curved; R_4 usually longer than R_5. LEGS. — Anterior surface of coxa 1 has 2 apical setae; posterior surfaces of coxae 1 and 2 shiny, not pilose, and at most very sparsely tomentose; femora have small, slender, almost exclusively av or pv setae; setae on femur 3 from occupying distinctly av and pv positions (mostly North American species) to scattered over ventral surface (mostly South American species); pile on anterior and dorsal surfaces of femur 3 scalelike, appressed; on ventral surface short, sparse, thin; tibia 1 relatively straight, elongate to stout, with dorsal setae lacking or at least shorter than width of tibia 1; basitarsus 1 (Fig. 24) swollen, enlarged.

ABDOMEN. — Narrow, nearly parallel sided from segment 1 through 4; thereafter abdomen tapers rapidly; segments 6–8 of males telescoped within segment 5 and taper is cut to blunt point; segments of females not telescoped and taper is long and pointed; dorsum of abdomen flattened, more so in males; tergites generally not fasciate, though tergite 2 is brown or gray fasciate in a few species; pile pattern variable, never dense; dorsum of males and, to a lesser degree of females of a few species, densely silver.

MALE TERMINALIA (Fig. 182–187). — Sternite 8 (Fig. 187) shallowly to deeply bilobate; tergite 8 (Fig. 186) narrowly constricted medially; epandrium (Fig. 183) large, covering most of terminalia, 1.3–1.8× (the higher values occurring in North American species) wider than long (bisected medially longitudinally and latitudinally), with outer posterior margins extended hindward to about level of apex of cerci and ventral epandrial sclerite, almost always bidentate; cerci (Fig. 183) slightly shorter than ventral epandrial sclerite; cerci joined only basally; ventral epandrial sclerite not keeled, usually incised; intersegmental membrane basad of this sclerite weakly to heavily sclerotized, strongly attached to sclerite base with 2 arms firmly attached to posterolateral projections of epandrium, and weakly to firmly attached to anterior margin of aedeagus; gonocoxites (Fig. 184) solidly fused along ventral margin, with an elongate, posterior projection (Fig. 182) extending beyond apex of gonostylus (South American species) or not (common North American species). According to Lyneborg (1969:407), *sumichrasti* (Bellardi) has a broader projection, but clearly this species falls within the concept limits of *Cyclotelus*. Hypandrium lacking or completely fused with gonocoxites, not identifiable; aedeagus not attached to ventral lobes, but attached to parameral apodeme (Fig. 185) by a heavily sclerotized rod, which bows anteriorly beyond gonocoxal cavity and sharply hindward and forms a firm connection to the posterolateral edge of the aedeagal dorsal apodeme; parameral process (Fig. 185) free, very reduced, knoblike; ventral lobes fused basally, elongate, probably function as a guide for the thin, elongate distiphallus; length of aedeagus basad of center 1.5–2.0× length distad of center (Fig. 185); aedeagal dorsal apodeme and inner dorsal shield each more than twice as wide as base of distiphallus; this curved slightly upward, outward, arching downward and inward, and slightly outward at tip; aedeagal ventral apodeme usually narrow (usually less than half as wide as inner shield, but nearly as wide in one South American species), elongate (slightly longer than inner dorsal shield), not forked; inner dorsal shield shallowly bilobate; ejaculatory apodeme large to mediumly small, the distal end expanded, usually horizontally flattened.

Habitat

E. I. Schlinger (personal communication) has collected specimens in Peru alighting on sunlit paths in otherwise dense, dank tropical forests. R. H. Painter (Cole 1960*a*: 168) has collected specimens of *rufiventris* (Loew) in "sand dunes" at Medora, Kansas. Three species, *rufiventris, pictipennis,* and *colei,* have been abundantly collected at Sand Ridge State Forest, Mason County, Illinois, on oak forested expanses of sand.

Distribution

Members of the genus *Cyclotelus* have been found throughout the New World tropics of Argentina, Brazil, Paraguay, Uruguay, Bolivia, and Peru and in southern, eastern, and central Mexico, through the eastern portion of the United States, and westward to the Rocky Mountains (e.g., Texas and Montana) and northward into Canada (Manitoba).

Included Species

bellus (Cole) 1923*a*: 32 ♂, ♀ (*Epomyia bella*), new combination. Distribution. — Texas: Macdona, Hidalgo County; Laguna Madre, 25 miles southwest of Harlingen; Padilla, Tamaulipas, Mexico.

colei Irwin & Lyneborg, new name for *scutellaris* Loew 1869*b*, not Walker 1857. Distribution. — Central and eastern United States.

> *scutellaris* Loew 1869*b*: 171 ♀ (*Psilocephala*), not *Cyclotelus* Walker 1857: 133 (Brazil, Uruguay, Paraguay).

hardyi (Cole) 1960*a*: 167 (*Furcifera*), new combination. Distribution. — Brownsville and Los Borregos, Texas.

> *flavipes* Hardy 1943: 26 ♂ (*Epomyia*), not Kröber 1928*b*: 113.

pictipennis (Wiedemann) 1821: 63 ♀ (*Thereva*), new combination. Distribution. — Eastern North America to Michigan and Texas.

> *erythrura* Loew 1869*b*: 172 ♂ (*Psilocephala*).

rufiventris (Loew) 1869*a*: 126 ♀ (*Psilocephala*), new combination. Distribution. — Ontario, Canada: Rhode Island, Massachusetts, New Jersey, Virginia, Maryland, Florida, Washington, D.C., Ohio, Indiana, Illinois, Michigan, Montana, Nebraska, Kansas, Texas, New Mexico, and Arizona.

> *lacteipennis* Kröber 1914: 53 ♂ (*Psilocephala*). Cole 1960*a*: 168.

sumichrasti (Bellardi) 1861: 91 ♂ (*Psilocephala*), new combination. Distribution. — Tuxpango, Orizaba, and Tabasco, Mexico.

All of the species from America north of Mexico have probably been described. There are 14 apparently valid species described from South America. Probably a few species remain undescribed from Mexico and Central America, and undoubtedly there are several undescribed species from the Amazon Basin northward to Panama.

Genus Ozodiceromya Bigot

(Fig. 5, 28, 29, and 188–193)

Feminine

Ozodiceromya Bigot 1889: 321. Type-species: *mexicana* Bigot 1889: 321 by original monotypy. Type-locality: Mexico.

Ozodiceromyia Bigot, error (Bigot 1889: 323).

Ozodiceronyma, error (Wulp 1898).

Diagnosis

Small and slender to large and robust species.

HEAD. — Frons of male at its narrowest narrower than half width of anterior ocellus; frons of female at level of anterior ocellus 1.3–2.3× as wide as ocellar tubercle; frons of female at level of antenna 2.8–4.6× as wide as ocellar tubercle; male frons from slightly raised in some species (e.g., *californica*) to flattened, narrow in most species, but broad in *nanella* and closely related species, triangular shaped and with some shiny bare area, usually central; male frons has some tomentose areas in most species; female frons broad, with shiny bare callus of various sizes and shapes, usually surrounded by fine tomentum; frons, face, and genae of both sexes with or without pile; pile usually short and concentrated on upper frons of female; tomentum on frons, face, and occiput usually silvery; genae usually enlarged, tomentum darker; head greatly (e.g., *mexicana*) to slightly protruding anteriorly at antennal level; head depth 0.4–1.4× antennal length (Fig. 28 and 29); scape usually slender, 0.5–1.3× as long as flagellum; first flagellomere variously shaped from elongate to pear shaped, with setae restricted to basal third; flagellar style usually apical, from long to short, usually two segmented, with a distinct, terminal spine (although *mexicana* (Fig. 28) and *argentifera* have style subapical, and spine of female *californica* not distinct); palps one segmented.

THORAX. — np 3–4 (usually 3), sa 1–2 (usually 2), pa 1, dc 0–2 (usually 0–1), sc 1–2 (usually 2); mesonotal pile of one

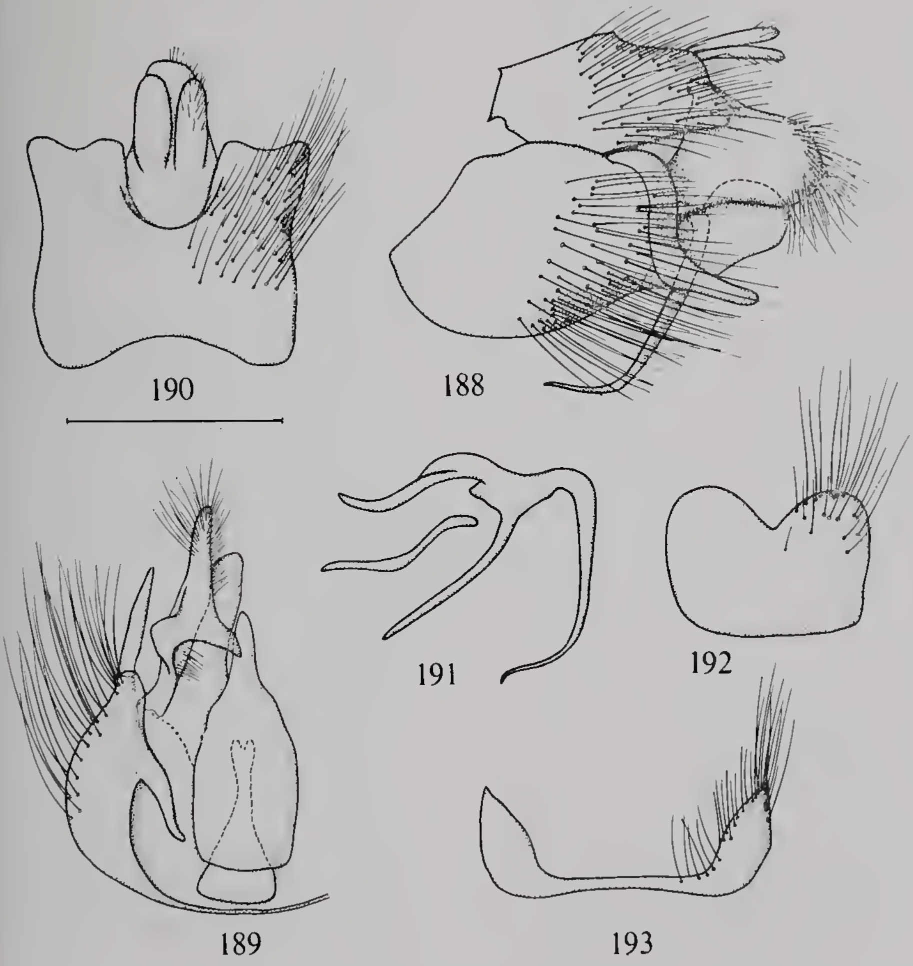

Fig. 188–193. — *Ozodiceromya mexicana* Big. male terminalia. 188. — Genitalia in lateral view. 189. — Right gonocoxite with appendages and aedeagus in dorsal view. 190. — Epandrium with appendages in dorsal view. 191. — Aedeagus in lateral view. 192. — Sternite 8. 193. — Tergite 8. Scale: 0.5 mm.

or two types, either simple, erect, relatively long or simple, long, erect and scalelike, appressed to semi-appressed, usually bronze to copper colored; prosternum has pile in and around central depression. WING. — Cell m_3 closed at wing margin; vein R_4 slightly longer than vein R_5; cell r_4 about 2.3 (range 1.6–2.9) × longer than wide at apex; color hyaline with darkened areas on some species but not highly mottled; stigma usually dark brown; costal cell darkened in some species. LEGS. — Fore coxa has 2 strong, apical setae; fore femur has 0–12 (usually 2–4) setae; hind femur has 4–20 anteroventral plus posteroventral setae (most are anteroventral); basitarsus of foreleg often swollen (cf. Fig. 24).

ABDOMEN. — Moderately slender to broad, gradually tapering from segment 2 to apex; segments 5–8 often telescoped within segments 2–5 of male; abdominal segments not telescoped in female; dorsum flattened in both sexes, dorsum of male usually has dense silvery tomentum; both sexes moderately pilose; female abdomen has grayish silvery tomentum along posterolateral corners of segments.

MALE TERMINALIA (Fig. 188–193). — Tergite 8 (Fig. 193) rather large, strongly constricted for most of medial portion; sternite 8 (Fig. 192) ovoid to rectangular, with a deep to shallow notch medially in posterior margin; epandrium (Fig. 190) shorter in midline than wide, ratio of medial length to width 1.7–4.0; posterolateral corners from greatly flanged (as in some species near *nanella*) to squarish, from extending posteriorly beyond cerci to not, from dentate to blunt or smooth, variable; cerci (Fig. 190) free, well separated and moderately to weakly sclerotized; posterior margins of cerci and ventral epandrial sclerites subequal, cerci longer in some species, shorter in others; ventral epandrial sclerite thinly to moderately sclerotized, with 1 sclerotized island beneath cerci posteriorly rounded or notched and 2 elongate islands attached to posterolateral margins of epandrium, usually united along midline of epandrium and extending anteriorly usually to or nearly to anterior margin of epandrium, sometimes extending anteriorly beyond epandrium; these anterior sclerites usually thinly, often membranously, attached to anterior margin of aedeagus; aedeagus relatively large; distiphallus variously shaped, from thin, tubelike to flattened, from long, sinuate, sometimes recurved beneath gonocoxites to short; tip of distiphallus usually thin, sometimes bulbous, swollen, some species (e.g., *anomala*) having a hooklike projection ventrally at base of distiphallus; dorsal apodeme from triangular to rectangular and sometimes truncate, the lateral margins often more heavily sclerotized, usually as long as or longer and much wider than ventral apodeme; ventral apodeme thin, scoop shaped, longer than dorsal apodeme in a few species; ejaculatory apodeme usually simple, sticklike, large and club shaped in a few species; center of aedeagus has a variously modified receptacle for proximal end of ejaculatory apodeme; ventral lobes well-developed, project dorsally and anteriorly and cradle distiphallus, usually rounded, not connected to aedeagus; parameral apodeme has occasionally a sclerotized and more commonly a membranous connection to lateral portion of aedeagus, this connection seems lacking in a few species (as in Fig. 189); parameral process usually vestigial or knoblike, present in the type-species (Fig. 188) as an S-curved sclerotization closely adjoining posterior margin of gonocoxite, not pilose; parameral apodeme heavily sclerotized, situated far from anterior margin of gonocoxite; gonocoxites solidly united ventromedially over entire length in most species, over anterior third in a few; posterior margin of gonocoxites has 1 or 2 (sometimes none) posteriorly directed protuberances, either pointed or flangelike; the dorsal portion of these protuberances may represent the parameral process, as in *mexicana* (Fig. 188); hypandrium absent or completely fused with gonocoxites, not discernible.

Habitat

Specimens can be encountered in mountainous environments and in deserts; adults at times can be found on shrubs containing aphid honey dew. Larvae of one species were found in mounds of dirt pushed up by gophers, while larvae of a different species were collected in sandy soils beneath sagebrush. *Ozodiceromya* is a diverse genus, and the habitats occupied by its various species are also diverse.

Distribution

The genus *Ozodiceromya* is found throughout the Nearctic Region southward into Ecuador and Venezuela in the Neotropical Region. The southwestern United States and northwestern Mexico seem particularly rich in species.

Included Species

albertensis (Cole) 1925:86 ♂, ♀ (*Psilocephala*), new combination. Distribution. — Alberta, Canada.

aldrichi (Coquillett) 1893*b*:227 ♂ (*Psilocephala*), new combination. Distribution. — Southern California.

anomala (Adams) 1904:444 ♂, ♀ (*Thereva*), new combination. Distribution. — Arizona, New Mexico, and north-central Mexico.

argentata (Bellardi) 1861:89 ♂ (*Thereva*), new combination. Distribution. — Cordova, Mexico.

argentifera (Kröber) 1929:418 ♂ (*Phycus*). Distribution. — Vera Cruz, Mexico. (This species name has been associated with specimens of *Ozodiceromya* with very long antennae from southern Arizona. Whether the specimens from southern Arizona are conspecific with the holotype from Vera Cruz is not known though an assumption of conspecificity seems unwarranted.)

arizonensis (Cole) 1923*a*:45 ♂, ♀ (*Psilocephala*), new combination. Distribution. — Arizona.

californica (Kröber) 1912:259 ♂ (*Thereva*), new combination. Distribution. — California.

coloradensis (James) 1936:341 ♂, ♀ (*Psilocephala*), new combination. Distribution. — Colorado.

costalis (Loew) 1869*a*:11 ♀ (*Psilocephala*), new combination. Distribution. — California and Nevada.

crassicornis (Bellardi) 1861:88 ♂ (*Thereva*), new combination. Distribution. — Truqui, Mexico.

davisi (Johnson) 1926:300 ♂ (*Psilocephala*), new combination. Distribution. — Southport, North Carolina.

flavipennis (Cole) 1923*a*:42 ♂, ♀ (*Psilocephala*), new combination. Distribution. — East-central United States.

frommeri Irwin & Lyneborg, new name for *Psilocephala lateralis* Adams 1904. Distribution. — Southern California, Arizona, and northwestern Mexico.

lateralis (Adams) 1904:444 ♂ (*Psilocephala*), new combination, not Eschscholtz 1822.

frontalis (Cole) 1923*a*:40 ♂, ♀ (*Psilocephala*), new combination. Distribution. — Northeastern United States.

germana (Walker) 1848:222 ♂ (*Thereva*), new combination. Distribution. — Southeastern United States.

hoemorrhoidalis (Macquart) 1840:26 ♂ (*Thereva*), new combination. Distribution. — Southeastern United States.

haemorrhoidalis, unjustified emendation.

johnsoni (Coquillett) 1893*b*:228 ♀ (*Psilocephala*), new combination. Distribution. — Southeastern United States.

levigata (Loew) 1876:319 ♀ (*Psilocephala*), new combination. Distribution. — Central California.

laevigata, unjustified emendation.

melanoneura (Loew) 1872:74 ♂ (*Thereva*), new combination. Distribution. — California.

metallica (Kröber) 1914:68 ♂ (*Thereva*), new combination. Distribution. — New Mexico.

mexicana Bigot 1889:321 ♀. Distribution. — Mexico.

setosa (Kröber) 1912:211 ♂, ♀ (*Euphycus setosus*), new combination, new synonym.

milleri (Irwin) 1977*b*:294 ♀ (*Breviperna*), new combination. Distribution. — Puebla, Oaxaca, Mexico.

montiradicis (James) 1949:10 ♂, ♀ (*Psilocephala*), new combination. Distribution. — Colorado.

nanella (Cole) 1960*b*:118 ♂, ♀ (*Thereva*), new combination for *nana* Cole 1959, not Fallén 1820.

  nana Cole 1959:148 (*Thereva*), not Fallén 1820 for *pygmaea* Cole 1923*a*, not Fallén 1820.

  pygmaea Cole 1923*a*:89 (*Thereva*), not Fallén 1820.

nigra (Say) 1823:40 ♀ (*Thereva*), new combination. Distribution. — Pennsylvania.

nigrimana (Kröber) 1912:238 ♀ (*Psilocephala*), new combination. Distribution. — Colorado.

notata (Wiedemann) 1821:114 ♂ (*Thereva*), new combination. Distribution. — Georgia.

obliquefasciata (Kröber) 1911:504 ♂, ♀ (*Psilocephala*), new combination. Distribution. — Costa Rica (this species may also be found in parts of Mexico and in other parts of Central America).

platancala (Loew) 1876:321 ♀ (*Psilocephala*), new combination. Distribution. — Texas.

? *ruficornis* (Macquart) 1840:25 ♂ (*Thereva*), new combination. Distribution. — Carolina.

rugifrons (Kröber) 1914:54 ♀ (*Psilocephala*), new combination. Distribution. — Chihuahua, Mexico.

schroederi (Kröber) 1911:503 ♀ (*Psilocephala*), new combination. Distribution. — Costa Rica (this species may also occur farther north in Central America).

signatipennis (Cole) 1923*a*:47 ♂, ♀ (*Psilocephala*), new combination. Distribution. — Northwestern United States.

subnotata (Johnson) 1926:299 ♂, ♀ (*Psilocephala*), new combination. Distribution. — St. Augustine, Florida.

univittata (Bellardi) 1861:90 ♀ (*Psilocephala*), new combination. Distribution. — Puebla, Mexico.

xanthobasis (James) 1949:12 ♂ (*Thereva*), new combination. Distribution. — Colorado.

There are several as yet undescribed species of *Ozodiceromya,* especially from western North America and Mexico. Many of the listed species, especially those from the eastern part of North America, are probably synonyms.

Note

We place species from several genera into *Ozodiceromya* primarily on the basis of male terminalia. As it stands, we believe the genus is monophyletic, but it might profitably be divided into three or more genera at a later date, once the species have been properly sorted out.

Genus **Chromolepida** Cole
(Fig. 31 and 194–199)

Feminine

Chromolepida Cole 1923*a*:23. Type-species: *Psilocephala pruinosa* Coquillett 1904*a*:91 by original designation. Type-locality: Granada, Nicaragua.

Diagnosis

Small, slender species.

Head (Fig. 31). — Compound eyes of male almost touch for a considerable distance; eyes of male of two distinct facet sizes, different facets either meeting along a line across the eye or grading gradually with no sharp line of differentiation. Frons of female exceptionally wide at level of anterior ocellus, slightly wider than twice width of ocellar tubercle, widening to about 3.5× width of ocellar tubercle at level of antennal insertion. Frons of both sexes has a rounded to oblong, shining callosity above antennal bases and silvery and velvety tomentum. Velvety tomentum in the form of two rounded patches, each adjacent to a compound eye of female, usually as a V-shaped wedge on the frons above the shining center callosity of the male. Remainder of frons of both sexes has silvery

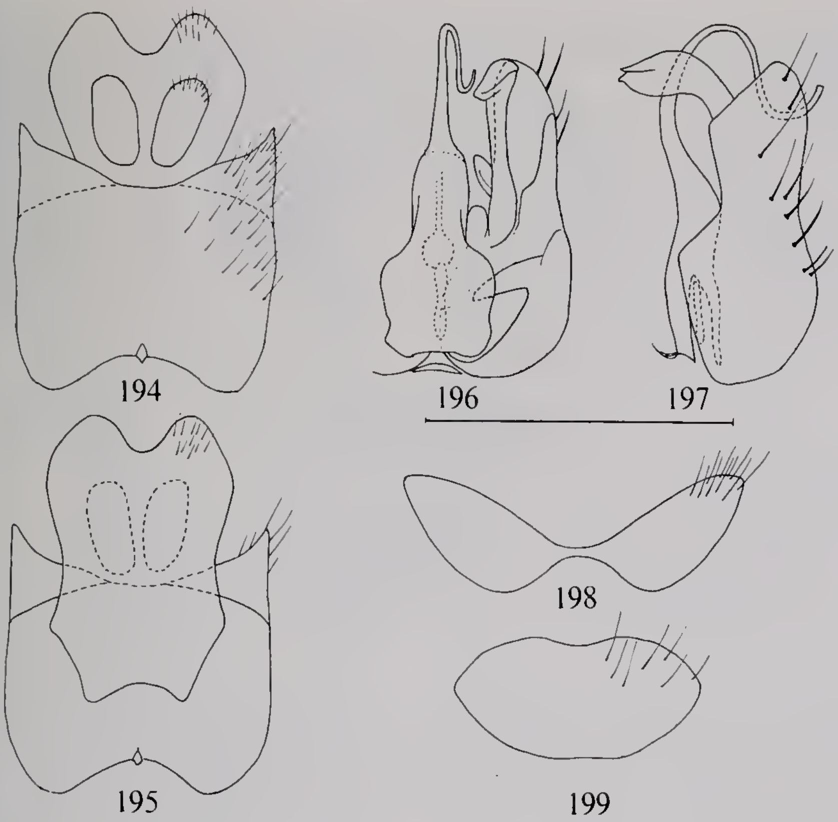

Fig. 194–199. — *Chromalepida bella* Cole male terminalia. 194. — Epandrium with appendages in dorsal view. 195. — Epandrium with appendages and aedeagus in ventral view. 196. — Left gonocoxite with appendages and aedeagus in dorsal view. 197. — Left gonocoxite with appendages and aedeagus in lateral view. 198. — Tergite 8. 199. — Sternite 8. Scale: 0.5 mm.

tomentum, except for a bare, shiny area near the vertex of female. Head slightly protrudes anteriorly. Two prominent facial calli below antennal bases and slightly offset to the sides (Fig. 31). Gena usually has a darkened tomentose area. Lateral portions of face without pile. Antenna (Fig. 31) 130–160 percent as long as head depth; scape 1.6–2.4× as long as flagellum, slender; flagellar style subapical, located in a laterally directed cavity, apparently one segmented with a distinct apical spine. Palps one segmented.

THORAX. — np 2–4 (usually 3), sa 1, pa 1, dc 0, sc 1–2 (usually 1); all thoracic setae dark brown to black; mesonotal pile of both sexes pale, of two types: one is appressed, silvery to metallic golden scalelike, and the other semito fully erect, the latter very short on female, much longer on male; prosternum usually without pile in and around central depression; a few sparse hairs can be found in prosternum of some males. WING. — Cell m_3 closed; veins R_4 and R_5 about the same length, or R_5 slightly longer; cell r_4 1.8–2.2× longer than wide at apex. LEGS. — Fore coxa has 2 subapical setae on anterior surface; middle coxa lacks pile on posterior surface; hind femur has 1–5 anteroventral setae.

ABDOMEN. — Rather slender, gradually tapering from segment 2 toward apex; segment 7 of male is sometimes partially telescoped into segment 6; male dorsum flattened, densely covered with appressed, elongate silvery scales; dorsum of both sexes often partially orange and dark brown.

MALE TERMINALIA (Fig. 194–199).— Tergite 8 (Fig. 198) relatively large, strongly constricted in middle; sternite 8 (Fig. 199) also large, oval, very slightly incised posteriorly; epandrium (Fig. 194) about 1.5× as wide as long along midline, otherwise as long as wide; posterolateral corners of epandrium flanged, sharpened; cerci free, moderately sclerotized; ventral epandrial sclerite (Fig. 195) large, extends beyond cerci, sclerotized to level of posterior margin of epandrium, anteriorly becoming more membranous and weakly attached to anterior margin of aedeagus; aedeagus (Fig. 197) has very large, S-curved distiphallus; dorsal apodeme broad, rectangular; ventral apodeme long, thin; ejaculatory apodeme short, weak; ventral lobes of gonocoxite short, supporting the base of the phallus but not attached to the aedeagus; parameral apodeme (Fig. 196) large, directed inward, apex situated below lateral margin of dorsal apodeme, but without a strongly sclerotized connection to the dorsal apodeme; parameral process lacking; gonocoxites (Fig. 196) separated, attached anteriorly by a narrow, crescent-shaped hypandrium; posteriorly directed scoop-shaped portion ventrally on each gonocoxite; gonostylus usually long, curved dorsally at apex.

Habitat

Species in *Chromolepida* occupy rather diverse habitats. *C. bella* occurs in the coastal dunes near San Francisco, California. Undescribed species were collected in the Sierra Nevada Mountains, Sierra County, California, in a meadow on *Daucus pusillus* flowers. Another undescribed species was collected on tropical roadside vegetation near Mazatlán, Mexico.

Distribution

Species in this genus are confined to the western portion of North America from Oregon, Idaho, Utah, and Colorado southward through New Mexico, Arizona, and California to Mexico, Central America, and northern South America, at least Venezuela and Colombia. It has not been recorded from the West Indies.

Included Species

bella Cole 1923*a*:24 ♂, ♀. Distribution. — West coast of California.

mexicana Cole 1923*b*:460 ♀. Distribution. — Sonora, Mexico.

pruinosa (Coquillett) 1904*a*:91 ♂ (*Psilocephala*). Distribution. — Nicaragua, Central America.

There are several undescribed species in this genus.

Subfamily Phycinae

These attributes characterize the subfamily Phycinae.

1. Dorsal sclerotized bridge present between dorsal apodeme of aedeagus and parameral apodeme, or if absent (*Henicomyia*), the hypandrium very large and haired, and dorsal apodeme of aedeagus reduced.
2. Ventral apodeme of aedeagus deeply forked or vestigial.
3. Tergite 9+10 of female slenderly and sparsely spinose, the spines of only one kind.
4. Intersegmental membrane between sternite 8 and sternite 9 (furca) of female membranose, not sclerotized.
5. Pregenital abdominal segments have spiracles incorporated in the tergal sclerites.
6. Vein R_1 often setose, though not setose in *Schlingeria*.

Genus Phycus Walker
(Fig. 33, 34, 36, and 200–207)

Masculine

Phycus Walker 1850:2. Type-species: *Xylophagus canescens* Walker 1848 (= *Xylophagus brunneus* Wiedemann 1824) by original monotypy. Type-locality: North Bengal, India.

Reference: Lyneborg 1978.

Diagnosis

Moderately sized, slender species.

HEAD (Fig. 33). — Frons of both sexes

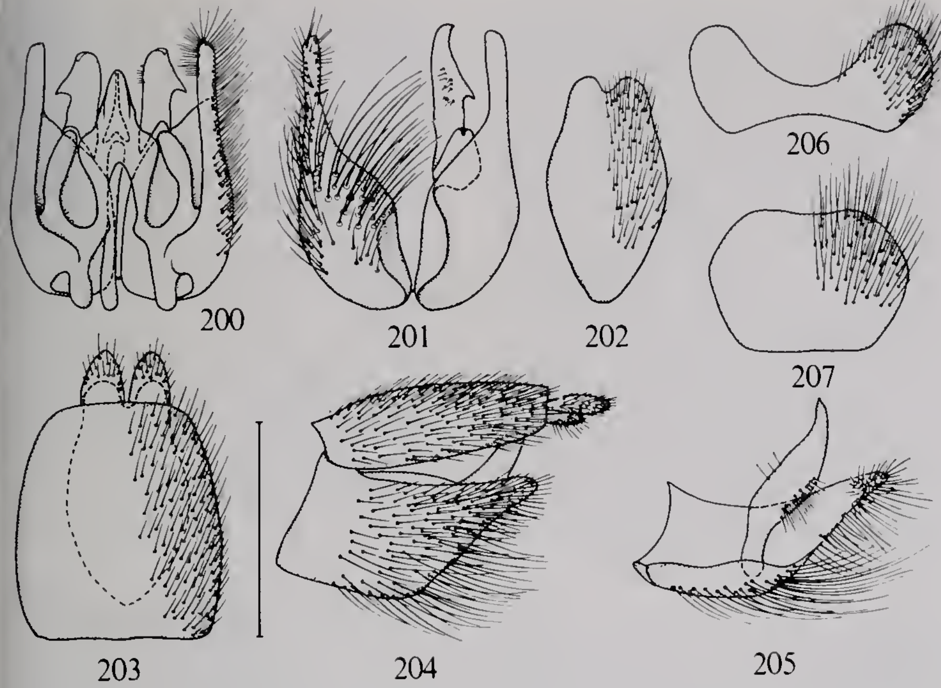

Fig. 200–207. — *Phycus brunneus* (Wied.) male terminalia. 200. — Gonocoxites with appendages and oedeagus in dorsal view. 201. — Gonocoxites and right gonostylus in ventral view. 202. — Ventral epandrial sclerite. 203. — Epandrium with appendages in dorsal view. 204. — Genitalia in lateral view. 205. — Right gonocoxite and gonostylus in internal view. 206. — Tergite 8. 207. — Sternite 8. Scale: 0.5 mm.

at its narrowest from as wide as to more than twice as wide as ocellar tubercle, wider in female than in male of same species; eye margins only slightly diverge from level of ocellar tubercle toward genae; frons bare or with sparse, scanty pile, its pattern composed of shining black areas and tomentose areas; face and gena without pile; head slightly to distinctly protrudes at antennal level; facial and genal calli absent; head depth 0.7–0.9× antennal length; ratio of lengths of scape and flagellum differs greatly among species, in the unnamed North American species (Fig. 36) scape about 0.6× as long as flagellum; flagellar style terminal, two segmented, with a very small terminal spine; palps two segmented (Fig. 34).

THORAX. — np 1–2, sa 1, pa 1, dc 0–1, sc 1; mesonotal pile short, uniform, erect, pale or blackish; prosternum bare in and around central depression; pleural pile very short and sparse. WING. — Cell m_3 usually closed and petiolate, rarely open; veins R_4 and R_5 about same length; cell r_4 2.2–2.6× as long as wide at apex; ground color hyaline to rather intensively brown, clouding very apparent near apex of wing. LEGS. — Fore coxa moderately long, sparsely haired, and with 1 or 2 slender apical setae; middle coxae bare on posterior surface; all femora without setae; tibiae have very short setae.

ABDOMEN. — Slender, especially in male, as wide as long, laterally compressed toward apex; dorsum convex, shining black or reddish brown; pile sparse and short.

MALE TERMINALIA (Fig. 200–207). — Tergite 8 (Fig. 206) comparatively wide and only moderately constricted medially; sternite 8 (Fig. 207) large and simple; epandrium (Fig. 202) very simple, without incisions or other modifications, may be shorter or longer in midline than maximum width; cerci free, well sclerotized, extending posteriorly beyond margin of ventral epandrial sclerite. This sclerite (Fig. 202) large, well sclerotized, setose, extending to anterior margin of epandrium, but without attachment to aedeagus; aedeagus (Fig. 200) laterally attached by a strongly sclerotized bridge to midsection of paramere; distiphallus forms a fine, downwardly directed tube; ventral apodeme shaped as two narrow, widely separated sticks; ejaculatory apodeme large; paramere composed of a distal process, which curves inward and downward approaching base of gonostylus, and a stout basal apodeme; gonocoxites (Fig. 201) not united ventrally, attached only anteriorly by a very narrow membrane; a minute remnant of a hypandrium exists at anterior margin of gonocoxites in some species; gonocoxite without a ventral lobe (Fig. 205).

Habitat

In Africa *Phycus* species are often found running along dead or dying tree trunks in riverine habitats. In southern California, an undescribed species can be encountered running (a fast walk) on rock faces directly below *Washingtonia* palms in desert canyon bottoms.

Distribution

The genus is represented in North America by a single undescribed species occurring in southern California and northwestern Mexico. There are about 20 species of *Phycus* in the Old World distributed throughout the Afrotropical Region, the Middle East, the Indian subcontinent, and eastward to China and the Philippines. The Afrotropical species were revised by Lyneborg (1978).

Note

The genus *Ataenogera* (Kröber 1914), with several species in Central and South America, is extremely similar in general appearance to certain species of *Phycus*. However, the two genera are quite distinct, the best distinguishing characters being: (a) palps two segmented in *Phycus,* one segmented in *Ataenogera;* (b) fore coxae have 1–2 apical setae in *Phycus,* but 4–6 setae in *Ataenogera;* (c) ventral epandrial sclerite large and free in *Phycus,* smaller and fused laterally with epandrium in *Ataenogera;* (d) hypandrium extremely small, or even absent, in *Phycus,* but large in *Ataenogera;* (e) ventral apodeme of aedeagus composed of two long, narrow rods in *Phycus,* but totally absent in *Ataenogera.*

Genus Henicomyia Coquillett
(Fig. 35 and 208–214)

Feminine

Henicomyia Coquillett 1898:187. Type-species: *hubbardii* Coquillett 1898 by original monotypy. Type-locality: Fort Grant, Arizona.

Reference: Lyneborg 1972.

Diagnosis

Long, slender species.

HEAD (Fig. 35). — Frons of both sexes at its narrowest wider than ocellar tubercle, slightly wider in female than in male; eye margins gradually but consistently diverge from ocellar tubercle downward to ventral aspect of head; frons bare and with pattern of grayish tomentum and shining black areas; face and genae bare; lower occiput has short, sparse pilosity; head distinctly protrudes at antennal level; facial and genal calli absent; head depth 0.4–0.8× antennal length; scape very short haired, 0.3–0.6× as long as, and often distinctly narrower than, flagellum; flagellum very short haired; flagellar style terminal, obviously one segmented, very short compared with first flagellomere; a terminal spine is not discernible; palps two segmented.

THORAX. — np 1–2, sa 1, pa 1, dc 0, sc 0–1; mesonotal pile very short, uniform, erect; prosternum has short, sparse pile in and around central depression; pleura practically bare. WING. — Cell m_3 closed and petiolate; veins R_4 and R_5 about the same length; cell r_4 3.8–5.3× as long as wide at apex; ground color hyaline, with a brownish band from outrun of R_{2+3} to region apical of discal cell; apex of second basal cell may be clouded. LEGS. — Fore coxae very long, sparsely haired, and with 1 or 2 short apical setae; middle coxae bare on posterior surface; all femora long, slender, and extremely short haired; appressed, scalelike pile lacking; setae absent.

ABDOMEN. — Long, slender in both sexes, nearly cylindrical or slightly laterally compressed, not markedly tapering toward apex; dorsum generally dark, mostly shining black, with at most small, inconspicuous areas of pale tomentum; pattern similar in both sexes; abdominal pilosity very short, sparse.

MALE TERMINALIA (Fig. 208–214). — Tergite 8 (Fig. 213) large, rhomboid, with dense, uniform pilosity; sternite 8 (Fig. 214) large, uniformly pilose; epandrium (Fig. 210) about as long in midline as maximum width, its shape simple; cerci free (Fig. 210), rather small, well sclerotized; ventral epandrial sclerite (Fig. 210) distinctly extends posteriorly beyond cerci; sclerotized part of ventral epandrial sclerite small, restricted to the portion below cerci; anterior part of ventral epandrial sclerite membranous, not attached to anterior margin of aedeagus (cf. *Phycus,* Fig. 200); aedeagus completely free, without marked attachments dorsally (to parameral apodeme) or ventrally; distiphallus broad and wide, upright, terminates in two processes (Fig. 209), of complicated structure; dorsal apodeme vestigial, rudimentary; ventral apodeme forked, composed of two widely spaced, stout arms; ejaculatory apodeme large; dorsal margins of gonocoxites connected over midline by a weakly sclerotized membrane

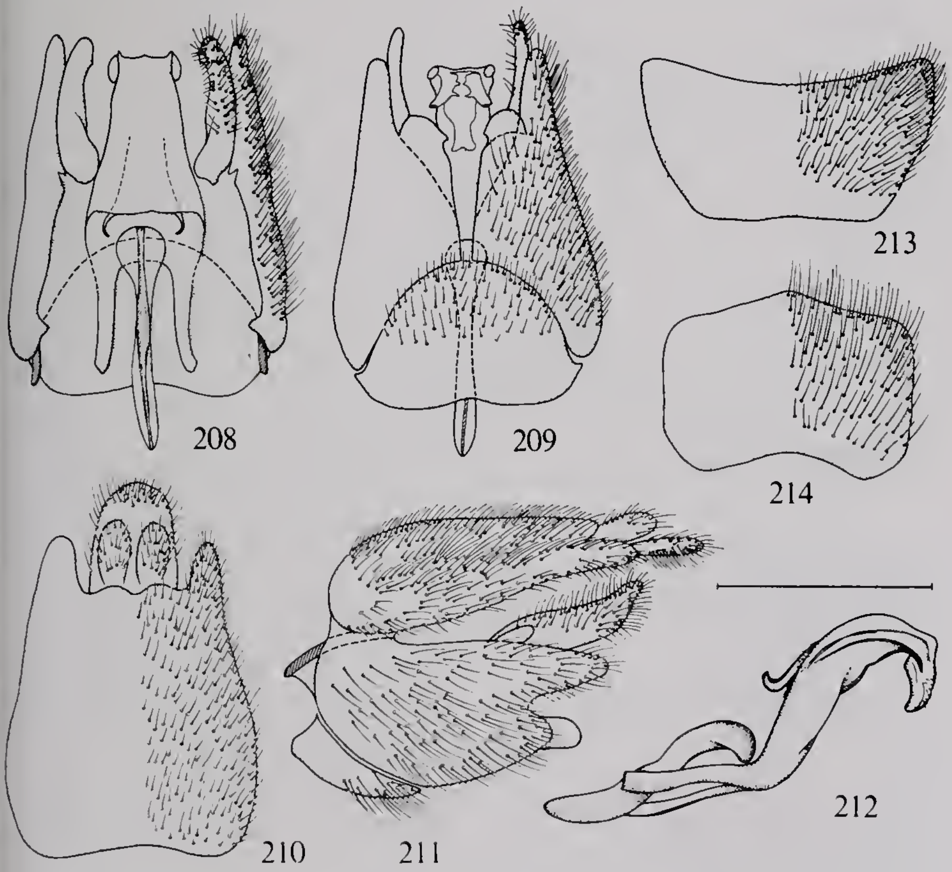

Fig. 208–214. — *Henicomyia hubbardii* Coq. male terminalia. 208. — Gonocoxites with appendages and aedeagus in dorsal view. 209. — Gonocoxites with appendages, hypandrium, and distiphallus in ventral view. 210. — Epandrium with appendages in dorsal view. 211. — Genitalia in lateral view, aedeagus omitted. 212. — Aedeagus in lateral view. 213. — Tergite 8. 214. — Sternite 8. Scale: 0.5 mm.

attached to triangular outshoots (= parameral apodeme) (Fig. 208); this connection not attached to aedeagus; distal parameral process not developed; gonocoxite in lateral view (Fig. 211) has an incision posteriorly; gonostylus a simple staff; gonocoxites (Fig. 209) not united ventrally; however, attached by a membrane; a membrane also attaches the enormous triangular hypandrium with the anterior, ventral edges of the gonocoxites.

Habitat

Henicomyia hubbardii has been collected inside of houses at windows in Portal, Arizona. Virtually nothing is known of the habitat of *Henicomyia* species.

Distribution

Species of *Henicomyia* range from the southwestern United States (Arizona and Colorado) through Mexico, Costa Rica, and Amazonian Peru to Brazil.

Included Species

hubbardii Coquillett 1898:187 ♂. Distribution. — Arizona, New Mexico, possibly southward to Mexico City, Mexico if *varipes* is a synonym, as suggested by Lyneborg (1972:367).
  hubbardi Cole 1923*a*:17, unjustified emendation.
  ? *varipes* Kröber 1912:213 ♀ (Lyneborg 1972:364). Distribution. — Mexico City, Mexico.

Five described species occur in the Neotropical Region, one from Costa Rica, one from Peru, and three from Brazil (Lyneborg 1972).

Genus **Parapherocera** Irwin
(Fig. 37, 40, and 215–221)

Feminine

Parapherocera Irwin 1977*a*:438. Type-species: *montana* Irwin 1977*a*:442. Type-locality: 6 km south of La Rumorosa, Baja California Norte, Mexico.

Reference: Irwin 1977*a*.

Diagnosis

Small, slender species; length, excluding antennae, 4–5 mm; males and females about the same size.

HEAD. — Frons of male (Fig. 40) at its narrowest wider than ocellar tubercle; frons of female at level of anterior ocellus about twice as wide as ocellar tubercle; eyes of both sexes of uniform facet size; frons of both sexes mostly shining, bare, with a few patches of tomentum along eye margins; antennal insertion about midway between ventral portion of genae and vertex; antennae as long as or longer than depth of head (except in *P. macswaini* females, which have antennae slightly shorter than head depth); face below antennae protrudes anteriorly farther than frons above antennae; scape (Fig. 37) 0.5–0.8× as long as flagellum; flagellar style terminal, two segmented with an apical spine; palps one segmented, very large.

THORAX. — np 2–4 (usually 3), sa 1, pa 1, dc 0–1, sc 1; mesonotal pile sparse, short, uniform, erect, some black and some white; prosternum bare in and around central depression; pleural area without pile; anepisternum, pleurotergite, and pteropleurite without tomentum; rest of pleural region and coxae have silver tomentum. WING. — Vein R_1 setose; cell m_3 closed; veins R_4 and R_5 about equal in length; cell r_4 about 2–3× as long as wide at apex; ground color hyaline. LEGS. — Fore coxa moderately long, with 2 apical, black setae and erect, thickened pile over anterior surface; fore and middle coxae bare or very sparsely tomentose on posterior surface, not pilose; femora without setae; fore tibia lacks setae or has at most a single seta in the anterodorsal position; hind tibia without setae in posteroventral position, but has 0–7 setae each in other three positions.

ABDOMEN. — Slender, cylindrical, tapered posteriorly in both sexes; dorsum strongly convex, shining; pile sparse, short.

MALE TERMINALIA (Fig. 215–221). — Tergite 8 (Fig. 220) large, only slightly constricted medially; sternite 8 (Fig. 221) large, rectangular; epandrium (Fig. 217) about as long as wide measured medially; cerci slightly bilobate, fused to one another, extending posteriorly slightly beyond ventral epandrial sclerite; ventral epandrial sclerite (Fig. 215) elongate, shield shaped, covering mid-posterior portion of epandrium, tapering anteriorly, and strongly attached to posterior edge of the broad and strongly sclerotized parameral bridge (Fig. 215); aedeagus rather large (Fig. 218); ventral apodeme (Fig. 216) has strong, diverging arms; dorsal apodeme short, narrower than base of distiphallus, distally sharply curved dorsally where it attaches to anterior margin of parameral bridge; ejaculatory apodeme (Fig. 216 and 218) very large, extending anteriorly well beyond gonocoxites, anterior end triangular, wedge shaped; distiphallus (Fig. 218) short, thick, with a short, sharp, apical section; gonocoxites (Fig. 219) have 2 posteroventral projections, not united ventrally; parameres very broad and heavily sclerotized, strongly connected by a bridge over midline and attached to ventral epandrial sclerite at posterior edge, while aedeagus hangs on under-

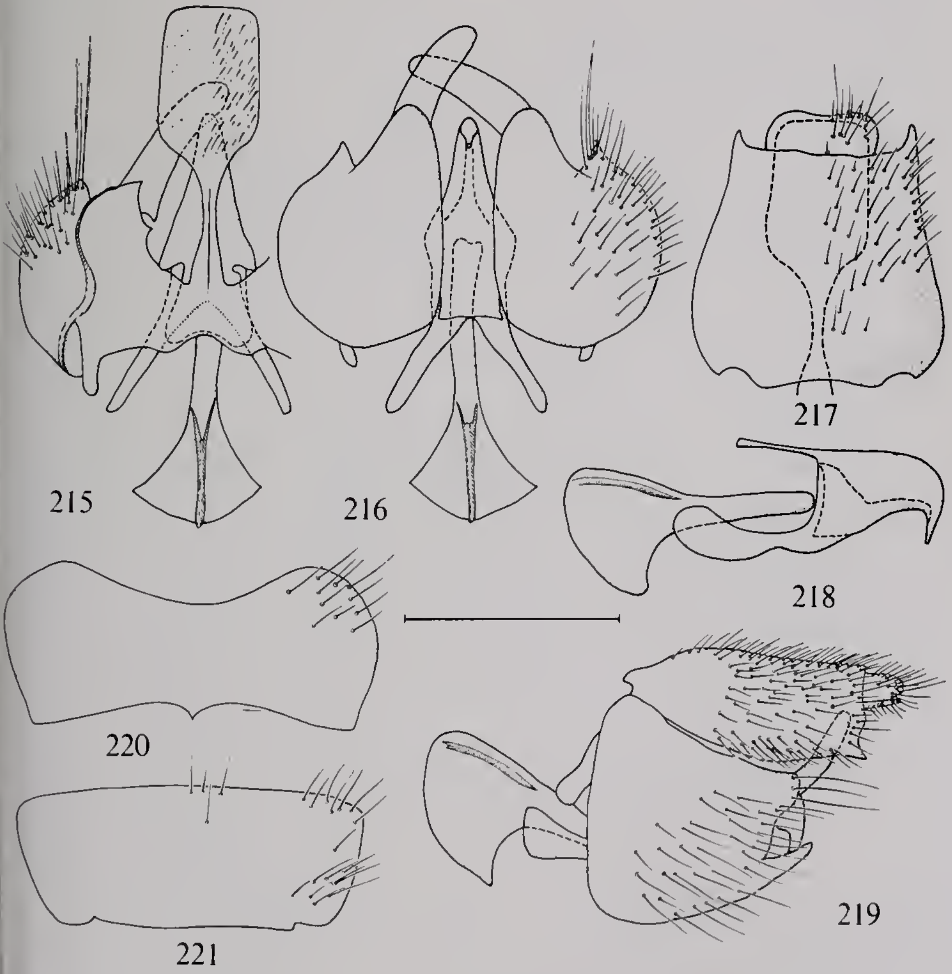

Fig. 215–221. — *Parapherocera montana* Irw. male terminalia. 215. — Right gonocoxite with appendages, ventral epandrial sclerite, and aedeagus in dorsal view. 216. — Gonocoxites with appendages and aedeagus in ventral view. 217. — Epandrium with appendages in dorsal view. 218. — Aedeagus in lateral view. 219. — Genitalia in lateral view. 220. — Tergite 8. 221. — Sternite 8. Scale: 0.5 mm.

side of anterior edge; distal portion of paramere slightly exceeds posterior margin of gonocoxite; parameral apodeme bulbous, enlarged; gonostylus elongate, projecting posteriorly beyond distiphallus; ventral lobes lacking; hypandrium lacking.

Habitat

Species in the genus *Parapherocera* can be found in mountainous regions, usually between 900 and 2,300 m above sea level. Most species have been encountered in sandy washes in pine-sagebrush woodland.

Distribution

Parapherocera seems confined to the western United States (Oregon and California) and the extreme northwestern part of Mexico (Baja California Norte).

Included Species

macswaini Irwin 1977*a*:448 ♂, ♀. Distribution.—Southeastern portion of the Sierra Nevada mountain range of southern California.

montana Irwin 1977*a*:442 ♂, ♀. Distribution. — Southern California and northern Baja California in these mountain ranges: San Jacinto, Santa Rosa, Laguna, and Sierra Juarez.

wilcoxi Irwin 1977*a*:446 ♂, ♀. Distribution. — San Bernardino Mountains, southern California.

One undescribed species has been discovered in Lake County, Oregon.

Genus **Pherocera** Cole
(Fig. 38, 41, and 222–227)

Feminine

Pherocera Cole 1923*a*:20. Type-species: *signatifrons* Cole 1923*a*:21 by original designation. Type-locality: Alamogordo, New Mexico.

Diagnosis

Small, generally slender species; length, excluding antennae, 2.7–7.4 mm; male usually slightly smaller than female.

Head (Fig. 41). — Frons of male at its narrowest much narrower than width

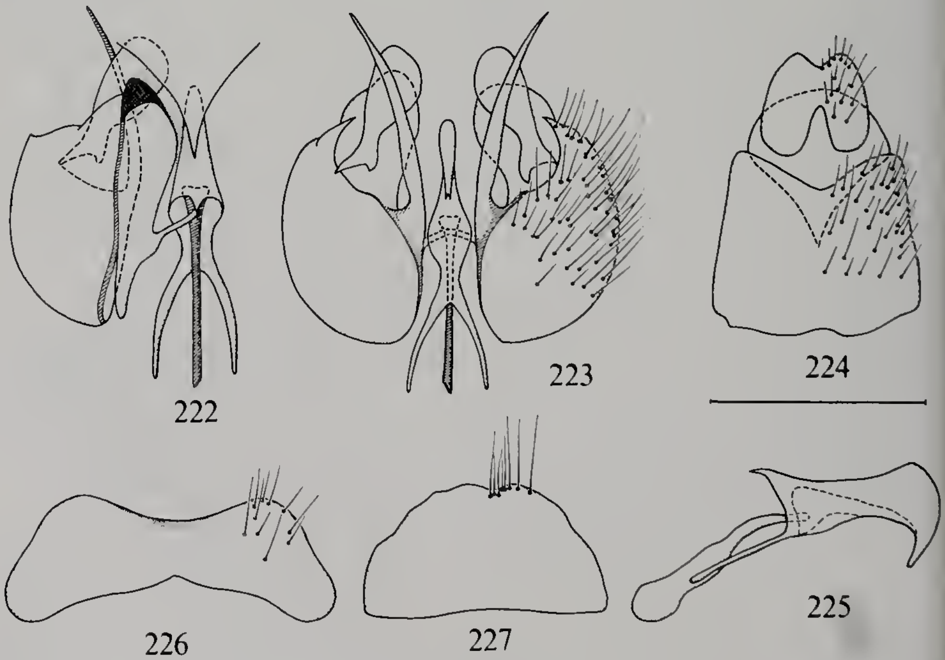

Fig. 222–227. — *Pheracera* sp., new species closely related to *signatifrons* Cole, male terminalia. 222. — Right gonocoxite with appendages and aedeagus in dorsal view. 223. — Gonocoxite with appendages and aedeagus in ventral view. 224. — Epandrium with appendages in dorsal view. 225. — Aedeagus in lateral view. 226. — Tergite 8. 227. — Sternite 8. Scale: 0.5 mm.

of anterior ocellus (except in one undescribed species from Mexico, which has frons wider than ocellar tubercle); frons of female at level of anterior ocellus 1–2× as wide as ocellar tubercle; eyes of female small, of uniform facet size; those of male larger, having smaller facets ventrally and often a definite line of demarcation between lower and upper facets; frons of male small, triangular, often completely tomentose, sometimes thinly pilose; frons of female almost always has species-characteristic calli of various shapes and sizes, usually surrounded by tomentum and, in some species, by thin pilosity; antennal insertion about midway between ventral portion of genae and vertex, sometimes a little lower; antennae (Fig. 38) slightly shorter than depth of head, sparsely tomentose; head often protrudes anteriorly at level of antennae; scape 0.3–0.5× as long as flagellum; flagellar style terminal, one or two segmented, with an apical spine; palps one segmented, slightly shorter than proboscis.

Thorax. — np 2–4 (usually 3), sa 1, pa 1, dc 0–1 (usually 1), sc 1–2 (usually 1); setae from black to pale; mesonotal pile thin to moderately dense, covering mesonotum, scutellum, and pleural area; tomentum dense to sparse, covering mesonotum, scutellum, and most of pleural region, with some bare areas in some species; coxae tomentose. Wing. — Vein R_1 setose; cell m_3 closed, with vein $M_3 + CuA_1$ extending or not extending to wing margin; veins R_4 and R_5 about equal in length; cell r_4 about 2–4× as long as wide at apex; ground color hyaline or translucent, pale yellow to white. Legs. — Fore coxa moderately long with 2 (infrequently 3) apical, black setae and erect, thickened pile over anterior surface; fore and middle coxae tomentose on posterior surface, not pilose; femora without setae; fore tibia lacks setae or has at most a few setae in the posteroventral position.

Abdomen. — Slender, cylindrical, tapered posteriorly in both sexes; dorsum flattened to convex, often shining, with tomentum or bare, and often posterior margin of tergites fasciate.

Male Terminalia (Fig. 222–227). — Tergite 8 (Fig. 226) only slightly constricted medially; sternite 8 (Fig. 227) shield shaped, rounded posteriorly; epandrium (Fig. 224) squarish, slightly wider than long along midline, posterolateral margins not greatly modified; cerci (Fig. 224) generally bilobate, fused to one another, extending posteriorly beyond ventral epandrial sclerite; ventral epandrial sclerite of various shapes, usually well sclerotized, wider distally and tapering anteriorly, not obviously united to epandrium, but anterior margin united to aedeagus in a few species; aedeagus (Fig. 225) moderately small in most species; ventral apodeme elongate, forked, always extends anteriorly beyond nearly vestigial dorsal apodeme, always extends anteriorly slightly less than ejaculatory apodeme; ejaculatory apodeme rod shaped, proximally fitting into a pocket in middle of aedeagus; distiphallus usually blunt, straight, in most species curved ventrally at apex, thinner, variously curved in some species; gonocoxite (Fig. 223) has an inner posteroventral projection of different shapes characteristic of distinct species; gonocoxites not united ventrally; paramere heavily sclerotized, large, both halves connected to one another by a sclerotized bar formed dorsad of aedeagus; parameral process slightly exceeds posterior margin of gonocoxite (excluding ventral posteriorly projecting process), usually bulbous; parameral apodeme somewhat pointed, heavily sclerotized; gonostylus projects posteriorly beyond distiphallus, pointed club shaped in most species; ventral lobes lacking; hypandrium lacking.

Habitat

Species within this genus occupy a wide variety of habitats from very xeric inland shifting dunes to coastal dunes, dry washes, and montane environments. These habitats are discussed in detail by Irwin (1971).

Distribution

Members of the genus *Pherocera* are found throughout a large portion of western North America from Oregon through Utah southward through Texas and California and into western Mexico and southward as far as Puebla.

Included Species

- *albihalteralis* Cole 1923*a*:22 ♀. Distribution. — Southwestern United States and northwestern Mexico, including Arizona, Nevada, Texas, New Mexico, extreme eastern California, and Sinaloa, Mexico.
- *flavipes* Cole 1923*a*:22 ♀. Distribution. — Western North America, including Idaho, Utah, New Mexico, Nevada, Arizona, and California in the United States, and Baja California Norte and Baja California Sur in Mexico.
- *nigripes* Cole 1923*b*:459 ♀. Distribution. — Ildefonso and San Pedro Nolasco islands in the Gulf of California, Mexico.
- *signatifrons* Cole 1923*a*:21 ♀. Distribution. — New Mexico.

Thirty species in the genus *Pherocera* have been described but not formally published (Irwin 1971). One further undescribed species has been collected since that date.

Genus Schlingeria Irwin
(Fig. 39 and 228–234)

Feminine

Schlingeria Irwin 1977*a*:424. Type-species: *ammobata* Irwin 1977*a*:427. Type-locality: Algadones Sand Dunes, 10 km north of Glamis, Imperial County, California.

Reference: Irwin 1977*a*.

Diagnosis

Small, squat species; length, excluding antennae, 4.5–7.5 mm; female larger and heavier than male.

Head (Fig. 39). — Frons of male at its narrowest much narrower than width of anterior ocellus; frons of female at level of anterior ocellus about 2× as wide as ocellar tubercle; eyes of female small, of uniform facet size; those of male large, have lower facets smaller than upper facets and a distinct demarcation line separating facet sizes; lower frons of female has a large shiny callus; rest of frons has powdery white tomentum; frons of male lacks callus or callus very small; antennal insertion low on male, about two-thirds of distance from vertex to genae; antennal insertion about midway between vertex and genae on female; head depth about 1.3× antennal length (Fig. 39); face below antennae does not protrude beyond frons; scape 0.4–0.7× (male) or 0.6–0.8× (female) as long as flagellum; flagellar style terminal, one segmented, with a partially recessed terminal spine; lower face and genae have sparse white pile; palps one segmented; mouthparts very small.

Thorax. — np 3–4 (usually 3), sa 1, pa 1, dc 0–1, sc 0; mesonotal setae pale; mesonotal pile whitish, sparse, thin, erect, on male long, on female short; prosternum bare in and around central depression; pteropleurite bare of tomentum; sternopleurite and pleurotergite sparsely tomentose; rest of pleural area and coxae have dense silvery tomentum. Wing. — Vein R_1 not setose; cell m_3 closed; R_4 slightly longer than R_5; cell r_4 about 2× as long as wide at apex; ground color translucent white, veins pale whitish yellow. Legs. — Fore coxae short, with short, thin pile over entire anterior surface; fore and middle coxae very sparsely tomentose, not pilose; femora without setae; fore tibia lacks setae; middle tibia lacks setae in the posterodorsal and posteroventral positions, has none to a few in the anteroventral position and none to many (15) in the anterodorsal position; hind tibia lacks setae in the anterodorsal, posterodorsal, and posteroventral positions, has 4–8 setae in the anteroventral position; males have more tibial setae than females.

Abdomen. — Swollen, wider than high,

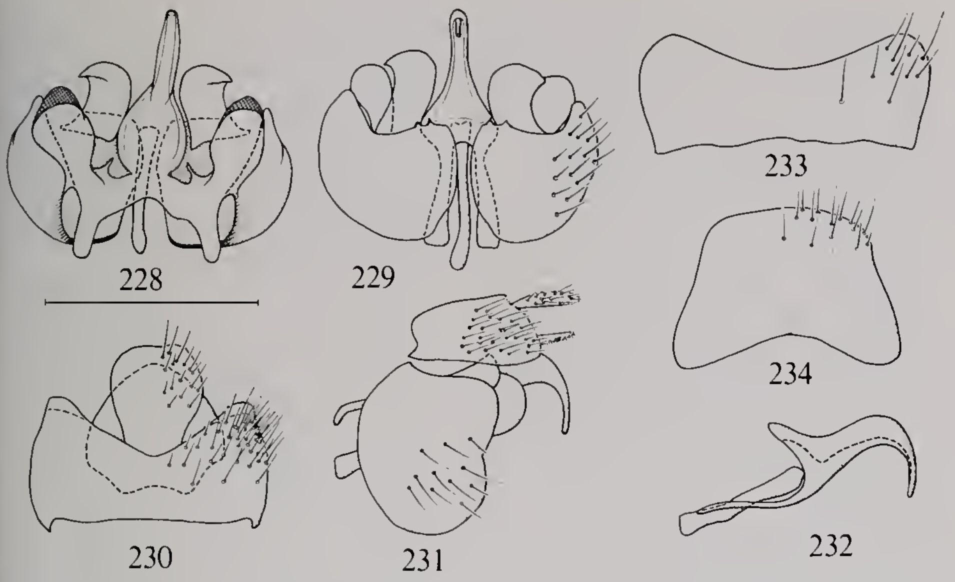

Fig. 228–234. — *Schlingeria ammobata* Irw. male terminalia. 228. — Gonacoxites with appendages and aedeagus in dorsal view. 229. — Gonacoxites with appendages and aedeagus in ventral view. 230. — Epandrium with appendages in dorsal view. 231. — Genitalia in lateral view. 232. — Aedeagus in lateral view. 233. — Tergite 8. 234. — Sternite 8. Scale: 0.5 mm.

tapers sharply at apex in female; smaller, cylindrically shaped, and gradually tapering to apex in male; male abdomen has sparse, erect, elongate pile; female abdomen has sparser, shorter pile; dorsum of both sexes tomentose, that of male less densely than that of female.

Male Terminalia (Fig. 228–234). — Tergite 8 (Fig. 233) only slightly constricted; sternite 8 (Fig. 234) rhomboid; epandrium (Fig. 230) much wider than long; cercus (Fig. 230) slightly bilobate, both halves solidly fused along midline, extends posteriorly slightly beyond ventral epandrial sclerite; ventral epandrial sclerite shield shaped, does not extend to anterior margin of epandrium, and is not attached to parameral bridge or aedeagus; aedeagus (Fig. 232) rather short; ventral apodeme elongate, reaching anteriorly almost to apex of ejaculatory apodeme; dorsal apodeme very short, solidly attached to posterior edge of parameral bridge; ejaculatory apodeme moderately long, rod shaped; distiphallus slender, curved downward; gonocoxites (Fig. 229) rounded, not united ventrally, with two posteriorly directed spinose projections at the inner lateral posterior margin of each gonocoxite; parameres form a large, hood shaped lobe distally; midsections of parameres strongly united to one another by a sclerotized bridge; parameral apodeme strong; gonostylus short, squat, with sharp point projecting outward and upward, not extending to tip of distiphallus; hypandrium lacking; ventral lobe lacking.

Habitat

The one known species, *ammobata,* has been collected in inland deserts, always associated with sand dune environments.

Distribution

Schlingeria occurs throughout most of the Colorado and the southern portions of the Mojave deserts of California and Arizona, extending southward into the Sonora Desert of northwestern Mexico.

Included Species

ammobata Irwin 1977*a*:427 ♂, ♀.
Distribution. — Los Angeles, San

Bernardino, Riverside, and Imperial counties, California, and Sonora, Mexico.

At present no undescribed species of *Schlingeria* are known.

Unplaced Species of Therevidae

aurata Harris 1835:596 (*Thereva*), nomina nuda.

plagiata Harris 1835:596 (*Thereva*), nomina nuda. This name was later referred to *Stichopogon trifasciatus* (Say) (Diptera: Asilidae) by Osten Sacken (1887:170).

pygmaea Kröber 1911:515 ♀ (*Psilocephala*). Distribution. — Saint Thomas Island, West Indies.

LITERATURE CITED

Adams, C. F. 1903. Descriptions of six new species. Pages 221–223 *in* F. H. Snow, A preliminary list of the Diptera of Kansas. Kansas University Science Bulletin 2:211–223.

———. 1904. Notes on and descriptions of North American Diptera. Kansas University Science Bulletin 2:433–455.

Baker, C. F. 1904. Diptera. Reports on Californian and Nevadan Diptera, I. Invertebrata Pacifica 1:17–39.

Becker, T. 1912. Beitrag zur Kenntnis der Thereviden. Verhandlungen der k.k. zoologische-botanischen Gesellschaft in Wien 62: 289–319.

Bellardi, L. 1861. Saggio di ditterologia messicana. Parte II. Torino. 99 p.

Bigot, J. M. F. 1889. Diptères nouveaux ou peu connus. XLIV Therevidi. Société Entomologique de France Annales, Série 6,9: 321–328.

Bromley, S. W. 1937. New and little-known Utah Diptera with notes on the taxonomy of the Diptera. Utah Academy of Sciences, Arts and Letters Proceedings 14:99–109.

Canada Department of Agriculture. 1981. Manual of Nearctic Diptera. Vol. 1. Queen's Printer, Ottawa. In press.

Cole, F. R. 1923*a*. A revision of the North American two-winged flies of the family Therevidae. U.S. National Museum Proceedings 62(4):1–140.

———. 1923*b*. Expedition of the California Academy of Sciences to the Gulf of California in 1921. Diptera from the islands and adjacent shores of the Gulf of California. II. General Report. California Academy of Sciences Proceedings, Series 4, 12:457–481.

———. 1925. Notes on the dipterous family Therevidae. Canadian Entomologist 57:84–88.

———. 1959. A new name proposed in the genus *Thereva* (Diptera: Therevidae). Pan-Pacific Entomologist 35:148.

———. 1960*a*. Stiletto-flies of the genus *Furcifera* Kröber (Diptera: Therevidae). Entomological Society of America Annals 53: 160–169.

———. 1960*b*. New names in Therevidae and Bombyliidae (Diptera). Pan-Pacific Entomologist 36:118.

———. 1965. Family Therevidae. Pages 348–354 *in* A. Stone, C. W. Sabrosky, W. W. Wirth, R. H. Foote, and J. R. Coulson, eds., A catalog of the Diptera of America north of Mexico. U.S. Department of Agriculture Handbook 276. Washington, D.C. 1696 p.

Coquillett, D. W. 1893*a*. Synopsis of the dipterous genus *Thereva*. Canadian Entomologist 25:197–201.

———. 1893*b*. Synopsis of the dipterous genus *Psilocephala*. Canadian Entomologist 25:222–229.

———. 1894. Revision of the dipterous family Therevidae. New York Entomological Society Journal 2:97–101.

———. 1898. A new dipterous genus belonging to the Therevidae. New York Entomological Society Journal 6:187–188.

———. 1904*a*. New Diptera from Central America. Entomological Society of Washington Proceedings 6:90–98.

———. 1904*b*. New North American Diptera. Entomological Society of Washington Proceedings 6:166–192.

———. 1910. New species of North American Diptera. Canadian Entomologist 42:41–47.

Curran, C. H. 1926. New Diptera from the West Indies. American Museum Novitates 220:1–14.

Eschscholtz, J. F. 1822. Entomographien. Reimer, Berlin. 128 p.

Fabricius, J. C. 1805. Systema antliatorum secundum ordines, genera, species. Brunswick. 373 p.

Fallén, C. F. 1814. Anthracides Sveciae. Dissertation. Lund University, Berling. 16 p.

———. 1820. Rhizomyzides Sveciae. Dissertation. Lund University, Berling. 10 p.

Frey, R. 1921. Beitrag zur Kenntnis der paläarktischen Thereviden (Dipt.). Notulae Entomologicae 1:81–85.

Hardy, D. E. 1938. New Therevidae (Diptera) from Utah. Entomological Society of America Annals 31:144–146.

———. 1943. New Therevidae and Asilidae in the Snow Entomological Collection. Kansas Entomological Society Journal 16:24–29.

Harris, T. W. 1835. VIII. Insects. Pages 553–602 *in* E. Hitchcock, Report on the geology, mineralogy, botany, and zoology of Massachusetts. 2nd ed. Amherst, Mass. 702 p.

Irwin, M. E. 1971. Ecology and biosystematics of the pherocerine Therevidae. Ph.D. Dissertation. University of California, Riverside. 256 p.

———. 1976. Morphology of the terminalia and known ovipositing behaviour of female Therevidae (Diptera: Asiloidea), with an account of correlated adaptations and comments on phylogenetic relationships. Natal Museum Annals 22(3):913–935.

———. 1977*a*. Two new genera and four new species of the *Pherocera*-group from western North America, with observations on habitats and behavior (Diptera: Therevidae: Phycinae). Entomological Society of Washington Proceedings 79(3):422–451.

———. 1977*b*. A new genus and species of stiletto-flies from southwestern North America with close affinities to Chilean and Australian genera (Diptera: Therevidae: Therevinae). Pan-Pacific Entomologist 58: 287–296.

JAMES, M. T. 1936. New species and records of Colorado Diptera. New York Entomological Society Journal 44:341–344.

———. 1949. Some new and poorly known Therevidae (Diptera) from Colorado. Entomological Society of America Annals 42: 10–13.

———, and HUCKETT, H. C. 1952. The Diptera collected by I. O. Buss in southwestern Yukon Territory during the summer of 1950. Canadian Entomologist 84:265–269.

JOHNSON, C. W. 1902. New North American Diptera. Canadian Entomologist 34:240–242.

———. 1926. New species of Diptera from North Carolina and Florida. Psyche 32: 299–302.

JOHNSON, S. J. 1978. The population dynamics and natural mortality of the lesser cornstalk borer, *Elasmopalpus lignosellus*, in the peanut agroecosystem and the biology of selected primary parasites. Ph.D. Dissertation. Texas A & M University. 112 p.

KRÖBER, O. 1911. Die Thereviden Süd- und Mittelamerikas. Musei Nationalis Hungarici Annales 9:475–529.

———. 1912. Die Thereviden Nordamerikas. Stettiner Entomologische Zeitung 73:209–272.

———. 1914. Beiträge zur Kenntnis der Thereviden und Omphraliden. Jahrbuch der Hamburgischen Wissenschaftlichen Anstalten (1913) 31 (Beiheft 2):29–74.

———. 1928*a*. Neue Dipteren des Deutschen Entomolog. Museums in Dahlem (Conopidae, Omphralidae, Therevidae, Tabanidae). Entomologische Mitteilungen 17(1): 31–41.

———. 1928*b*. Neue und wenig bekannte Dipteren aus den Familien Omphralidae, Conopidae und Therevidae. Konowia 7(2): 113–134.

———. 1929. Neue Beiträge zur Kenntnis der Thereviden und Tabaniden (Dipt.). Deutsche Entomologische Zeitschrift 1928: 417–434.

LATREILLE, P. A. [1796.] Précis des caractères génériques des Insectes, disposés dans un ordre naturel. An V. Paris. 179 p.

———. [1802.] Histoire naturelle, générale et particulière, des Crustacés et des Insectes. Vol. 3. 468 p. *in* C. S. Sonnini, ed., Histoire naturelle par Buffon. An X. Paris.

LE CONTE, J. L., ed. 1859. The complete writings of Thomas Say on the entomology of North America. Vol. 2. H. Bailliere, New York. 814 p.

LINNAEUS, C. 1758. Systema naturae per regna tria naturae. Holmiae [Stockholm]. 824 p.

———. 1761. Fauna svecica sistens animalia Sveciae regni. Stockholmiae. 578 p.

LOEW, H. 1845. Dipterologische Beiträge. *In* F. G. Kiessling, zu der öffentlichen Prüfung der Schüler des Königlichen Friedrich-Wilhelms-Gymnasiums zu Posen. W. Decker & Comp., Posen.

———. 1856. Neue Beiträge zur Kenntnis der Dipteren. Vierter Beitrag. Pages 1–57 *in* K. Realschule zu Meseritz Programm. Mittler, Berlin.

———. 1869*a*. Diptera Americae septentrionalis indigena. Centuria octava. Berliner Entomologische Zeitschrift 13:1–52.

———. 1869*b*. Diptera Americae septentrionalis indigena. Centuria nona. Berliner Entomologische Zeitschrift 13:129–186.

———. 1872. Diptera Americae septentrionalis indigena. Centuria decima. Berliner Entomologische Zeitschrift 16:49–124.

———. 1874. Neue nordamerikanische Diptera. Berliner Entomologische Zeitschrift 18:378–384.

———. 1876. Beschreibungen neuer amerikanischer Dipteren. Zeitschrift für die Gesammten Naturwissenschaften 14:317–340.

LYNEBORG, L. 1968*a*. A comparative description of the male terminalia in *Thereva* Latr., *Dialineura* Rond., and *Psilocephala* Zett. (Diptera, Therevidae). Entomologiske Meddelelser 36:546–559.

———. 1968*b*. On the genus *Dialineura* Rondani, 1856 (Diptera, Therevidae). Entomologisk Tidskrift 89:147–172.

———. 1969. Redescriptions of six Therevidae from the Americas, described by J. C. Fabricius and L. Bellardi. (Diptera). Entomologiske Meddelelser 37:389–412.

———. 1972. A revision of the *Xestomyza*-group of Therevidae (Diptera). Natal Museum Annals 21(2): 297–376.

———. 1975. The first record of an authentic *Dialineura* species in North America (Diptera: Therevidae). Quaestiones Entomologicae 11:577–578.

———. 1976. A revision of the Therevine stiletto-flies (Diptera: Therevidae) of the Ethiopian Region. British Museum (Natural History) Entomology Bulletin 33(3): 191–346.

———. 1978. The afrotropical species of *Phycus* Walker (Diptera: Therevidae). Entomologica Scandinavica 9:212–233.

———, and K. Spitzer. 1974. The Czechoslovak species of *Thereva* Latr. (Therevidae, Diptera), with the description of a new species from Hungary and Austria. Sbornik Jihočeskeho Muzea v Českych Budějovicich Prirodni Vedy 14:13–42.

Macquart, J. 1840. Diptères exotiques nouveaux ou peu connus. Vol. 2, Part 1. Librairie Encyclopédique de Roret, Paris. 135 p.

Malloch, J. R. 1932. Therevidae. Pages 235–257 *in* Diptera of Patagonia and south Chile. British Museum, London.

Osten Sacken, C. R. 1877. Western Diptera: Descriptions of new genera and species of Diptera from the region west of the Mississippi and especially from California. U.S. Department of the Interior, U.S. Geological and Geographical Survey of the Territories 3:189–354.

———. 1887. Diptera, Vol. 1. Pages 129–216 *in* F. D. Godman and O. Salvin, eds., Biologia Centrali-Americana. London.

Rondani, C. 1856. Dipterologiae Italicae prodromus. Vol. 1. Genera Italica ordinis dipterorum ordinatim disposita et distincta et in familias et stirpes aggregata. Parma. 228 p.

Say, T. 1823. Descriptions of dipterous insects of the United States. Academy of Natural Sciences of Philadelphia Journal 3:9–54, 73–104.

———. 1824. Appendix. Part I. Natural History. 1. Zoology. E. Class Insecta. Pages 268–378 *in* W. H. Keating, Major Long's second expedition. Vol. 2. Philadelphia. 459 p.

———. 1829. Descriptions of North American dipterous insects. Academy of Natural Sciences of Philadelphia Journal 6:149–178.

Walker, F. 1848. List of the specimens of dipterous insects in the collection of the British Museum. Vol. 1. London. 229 p.

———. 1850. Diptera. Vol. 1. Pages 1–76 *in* W. W. Saunders, ed., Insecta Saundersiana. John Van Voorst, London.

———. 1852. Diptera. Vol. 1. Pages 157–414 *in* W. W. Saunders, ed., Insecta Saundersiana. London.

———. 1857. Characters of undescribed Diptera in the collection of W. W. Saunders. Entomological Society of London Transactions, New Series, 4:119–158.

Wiedemann, C. R. W. 1821. Diptera exotica. 2nd ed. Kiliae [Kiel]. 244 p.

———. 1824. Munus rectoris in Academia Christiana Albertina aditurus analecta entomologica ex Museo Regio Havniensi. Kiliae [Kiel]. 60 p.

———. 1828. Aussereuropäische zweiflügelige Insekten. Vol. 1. Hamm. 608 p.

Williston, S. W. 1886. Dipterological notes and descriptions. American Entomological Society Transactions 13:287–307.

Wulp, F. M. van der. 1898. Family Muscidae. Pages 377–384 *in* F. D. Godman and O. Salvin, eds., Biologia Centrali-Americana. Vol. 2. London. 489 p.

Zaitzev, V. F. 1971. A revision of the Palearctic species of the genus *Dialineura* Rondani (Diptera, Therevidae) (In Russian). Entomologicheskoye Obozreniye 50:183–199.

Zetterstedt, J. W. 1838. Dipterologis Scandinaviae. Section 3: Diptera. Pages 477–868 *in* J. W. Zetterstedt, Insecta Lapponica. Lipsiae [Leipzig].

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Page entries in **boldface** type refer to the principal treatment of the subjects; however, references to the illustrations are not given. *Italicized* names are currently in synonymy.

Some Publications of the ILLINOIS NATURAL HISTORY SURVEY

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BULLETIN

The Lake Sangchris Study: Case History of an Illinois Cooling Lake

don Larimore
. Tranquilli
EDITORS

LINOIS
INSTITUTE OF NATURAL RESOURCES

L HISTORY SURVEY DIVISION
AIGN, ILLINOIS

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Preface

Lake Sangchris, in central Illinois, provides cooling water for the Kincaid Generating Station, a coal-fired electric generating plant that was developed by Commonwealth Edison Company of Chicago in the early 1960's.

During the years 1961 through 1963 several engineering reports were prepared for Commonwealth Edison Company regarding the construction of Kincaid Generating Station and its cooling lake. By July 1963 the company had decided to proceed with construction, starting the following summer. The first electrical power was produced at the plant in June 1967.

Legal issues have arisen along with the development of Kincaid Generating Station. Even before the construction of the lake, questions were raised concerning public use of cooling reservoirs. This led to several years of negotiations with the Illinois Department of Conservation and an ultimate agreement in 1969 for the management of the lake and surrounding lands as a recreation facility. Until this time Commonwealth Edison's only necessary legal licenses had been those to construct a dam across Clear Creek and for the construction and operation of a sewage treatment facility. Passage of the Illinois Environmental Protection Act of 1970 and the adoption of water-quality regulations under the Illinois Pollution Control Board in 1972 made it necessary for the company to gather environmental information in support of the lake as a waste-water treatment facility.[1] Limnological data were urgently needed; so the company contracted with Limnetics, Inc., Milwaukee, Wisconsin, to conduct limnological baseline studies. Limnetics, Inc., studied the lake from June 1971 to June 1972 and submitted a report to the company entitled *A Limnological Survey of Lake Sangchris, Illinois* dated December 1972. In May 1973 Limnetics, Inc., filed another report with Commonwealth Edison, *A Second Limnological Survey of Lake Sangchris, Illinois,* based on studies conducted during October 1972.

Additional unpublished reports that have served as background materials in the present study include fish surveys by the Division of Fisheries, Illinois Department of Conservation, in October 1971 and 1972. These reports are on file in the division's office in Springfield. A report by William Anderson, Illinois Natural History Survey, on the mercury levels in the flesh of Lake Sangchris fish was submitted to Commonwealth Edison in 1972. The Illinois Natural History Survey also completed a report to Commonwealth Edison in 1973 entitled *Comparative Limnological Literature Survey—Sangchris Lake,* which compared information on Lake Sangchris with available information on five reservoirs of similar size, geographical location, and general hydrological characteristics. Soon after the beginning of the present study in August 1973, Mr. Edward Juracek, biologist with Commonwealth Edison, presented a report entitled *Lake Sangchris: Case History of an Illinois*

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[1] Dr. Richard G. Monzingo, Aquatic Biologist, Commonwealth Edison Company, has provided this updated account of the regulatory history of Lake Sangchris.

On July 18, 1974, the Pollution Control Board (PCB) of the State of Illinois ruled (in PCB 73-245/248 consolidated) that Lake Sangchris is not a "treatment works" but is, in fact, "waters of the state." The Board determined that an operating permit was required with respect to discharges from the Kincaid Generating Station into Lake Sangchris and that as a condition to the issuance of the permit, Commonwealth Edison Company would be required to demonstrate compliance with the thermal standards contained in Chapter 3, Rule 203(i)(1-4) or to obtain regulatory relief from these standards.

In PCB R75-2, Commonwealth Edison proposed a regulation that would exempt artificial cooling lakes (impounded) from otherwise applicable thermal standards of Rule 203(i)(1-4) and requested specific thermal limitations for Lake Sangchris. On 29 September 1975, the Board ruled instead to set standards by which individual artificial cooling lakes could receive specific thermal limitations. In addition, the Board did not approve the specific thermal limitations for Lake Sangchris because the limitations were not based on historic temperatures in the lake.

In April 1976, Commonwealth Edison proposed

Cooling Lake as part of a workshop on energy production and thermal effects; the papers read at that workshop were published in January 1974 by Limnetics, Inc. Juracek's report contained much of the information mentioned in the preceding paragraphs and served as a review of the development of the power plant, its lake, and the legal statutes associated with the Kincaid Generating Station.

Under contract with Commonwealth Edison Company, the Illinois Natural History Survey studied this cooling lake ecosystem intensively from August 1973 through August 1977 to determine the effect of the thermal discharge and combustion byproducts on the local environment. Investigations included detailed studies of water quality, plankton, aquatic macrophytes, clams, benthos, fish, fish harvest or creel, waterfowl, trace metals, and pesticides. Some studies (water quality, benthos, clams, and aquatic macrophytes) were terminated in 1976, and others were initiated to consider the distribution of larval fishes in the cooling loop and the effect of the impingement and entrainment of fish by the power plant.

In June 1975, the Illinois Natural History Survey received additional support from the Electric Power Research Institute (EPRI) of Palo Alto, California, to expand investigations at Lake Sangchris. The expanded work consisted of three parts: (1) a study of the relationship between the fisheries and the physicochemical conditions associated with power production, including fish temperature preferences, potential dangers to the biological system, benefits to plant and animal communities, and causes of environmental degradation associated with power production; (2) construction of a fish production model from the large accumulation of physical-chemical-biological data; and (3) a comparison of fish production in Lake Sangchris with that of Lake Shelbyville, a nearby flood control reservoir. This work has been completed, and a four-volume final report, *Evaluation of a Cooling Lake Fishery,* has been published by EPRI (1979–1980). However, those investigations cannot be completely separated from the work supported by Commonwealth Edison and reported here.[2]

The investigative work was carried out by an interdisciplinary team of specialists. Administration and overall coordination of the project were handled at the Illinois Natural History Survey headquarters in Urbana, while field activities were coordinated through a field station at Kincaid, a few miles from the lake. Most of the fishery biologists were based at the field station; other team members were based in Urbana where more extensive laboratory and analytical facilities were available.

The Lake Sangchris Project enjoyed consistent support and cooperation from officials of Commonwealth Edison Company, especially from John H. Hughes, Head of the Environmental Quality Section; Edward Juracek, James

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the following specific thermal standards based on historic fact: the effluent temperature shall not exceed 99°F (37°C) during more than 7 percent of the hours in the 12-month period ending with any month and shall at no time exceed 111°F (44°C) (PCB 76-11). In December 1976, an economic impact statement prepared by the Illinois Institute of Environmental Quality indicated that both economic and environmental considerations favored the proposed standards. On 13 October 1977, the Board approved the proposed standards. The Board commented that although the records in R75-2 and 76-11 contained other useful reports concerning Lake Sangchris, the most valuable testimony came from studies performed by the Illinois Natural History Survey (INHS).

On 11 May 1978, the Board approved Commonwealth Edison's 203(i)(5) demonstration (PCB 77-309). This demonstration (similar to the USEPA 316 (a) demonstration) incorporated the records of the previous three hearings, including all of the data from the Illinois Natural History Survey studies.

The studies the INHS performed also provided data to support the 316(a) (thermal) and 316(b) (intake) demonstrations to the USEPA. The 316(a) demonstration was accepted on 11 May 1977 and the 316(b) demonstration was approved on 2 January 1979.

[2] Fishery investigations were continued at Lake Sangchris in 1979, when funding for fishery management research was received for a 3-year period from Federal Aid in Fish Restoration.

C. Rice, and Richard Monzingo, project managers during the investigations; and Bud Stauffer, Charles Polito, and Ed Swenson, Kincaid Generating Station superintendents. Commonwealth Edison also contributed substantially toward the publication costs. We sincerely appreciate the help that made the investigations possible and pleasant.

We are also indebted for the help we received from many University of Illinois and Eastern Illinois University students in both field and laboratory studies, other members of the Illinois Natural History Survey staff, and Illinois Department of Conservation personnel stationed at Lake Sangchris State Park and in the Fisheries Division.

We acknowledge the help of Dr. Loren Wheeler, presently at the University of Arkansas, for his statistical advice with reference to the *Corbicula* paper, and Dr. Clyde Anderson, presently at Michigan State University, for his statistical help on the fish population dynamics, fish tagging, and radiotelemetry papers.

Dr. Louis A. Krumholz, University of Louisville, critically reviewed the manuscripts. We sincerely appreciate his valuable technical suggestions and recognize that his skills and editorial discipline contributed greatly to the final development of this monograph.

Manuscripts were also reviewed by various members of our Survey staff. The final editing of the entire set of manuscripts was done by Robert M. Zewadski, Technical Editor, and by Shirley McClellan, Assistant Technical Editor. Technical Illustrator Lloyd LeMere did much of the drafting, and various staff members contributed photographs. Jana Waite, Administrative Assistant in the Section of Aquatic Biology, carefully typed the final copy. To these, our supportive associates, we extend sincere appreciation for their careful work.

Careful readers will notice some deficiency in up-to-date literature, resulting from the time required to edit and print such a large monograph. Please notice the submission date at the bottom of the first page of each chapter.

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Aquatic Biologist, Illinois Natural History Survey

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CONTENTS

This report is printed by authority of the State of Illinois. It is a contribution from the Section of Aquatic Biology, Section of Faunistic Surveys and Insect Identification, and Section of Wildlife Research of the Illinois Natural History Survey.

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Photomosaic of the Lake Sangchris area, showing the intensive agricultural development. (Aeri photographs courtesy of the Illinois Department of Transportation.)

The Lake Sangchris Project

R. Weldon Larimore and John A. Tranquilli

INTRODUCTION

Reservoirs constructed specifically for the dissipation of waste heat constitute a relatively new aquatic environment that creates both problems and attractive potentials. The most apparent environmental problems are those associated with waste heat from a production process; the most obvious benefits are recreational, especially the unique opportunity for open-water fishing in a northern climate during winter. To evaluate the detriments and benefits of a cooling-lake ecosystem, one must consider the physical attributes of this man-made system before attempting to understand the more complex biological relations. Those relationships include the entire trophic structure of the aquatic ecosystem.

These physical functions and their associated biological systems have been intensively investigated at Lake Sangchris, an 876-ha cooling lake that serves a coal-fired, steam-driven electric generating station in central Illinois. There it has been found, for example, that the plankton population was directly associated with the water currents produced by pumping, the benthos was influenced by the modification of bottom substrates in the discharge canal, and fish distribution was affected by temperature gradients within the cooling loop. Before these and other relations are fully reported in the series of papers presented in this monograph, it seems necessary to point out the physical factors that ultimately drive the associated biological system within a cooling lake.

Any cooling lake is a massive heat exchanger that takes waste heat from the plant's condenser system and transfers it to the environment. The efficiency of that exchange depends on the local climate, the morphometry of the lake basin, the exposure of the lake surface to wind, the volume of water moving through the plant and through the lake, and the amount of heat carried away from the condenser tubes. The efficiency of the heat-exchanging process is also related to several peculiar physical characteristics of water, such as its specific heat, heats of vaporization and fusion, and density at different temperatures.

In most lakes, the primary source of heat is radiant energy from the sun, with lesser amounts from groundwater seepage or through conduction from the air or from the basin materials. By design, an additional source to a cooling lake is the heat that must be removed in power production to convert spent steam to water. Although part of the radiant heat penetrates the water mass and is transmitted into deeper waters by conduction and convection, heat from both the sun and the power plant is distributed throughout the lake ecosystem by the force of wind on the water surface and, in a cooling lake, by the circulation produced by the withdrawal and discharge of cooling water at the power plant.

In the process of exchanging heat from the power plant to the environment, the cooling lake serves as a heat sink that absorbs and stores heat for various lengths of time. The high specific heat of water permits the absorption of large amounts of heat with relatively modest increases in water temperature. Although some heat is transmitted by conduction into the lake sediments, the total heat capacity of most lakes is primarily proportional to the water volume, because the water has the high specific

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heat and capacity to absorb heat. The heat storage capacity of most lakes in temperate regions is significantly reduced during the summer by stratification, caused by differential density layers that serve as barriers to the mixing of warm surface waters into the cooler deep waters. In a cooling lake, where currents produced by pumping prevent thermal layers from being maintained, such stratification may never be established or may last for only short periods. If part of the thermal discharge from the power plant enters the deeper waters of the lake, the deeper layer may warm at nearly the same rate as the surface waters, so that there is less difference in density from top to bottom and mixing is facilitated.

Heat acquired by a lake from the sun or from electric power production is largely dissipated through evaporation and back radiation. Lesser amounts of heat are lost through conduction to the air and to basin materials. The enormous amounts of heat involved in the evaporation of water (539.6 calories per gram of water) keep our temperate and tropical lakes from being much warmer than they are in the summer and establish a lake as an efficient heat exchanger for dissipating heat from either natural sources or from industrial processes.

The rate of evaporation (and thus of heat loss) increases with increased temperature and with reduced vapor pressure, barometric pressure, and salinity. The increase in evaporation with increase in temperatures moderates or damps thermal maxima: as summer temperatures rise or as more thermal wastes are introduced, the loss of heat through evaporation is greatly increased. Back radiation, on the other hand, is virtually independent of temperature and thus assumes a higher percentage of heat dissipated at progressively lower temperatures.

The greater the exposure of the lake's surface to air movements (wind), the greater will be the heat dissipation. A lake with high banks, banks covered with tall trees, or a surface area arranged in many coves will not be as efficient a heat exchanger as an open lake with a long fetch in a flat basin. With other conditions being similar, heat loss through evaporation is more rapid from high-altitude lakes with lower barometric pressure than from low-altitude lakes. The decrease in evaporation with increased salinity makes a brackish-water coastal lake a less efficient heat dissipator than a freshwater lake and suggests reduced heat transfer in cooling lakes in which salts have accumulated.

For heat to be discharged from a lake into the atmosphere through any dissipating process, the heat must be delivered to the surface layers. Since convection currents are generally weak and since water is a relatively poor heat conductor, wind-induced circulation is the primary transport mechanism and depends largely on lake morphology and the exposure of the lake surface to winds.

Winter ice on lakes virtually eliminates evaporation and permits only small heat and water losses through sublimation. It is, however, of little concern in cooling lakes in the Midwest, because open water is maintained throughout the year by the heated discharge.

Heat gains and losses not only determine a lake's annual heat budget and its effectiveness in dissipating waste heat from a power plant, but also impose a strong influence on the lake's biological systems. Primary and secondary production are directly proportional to water temperature within the range of temperature in which metabolism occurs normally. Each organism has an optimal temperature for maximal growth as well as limits of tolerance for high and low temperatures above and below which it cannot survive. But the controls of biological systems are not restricted to temperature alone.

Stress, whether due to temperature extremes or one of the many other physical or chemical parameters that modify physiological and behavioral functions, is relatively simple to detect and measure in individual organisms and usually can be determined for any species, even though each life state may have to be considered distinctly. Problems of a much greater complexity are encountered in measuring stress in a community composed of many kinds of organisms of different life stages. For instance, a temperature change might modify diatom photosynthesis, which would alter the forage base of the gizzard shad and thus affect the forage base for the largemouth bass. Such interactions in communities of plants and animals should be the primary concerns in evaluating environmental disturbances. The elevated temperature of a cooling lake may impose short-term stresses on an individual plankter or fish, but the most important consideration is whether such stresses cause measurable changes in the trophic structure or function of the aquatic community.

Under the stress of an environmental disturbance, individual organisms may die, adjust (acclimate) to the new conditions, or behaviorally adapt by moving away. If the natality, mortality, metabolism, or longevity is affected, the relative abundance, growth rate, or behavioral activity, and thus the place of that organism in the community, will be altered. The environmental modification may not only have direct influences on the individual of a particular species, but can also have a more subtle effect by changing an animal's food resources, the abundance of its predators, or the occurrence of pathogens. From man's point of view, changes in the community are not necessarily detrimental. An attractive sport fish may displace an unattractive rough fish, or a species entirely new to the community may be able to survive and thrive in the modified habitat. As an example, the threadfin shad, a species with a low temperature threshold, may be desirable for man's interests because of its value as a forage base for sport fishes, whereas other species, such as pathogenic fungi or protozoa or blue-green algae that thrive at elevated temperatures, may be highly undesirable.

Industrial production of waste heat has a direct influence on the physical systems that function naturally in a lake. At Lake Sangchris, the operation of the electric generating plant modifies the daily and seasonal physical relations mentioned in the preceding paragraphs. Discharged heat, impingement of organisms on intake screens, entrainment of organisms through the pumps and condenser tubes, and water currents produced by pumping are the primary operational influences at Lake Sangchris and at most cooling lakes.

The quantity of heat discharged and the amount of water moving through the plant determine the total temperature change produced by the electrical generating station. Increased pumping rates yield reduced temperatures along with higher intake velocities and thus increase the impingement and entrainment of aquatic organisms. The higher discharge velocities result in greater mixing of the heated waters.

Most industries, and especially power plants, have scheduled shutdowns for maintenance and unscheduled ones for emergency repairs. The continuity of plant operations plays an important role in the physicochemical characteristics of a cooling lake. Effects of a shutdown are most drastic during winter, when organisms acclimated to warm discharge waters suddenly become exposed to much colder water as the thermal discharge stops but pumping continues to move cold water into the system.

Lake Sangchris experienced many shutdowns during the 4-year period of study. Although such irregularities caused only minor difficulties in the interpretation of overall temperature effects, sudden changes in waste heat discharge did permit observations of the most severe thermal conditions. While temperature shock may cause mortality among aquatic organisms, more often it simply modifies the immediate habitat and produces subtle behavioral changes in the animals.

THE INQUIRY

When this investigation began, there were many questions regarding the effects of thermal discharges and combustion byproducts on the fauna and flora of cooling lakes and the lands surrounding them. Those questions could most readily be answered by careful examination of a relatively confined, closed-cycle cooling system, such as Lake Sangchris. The following is a partial list of questions toward which this investigation was directed.

What factors govern water quality in a cooling lake ecosystem?

How is the annual temperature regime affected by power plant operation, and what is the effect of the circulation and mixing of waters on their physical and chemical constituents?

Is photosynthesis inhibited at high temperatures, and do blue-green algal forms become dominant?

What aquatic vascular plants are present, and how are their distribution and biomass affected by the thermal discharge?

Are the phytoplankton and zooplankton communities in heated and unheated areas quantitatively and qualitatively similar?

Is zooplankton production enhanced or depressed by the thermal effluent, or is normal seasonal variation reduced?

What inhibits benthic production in the discharge canal?

How does the diversity of benthic organisms in cooling reservoirs compare with that of unheated reservoirs in the region?

Is the life history of the Asiatic clam, *Corbicula,* altered in a cooling lake?

Is the standing crop of fish in cooling lakes within the range expected for reservoirs of similar size in the Midwest?

How do fish populations respond to the thermal effluent—are they attracted or repelled—in different seasons?

Will fish travel relatively long distances in a thermal gradient to select preferred temperatures?

Does production of fish in cooling lakes decline with increasing age of the impoundment, as often occurs in unheated reservoirs?

Is fish growth enhanced or depressed?

Do fish in heated and unheated areas of a cooling lake have similar feeding habits?

How does the thermal effluent affect the timing of reproduction by fishes?

What effect does the effluent have on spatial, temporal, and vertical distribution of fish larvae?

Is the standing stock of fish in the lake significantly reduced by impingement of individuals on the traveling intake screens or by entrainment of fish eggs and larvae through the condensers?

Are fish kills common as a result of cold shock and/or gas supersaturation, and are the fishes in cooling lakes under stress and thus more susceptible to infestation by parasites or infection by disease organisms?

Which fish species occur most often in the fisherman's catch, in which areas and seasons?

Are catch rates by anglers reduced or enhanced by the thermal effluent?

How are airborne particulates from the power plant stack distributed in the land and water surrounding the generating facility?

Are heavy metals, such as mercury, being magnified as they pass through the food chain, and are they being concentrated in the predatory fish?

How are the behavior and migration of the large numbers of waterfowl attracted to cooling lakes altered?

Do the high transmission lines emanating from power plants present hazards to flying birds?

Are waterfowl that ingest slag adversely affected, and what is the effect on the lake of nutrient loading by these large bird populations?

The strength of the Lake Sangchris case history lies in the intensive sampling program simultaneously carried out over a 4-year period by a team of investigators approaching the problems of ecosystems by looking at all trophic levels.

LAKE SANGCHRIS AND THE KINCAID GENERATING STATION, LOCATION AND DEVELOPMENT

The Kincaid Generating Station is located in central Illinois 24 km (15 miles) southeast of Springfield. It was developed by Commonwealth Edison Company from 1963 through 1966 to supply electricity to northeastern Illinois. The plant is adjacent to Peabody Coal Company's No. 10 mine, which supplies the fuel for steam production. Lake Sangchris, constructed to provide cooling water for the plant's condenser system, was formed by damming Clear Creek, a small tributary to the South Fork of the Sangamon River. Clear Creek flowed from south to north. Above where it was dammed the stream was divided into three branches, so that the resulting lake was composed of three relatively long and narrow arms that converged northward toward the dam (Fig. 1).

Over 5,000 ha of land were acquired for the plant and its cooling lake. The lake covers 876 ha, a 30-m buffer zone around the lake comprises approximately 275 ha, and the company gave the state of Illinois 607 ha to be used for recreation and wildlife habitat. The plant, slag pond (32 ha), and adjacent agricultural fields occupy the remaining area.

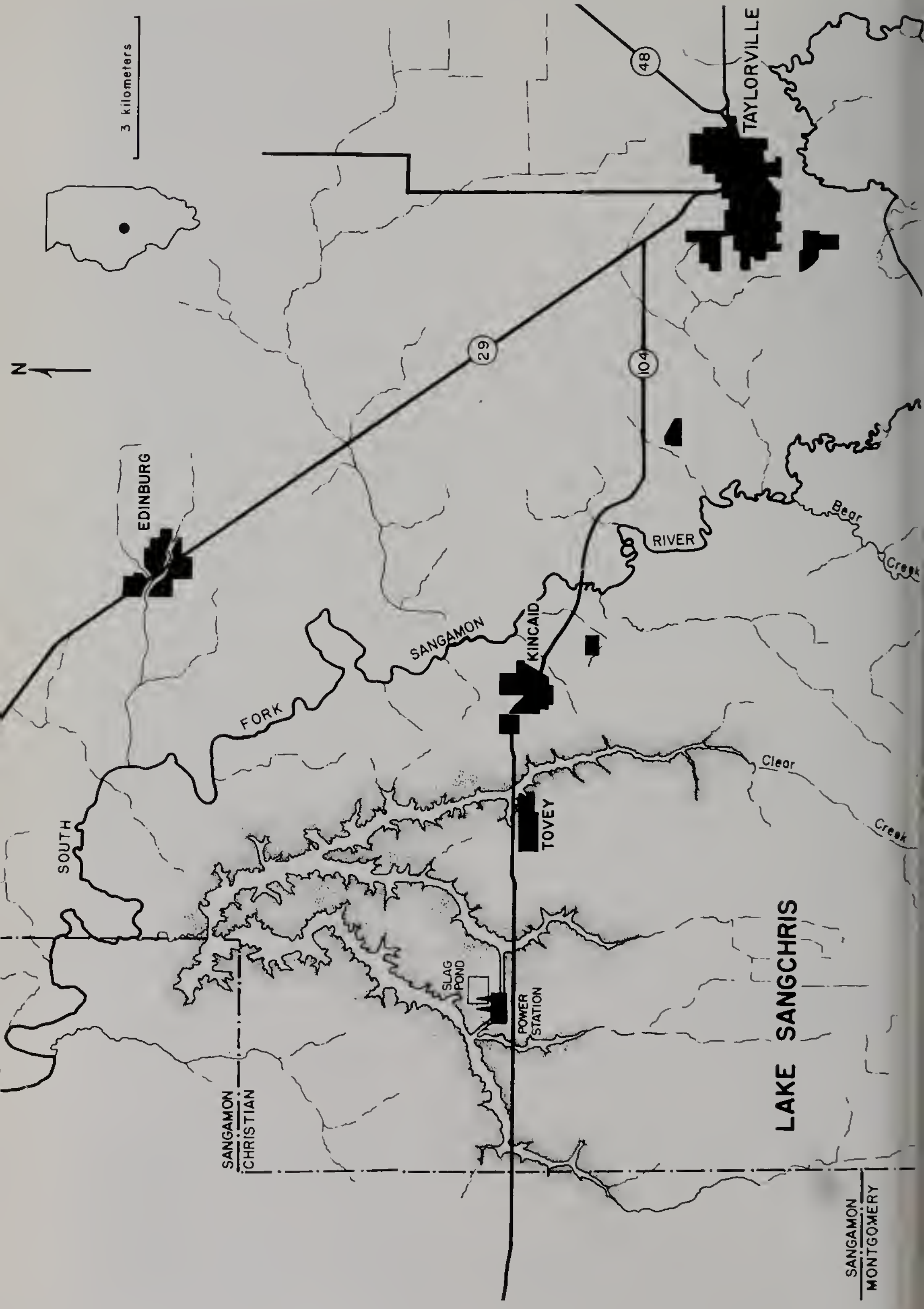
THE GENERATING STATION AND COOLING SYSTEM

The Kincaid Generating Station began commercial operation in 1967. The plant, positioned between the southern ends of the western and middle arms of Lake Sangchris, is a coal-fired facility with two 616-megawatt steam turbine units. Water carrying the waste heat is discharged 1.5 m below the surface through a 4.6-m diameter pipe into a canal (1,100 m long and 30 m wide) that flows into the middle (discharge) arm of the lake. Waste heat is dissipated rapidly as the water moves through the middle (discharge) arm toward the dam and then into the west (intake) arm, a 16.1-km (10-mile) course to the plant's cooling water intake structure. Condenser cooling water is drawn from the lake by four pumps, each with a capacity of 160,000 gpm (10.1 m^3/sec) or a total capacity of 640,000 gpm (40.4 m^3/sec). The intake pumps are located 18.3 m below the surface of the lake. A skimmer wall prevents the circulation of water from the upper 6.1 m of the water column (Porak & Tranquilli 1981: Fig. 2). The intake canal is approximately 6.1 m deep, 1,219 m long, and 30 m wide.

Depending on the plant loading and the amount of water being pumped, the recirculating water moves through the cooling loop in about 11 days. The cooling loop constitutes approximately 64 percent of the lake's area. The eastern (control) arm of the lake receives heat from the plant only through back circulation at its confluence with the discharge arm.

Gross electrical output for the Kincaid Generating Station from September 1973 through August 1977 generally showed a dicyclic annual trend with peak power output during winter and summer and reduced loads during autumn and spring (Fig. 2). Two exceptions to this generalization occurred as a result of scheduled maintenance and repair work on one of the two units in the winter of 1974–1975 and on both units for a 46-day period during the summer of 1976. Production outages of both units for 3 or 4 days at a time were not uncommon during the 4-year study period (Fig. 2), but outages for more than 1 week occurred only twice, during the summer of 1976 for about 6 weeks and for 8 days during November 1976.

While maximum power production and a continuous heat load throughout the study period would have been the most desirable experimental situation, the production record of Kincaid Generating Station was typical of coal-fired units, and the changing power plant loading factor may have been more stress-


3 kilometers
N
TAYLORVILLE
48
29
104
EDINBURG
RIVER
SANGAMON
Bear
Creek
KINCAID
FORK
SOUTH
Clear
Creek
TOVEY
SLAG POND
POWER STATION
LAKE SANGCHRIS
SANGAMON
CHRISTIAN
SANGAMON
MONTGOMERY

ful to the biota of the cooling lake than a steady load would have been.

THE LAKE BASIN

The Lake Sangchris basin is near the center of Illinois (Fig. 1), with 89° 29' west longitude bisecting the basin that extends from 39° 39' north latitude at the dam southward to 39° 29' north latitude. The 18,880 ha (73 square miles) drainage basin lies mostly within northwestern Christian County, and only a small portion of the basin extends westward into Sangamon County.

The basin is in the northwestern part of the Springfield Plain, a physiographic province that crosses central Illinois southwest of the Shelbyville Moraine. The province has a flat to rolling surface occasionally incised by shallow valleys. Fifteen to 60 m of unconsolidated drift, loess, and alluvium overlie Pennsylvanian bedrock (Willman et al. 1967). Two major coals, Springfield (No. 5) Coal and Herrin (No. 6) Coal, underlie the area. Each varies up to 2 m in thickness in that area. Herrin Coal is mined for the Kincaid Generating Station.

The soils surrounding the lake proper are dark and moderately permeable, having developed from moderately thick loess. Immediately surrounding the lake are three main soil types—Illiopolis silty clay loam, Ipava silt loam, and Bolivia silt loam—overlain with 2–3 m (7–10 feet) of upland loess. Farther south of the lake and in the lake's upper drainage basin, Herrick silt loam and Virden silty clay loam are overlain with about 2 m (5–7 feet) of loess (Fehrenbacher et al. 1950).

Aerial view of Kincaid Generating Station and the discharge canal.

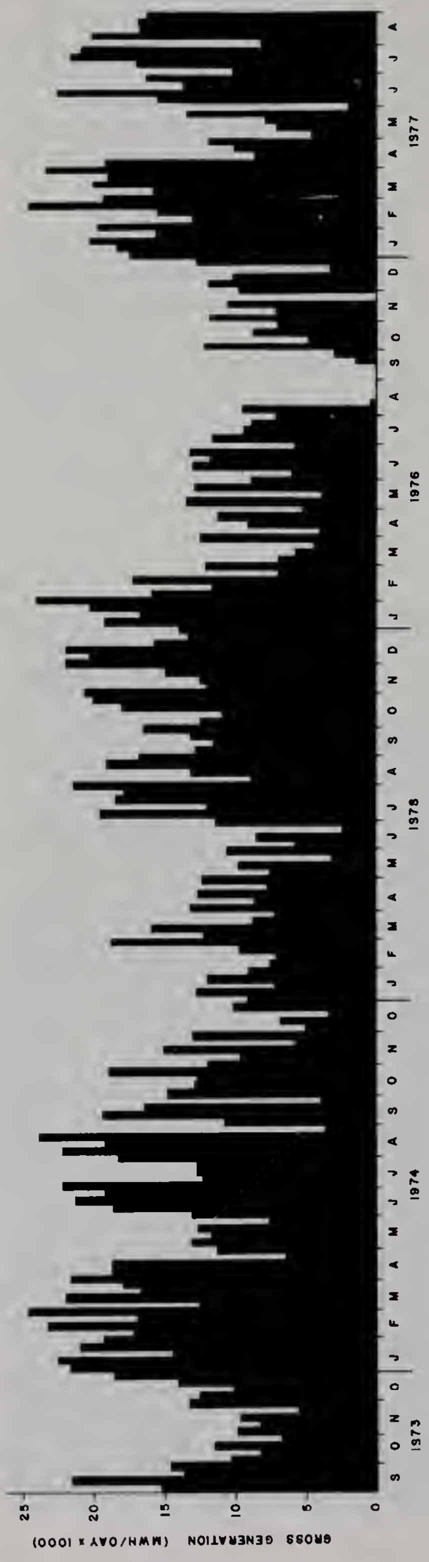


Fig. 2.—Gross weekly production of electricity by the Kincaid Generating Station, September 1973–August 1977.

These are highly productive soils, and when properly farmed, are not particularly erodable.

Before inundation the soils of the lake basin were light colored and moderately permeable and had developed under timber vegetation from moderately thick loess. Hickory gravelly loam (sides of the valley) and Radford silt loam (bottom of the valley) constitute the major soil types (Fehrenbacher et al. 1950). These soils are only moderately fertile and are subject to serious erosion.

Central Illinois, including the Sangchris basin, has a typical continental climate with sharp seasonal changes, including warm summers and cold winters (NOAA Environmental Data and Information Service 1972 and 1978). Average monthly temperatures range from 25°C in July to − 3°C in January (Fig. 3). Although the summers are humid, there are no distinct wet and dry seasons. Mean monthly precipitation varies considerably, as can be seen in Fig. 4; it ranges from a little over 10 cm in May and June to slightly less than 5 cm in January, with an annual average of 89 cm. Wind velocities of more than 64 km/hour are not uncommon for brief periods in most months, with prevailing winds southerly during most of the year and northwesterly only in late fall and spring. Such winds have a profound effect on the stability of the exposed waters of Lake Sangchris, which has low banks and relatively little tree growth along its shoreline.

THE LAKE

Lake Sangchris was formed during 1963–1966 by damming Clear Creek, a small tributary of the South Branch of the Sangamon River. The stream and its tributaries were low gradient and collectively had a mean flow of 1.2 m^3/sec (U.S. Environmental Protection Agency 1975).

The lake began to fill as the dam was being finished, and water reached the spillway level (elevation 178.3 m above sea level) in June 1966, thus completing the 876-ha cooling reservoir. The impoundment produced a lake composed of three narrow arms joined at the northern end at the dam. Only near the dam and in stream channels do depths exceed

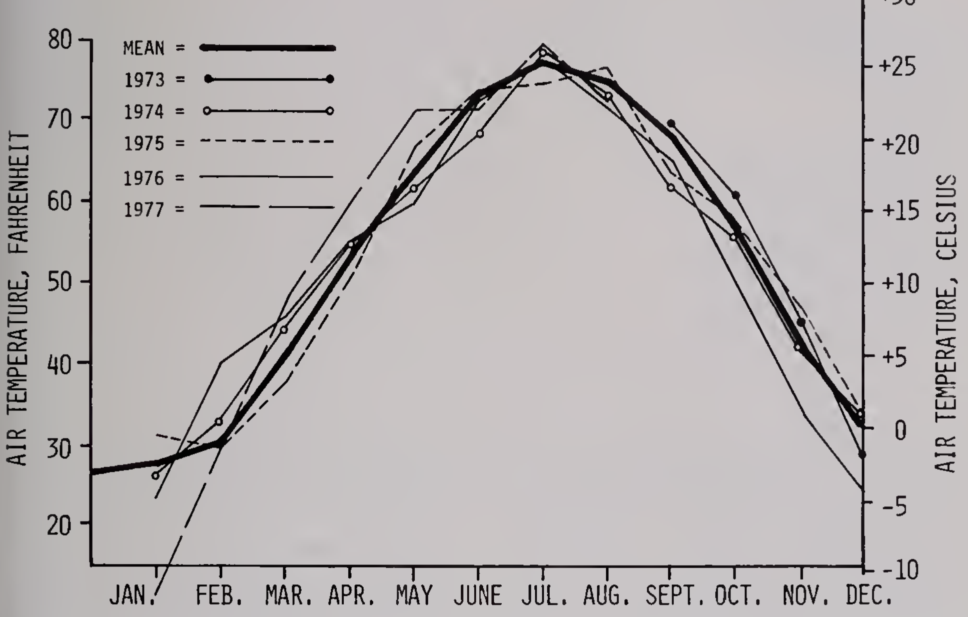


Fig. 3.—Mean monthly air temperatures near Lake Sangchris, 1973–1977, and for the combined 40 years before 1973 (labeled MEAN).

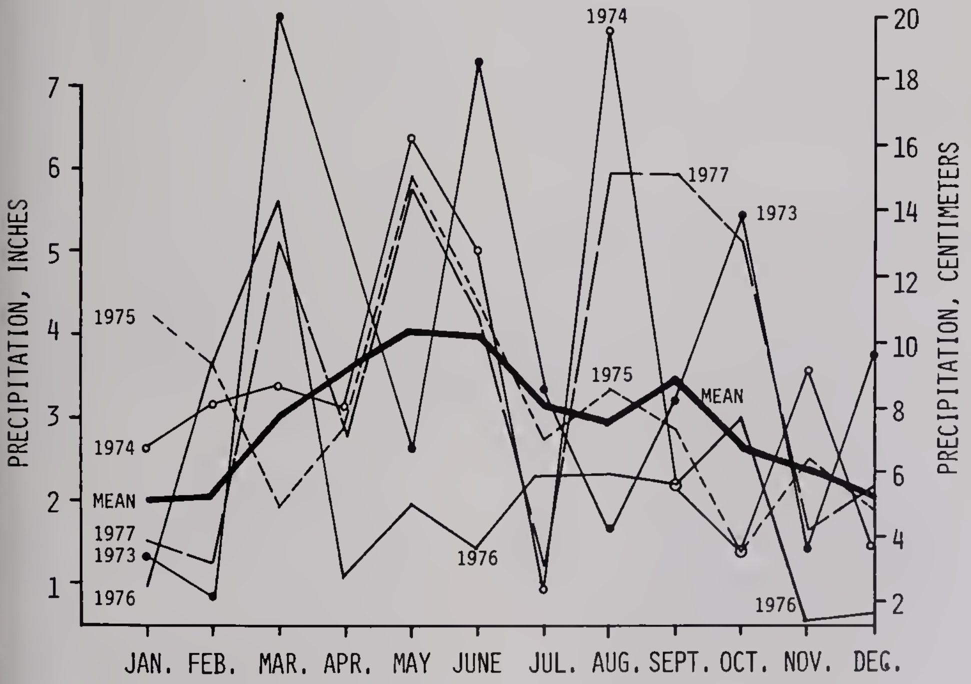


Fig. 4.—Mean monthly precipitation near Lake Sangchris, 1973–1977, and for the combined 40 years before 1973 (labeled MEAN).

Table 1.—Physical characteristics of Lake Sangchris.

Characteristic	Measurement
Surface area	876 ha (2,165 a)
Maximum depth	13.7 m (45 ft)
Average depth	4.6 m (15 ft)
Volume	$37.4 \times 10^6 m^3$ ($1,320.74 \times 10^6 ft^3$)
Shore length	150 km (93 miles)
Maximum effective length	4,950 m (16,240 ft)
Maximum effective width	1,170 m (3,840 ft)
Area of drainage basin	18,880 ha (46,652 a)
Spillway elevation (msl)	178.31 m (585.0 ft)
Mean hydraulic retention time	438 days
Volume development index	1.08
Surface-area-to-volume ratio	0.23 m^{-1}(0.07 ft^{-1})
Shoreline development index	14.23

9 m. Although not a deep lake, Lake Sangchris has an average depth of 4.6 m (Table 1), a depth similar to those of many central Illinois reservoirs of comparable size. The volume development index, which compares the volume of the lake to the volume of a cone with a base equal to the area of the lake and a height equal to the maximum depth, suggests a bowl-shaped basin. The ratio between surface area and volume (Table 1) further suggests a somewhat flattened basin. In general, the higher that ratio, the greater the cooling capacity of lakes of the same volume, since most of the heat dissipation is at the water's surface.

Although Lake Sangchris has a maximum effective length of less than 5,000 m and a maximum effective width of slightly over 1,000 m (Table 1) only at the dam, the effective exposure to the wind is maximized by the long, nearly parallel arms of the lake. And, too, the dendritic surface arrangement, with a relatively high shoreline development value of 14.23, expressing the relation of total shoreline to a circle with a circumference equal to the area of the lake, suggests protection from straight sweeps of winds. In actuality, the fingerlike arrangement of the surface area exposes the waters to relatively long fetches, increasing wave action and heat exchange with the atmosphere.

The relatively small flow of water feeding Lake Sangchris (1.2 m^3/sec) results in a mean hydraulic retention time of 438 days (U.S. EPA 1975). This is a very low rate compared with those of several nearby reservoirs, such as Lake Shelbyville (131 days), Lake Springfield (176 days), and Lake Lou Yaeger (121 days). The low flow through Lake Sangchris not only limits heat dispersal by internal currents, compared with such heat dispersion in reservoirs with more rapid flushing rates, but also virtually eliminates loss of heat from the lake by discharge over the dam and thus any thermal effects on the receiving waters below the lake.

The morphology of Lake Sangchris is, if not unique, at least nearly ideal as a cooling lake and for thermal studies. It permits efficient heat dissipation through a relatively long cooling loop, minimizes the thermal effects on biological systems by having many side coves and an unheated arm, and provides a convenient size and arrangment for experimental work.

REFERENCES CITED

Fehrenbacher, J.B., R.S. Smith, and R.T. Odell. 1950. Christian County soils. University of Illinois Agricultural Experiment Station Soil Report 73. 64 p.

National Oceanic and Atmospheric Administration Environmental Data and Information Service. 1972. Local climatological data: Springfield, Illinois. National Climatic Center, Asheville, N.C.

———. 1978. Local climatological data: Springfield, Illinois. National Climatic Center, Asheville, N.C.

PORAK, W., and J. A. TRANQUILLI. 1981. Impingement and entrainment of fishes at Kincaid Generating Station. Pages 631–655 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32 (4).

U.S. ENVIRONMENTAL PROTECTION AGENCY. 1975. National eutrophication survey. Report on Sangchris Lake, Christian County, Illinois. Working Paper No. 314. Corvallis Environmental Research Laboratory, Corvallis, OR. 15 p. + appendices.

WILLMAN, H.B., ET AL. 1967. Geologic map of Illinois. Illinois State Geological Survey, Urbana.

Water Quality in a Cooling Water Reservoir

Allison R. Brigham

ABSTRACT

Lake Sangchris is an 876-ha reservoir constructed from 1963 to 1966 as a cooling water supply for Commonwealth Edison's 1,232-megawatt coal-fired Kincaid Generating Station. Two factors govern existing water quality in the lake: the operation of the power plant and urban and agricultural runoff from the watershed.

The annual temperature regime is affected by plant operation as waste heat is dispersed and eliminated through the lake. More important, however, is the beneficial side effect of plant operation on water quality: the lake does not achieve permanent thermal or chemical stratification during summer and winter. Because of the circulation and mixing of water in the lake induced by plant operation, the deleterious effects of stratification (anoxic waters; formation of decomposition gases, such as ammonia and hydrogen sulfide) are uncommon to absent. In addition, waste heat is dissipated quickly. Generally, approximately 70 percent of the added heat is lost by the time the water mass has flowed halfway around the cooling loop.

Chemical input to the lake is derived primarily from surrounding urban and agricultural areas. During periods of high surface runoff (spring thaw and following heavy rains), turbidity increases in the lake. Chemical constituents associated with turbidity, such as phosphorus, iron, and frequently, organic nitrogen, enter the lake chiefly via this route. Urban influences are highly localized in the southern portion of the east arm of the lake and are reflected in slightly elevated organic phosphorus concentrations.

INTRODUCTION

Lake Sangchris is an 876-ha impoundment surrounded by flat to gently rolling agricultural land in Christian and Sangamon counties in central Illinois (Fig. 1). The primary purpose associated with the creation of Lake Sangchris was to provide adequate condenser cooling water for the coal-fired Kincaid Generating Station of Commonwealth Edison Company, a plant with a net generating capacity of 1,232 megawatts. Maximum cooling water flow through the plant is 640,000 gpm, or approximately 900 mgd. As water flows through the plant, the water temperature rises between 7° and 10°C.

Water flow around Lake Sangchris follows a circular pattern. The power plant is located between the west and middle arms of the lake at the extreme southern end adjacent to Illinois Route 104. Cooling water is taken into the plant at the southern end of the west arm, pumped through the plant, and discharged into the southern end of the middle arm. This continuous pumping action creates a flow which proceeds north along the middle arm to the dam area, then south along the western arm of the lake to the intake canal, a total distance of approximately 16 km. Flow time varies from 7 to 11 days, depending upon the time of year and the volume of plant operation.

The operation of the Kincaid Generating Station is the predominant influence upon water quality in Lake Sangchris, not only because of the additions of waste heat from the generation of electricity, but also because of the velocity maintained around the cooling loop, resulting from the operation of the pumps. The 32-month water quality study in the lake was intended to document baseline conditions to support biological investigations and to

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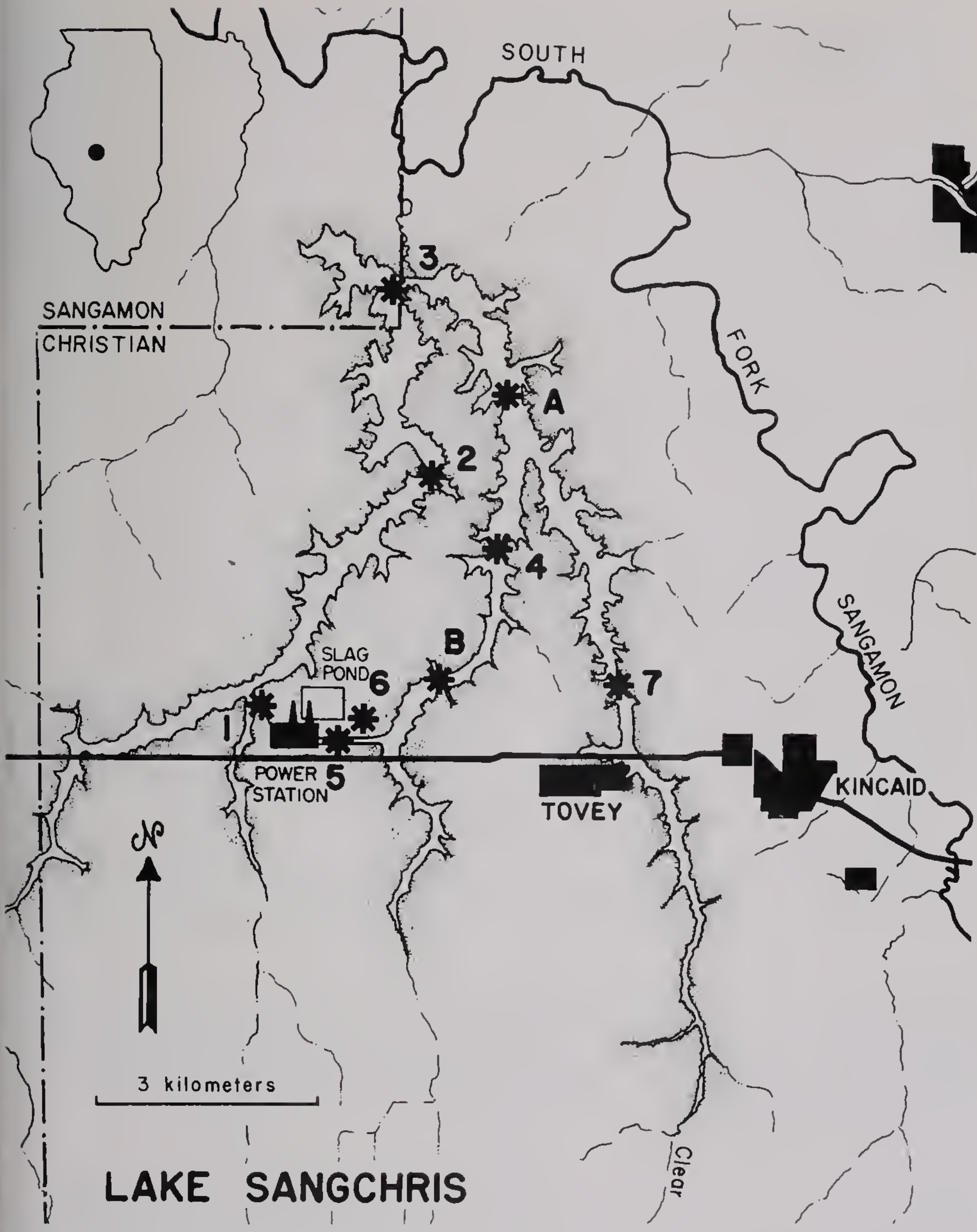

Fig. 1.—Location of Lake Sangchris and the water-quality sampling stations.

determine what, if any, water quality problems existed as a result of plant operation.

METHODS

Stations were selected (1) to characterize any potential effect of condenser passage upon water quality as water flowed around the cooling loop [Station 5 (discharge point) to stations 4, 3, 2, and 1 (plant intake)] and (2) to provide a control site potentially unaffected by power plant operation (Station 7). Locations of the sampling stations appear in Fig. 1. Six sites were sampled for routine water quality analyses. Stations A and B were sampled for water temperature and dissolved oxygen profiles only.

Sampling was conducted at biweekly intervals from September 1973 through August 1974 and at monthly intervals until the termination of field sampling in April 1976. Approximately 140 water temperature and 95 dissolved oxygen profiles were recorded from each Lake Sangchris station from September 1973 through August 1976.

Sample profiles were collected at all stations at these depths from September 1973 through August 1975: 0 m, 2 m, 5 m, and 7 or 8 m, stations 1 and 2; 0 m, 5 m, 10 m, and 12 m, Station 3; 0 m, 2 m, and 5 m, stations 4 and 7; and 0 m, and 2 m, Station 5. The 2-, 7- or 8-, and 12-m depths were eliminated for the final sampling period (September 1975 through April 1976).

Samples were collected with a 4.2-liter plastic Kemmerer bottle. Field measurements included water temperature and dissolved oxygen profiles at 1-m depth intervals, hydrogen ion concentration (*p*H), and free carbon dioxide. Laboratory methods are summarized in Table 1. Where more than one method is described for any variable in *Standard Methods for the Examination of Water and Wastewater,* 13th edition (American Public Health Association, American Water Works Association, and Water Pollution Control Federation 1971), the method used is listed in Table 1. For continuity, the 13th edition was used throughout the study.

Statistical analyses were performed on the variables which constituted the regular biweekly or monthly sampling program. Descriptive statistics consisting of the number of measurements, mean, standard deviation, and minimum and maximum values are included in Table 2 for each sampling station. Model I analysis of variance followed by the modified Duncan multiple-range test (Kramer 1956) were used to assess the relationships among variables at stations in the lake. In this way it was possible to determine whether significant differences existed among stations for any variable and to demonstrate which stations were significantly different. References to statistical significance in the text imply

Table 1.—Methods and equipment used in analyzing physical and chemical variables monitored at Lake Sangchris.

Variable[a]	Method and Equipment
Water temperature (C)	Mercury thermometer and thermocouple circuitry
Dissolved oxygen	YSI Model 51A DO meter
Free carbon dioxide	Titrimetric method and nomographic method
Hydrogen ion concentration (*p*H)	Sargent-Welch Model PBX meter
Total alkalinity (as $CaCO_3$)	Standard methods with Metrohm autotitrator
EDTA hardness (as $CaCO_3$)	EDTA colorimetric method (autoanalyzer)
Specific conductance (μmho/cm at 25°C)	YSI Model SCT meter
Total dissolved ionizable solids (as NaCl)	By calculation from specific conductance
Nitrate (as N)	Cadmium reduction method (autoanalyzer)
Nitrite (as N)	Diazotization method (autoanalyzer)
Ammonia (as N)	Modified phenate method (autoanalyzer)
Organic nitrogen (as N)	Total Kjeldahl method (autoanalyzer modified phenate method)
Total nitrogen	Sum all forms
Chloride	Argentometric method with Metrohm autotitrator
Total phosphorus (as P)	Stannous chloride method
Soluble orthophosphate (as P)	Stannous chloride method
Turbidity (Jackson turbidity units)	Monitek Model 150 turbidimeter
Total iron	Phenanthroline method
Soluble iron	Phenanthroline method
Sulfate (as S)	Turbidimetric method
Organic carbon (total, particulate, dissolved)	Direct injection with Oceanography International carbon system
Molybdate-reactive silica (as SiO_2)	Molybdosilicate method

[a] Shown as mg/l except where other units are indicated.

significance at the 0.05 level unless another level is specified.

Logarithmic transformation was used here for all input data. This treatment equalizes variances when variances are proportional to the squares of the station

Station and Depth	Water Temperature (°C)	Dissolved Oxygen	Dissolved Oxygen (Percent of Saturation)	Free Carbon Dioxide	Hydrogen Ion Concentration (*p*H)	Total Alkalinity (as $CaCO_3$)	EDTA Hardness (as $CaCO_3$)	Total Dissolved Ionizable Solids (as NaCl)
1 (0 m)	45 – 15.23(8.77) 1.0 to 30.5	45 – 10.13(2.18) 7.0 to 15.0	45 – 97.79(15.72) 59.0 to 145	45 – 2.3(2.3) 0 to 9	45 – 7.95(0.30) 7.4 to 8.6	45 – 89.1(7.6) 70 to 101	45 – 182.6(29.5) 136 to 241	45 – 314.6(51.7) 193 to 405
1 (2 m)	35 – 16.15 (8.66) 3.0 to 30.0	35 – 8.30(2.96) 3.6 to 15.0	35 – 83.09(28.76) 31.3 to 151	36 – 2.3(2.0) 0 to 9	37 – 7.97(0.28) 7.4 to 8.6	37 – 88.8(7.8) 69 to 99	37 – 173.9(19.7) 144 to 213	37 – 304.8(39.6) 204 to 357
1 (5 m)	41 – 15.63(8.14) 3.0 to 28.6	41 – 7.18(3.40) 1.9 to 15.0	41 – 70.22(33.54) 20.4 to 155	42 – 2.2(1.7) 0 to 7	43 – 7.94(0.25) 7.4 to 8.4	43 – 89.3(6.7) 72 to 100	43 – 183.9(29.0) 138 to 247	43 – 312.3(53.4) 156 to 415
1 (7 m)	30 – 15.18(8.23) 3.0 to 28.6	30 – 6.79(3.83) 1.5 to 15.0	30 – 66.01(38.13) 14.8 to 160	31 – 2.6(1.8) 0 to 7	33 – 7.90(0.27) 7.3 to 8.4	33 – 89.3(8.6) 67 to 104	33 – 175.6(19.0) 139 to 207	33 – 302.5(45.4) 152 to 358
2 (0 m)	42 – 15.26(8.84) 1.0 to 32.0	41 – 9.92(2.05) 6.7 to 15.0	41 – 95.96(15.87) 59.0 to 131	42 – 2.0(2.0) 0 to 9	42 – 8.05(0.32) 7.3 to 8.8	42 – 89.1(6.6) 78 to 102	42 – 189.1(27.4) 152 to 244	42 – 323.8(44.6) 222 to 414
2 (2 m)	32 – 16.51(8.51) 3.3 to 31.5	32 – 9.20(2.93) 3.0 to 15.0	32 – 91.18(24.64) 33.6 to 134	33 – 1.9(1.4) 0 to 5	34 – 8.01(0.30) 7.5 to 8.9	34 – 88.5(9.5) 57 to 108	34 – 179.1(19.1) 152 to 214	34 – 317.3(35.6) 217 to 361
2 (5 m)	40 – 15.40(8.18) 2.8 to 29.2	40 – 8.09(3.20) 1.4 to 15.0	40 – 77.59(27.94) 16.1 to 137	41 – 2.3(1.6) 0 to 7	42 – 7.94(0.25) 7.4 to 8.4	42 – 89.0(6.7) 75 to 100	42 – 188.2(26.8) 150 to 244	42 – 321.5(43.3) 222 to 415
2 (8 m)	32 – 15.43(7.90) 3.1 to 27.5	31 – 6.15(4.00) 0.7 to 14.0	31 – 59.36(36.01) 7.0 to 146	32 – 2.9(1.9) 0 to 9	32 – 7.84(0.25) 7.4 to 8.4	32 – 89.9(9.6) 73 to 113	32 – 177.7(20.1) 131 to 205	32 – 310.8(38.0) 219 to 364
3 (0 m)	43 – 16.80(8.91) 2.5 to 33.0	42 – 9.66(2.05) 6.6 to 15.0	42 – 96.64(15.99) 59.0 to 146	45 – 1.6(1.2) 0 to 5	45 – 8.08(0.30) 7.5 to 8.9	45 – 88.4(6.5) 72 to 98	45 – 186.0(28.6) 143 to 246	45 – 321.2(44.9) 215 to 412
3 (5 m)	42 – 16.57(8.06) 3.9 to 28.8	42 – 7.49(3.34) 1.2 to 13.6	42 – 73.87(32.63) 13.8 to 166	44 – 1.9(1.1) 0 to 5	45 – 7.98(0.27) 7.5 to 8.7	45 – 88.6(6.6) 76 to 97	45 – 186.5(29.2) 142 to 245	45 – 322.3(45.0) 207 to 416
3 (10 m)	41 – 14.97(6.92) 3.1 to 23.9	41 – 6.13(4.01) 0.1 to 15.0	41 – 58.32(38.94) 0.0 to 176	43 – 3.5(3.1) 1 to 16	45 – 7.82(0.32) 7.0 to 8.4	45 – 93.2(14.0) 75 to 142	45 – 187.4(30.2) 135 to 245	45 – 321.2(43.0) 219 to 420
3 (12 m)	28 – 16.20(6.58) 4.0 to 26.0	28 – 4.64(4.06) 0.0 to 15.0	28 – 45.66(40.91) 0.0 to 170	30 – 5.4(8.2) 1 to 45	33 – 7.74(0.38) 6.8 to 8.4	33 – 98.2(20.8) 68 to 153	33 – 178.7(21.4) 140 to 220	33 – 312.5(40.3) 200 to 371
4 (0 m)	45 – 19.90(9.28) 4.0 to 37.0	44 – 9.62(2.16) 6.4 to 15.0	44 – 101.0(15.37) 65.0 to 139	45 – 1.7(1.4) 0 to 7	45 – 8.02(0.26) 7.5 to 8.6	45 – 88.5(6.4) 72 to 97	45 – 187.4(29.3) 142 to 248	45 – 326.0(42.1) 248 to 412
4 (2 m)	36 – 21.06(8.54) 6.3 to 35.8	36 – 8.19(3.00) 1.8 to 13.8	36 – 89.20(28.03) 17.3 to 136	36 – 1.5(1.1) 0 to 4	37 – 7.98(0.24) 7.5 to 8.5	37 – 87.4(7.5) 68 to 98	37 – 177.1(21.1) 141 to 215	37 – 311.6(38.4) 199 to 383
4 (5 m)	44 – 17.48(7.85) 5.1 to 29.2	44 – 6.98(3.71) 0.2 to 14.3	44 – 69.79(36.98) 2.5 to 174	44 – 2.3(1.5) 0 to 8	45 – 7.88(0.24) 7.3 to 8.4	45 – 88.6(9.1) 61 to 122	45 – 185.4(30.0) 129 to 247	45 – 321.6(39.7) 248 to 412
5 (0 m)	45 – 21.67(8.96) 5.0 to 37.8	44 – 9.49(2.44) 5.3 to 15.0	44 – 101.8(18.37) 55.0 to 144	45 – 1.7(1.2) 0 to 6	45 – 8.00(0.24) 7.5 to 8.5	45 – 89.0(7.3) 68 to 100	45 – 184.3(28.7) 135 to 246	45 – 325.2(51.1) 181 to 487
5 (2 m)	36 – 23.27(8.70) 9.8 to 37.9	36 – 8.57(2.95) 1.9 to 14.6	36 – 96.81(28.14) 22.6 to 143	36 – 1.5(1.0) 0 to 3	37 – 8.00(0.25) 7.5 to 8.6	37 – 88.4(7.1) 74 to 100	37 – 175.3(20.4) 135 to 213	37 – 311.6(32.3) 228 to 359
7 (0 m)	42 – 16.33(9.85) 0.8 to 32.2	41 – 10.32(2.01) 7.5 to 15.0	41 – 102.0(15.16) 73.0 to 159	42 – 2.0(2.8) 0 to 16	43 – 8.11(0.44) 7.2 to 9.5	43 – 86.4(15.3) 16 to 103	43 – 174.0(40.4) 30 to 261	43 – 305.7(59.2) 70 to 454
7 (2 m)	35 – 15.90(9.41) 1.8 to 31.3	34 – 9.29(2.45) 3.2 to 13.6	34 – 93.34(24.76) 25.2 to 143	35 – 2.0(2.5) 0 to 11	35 – 8.09(0.38) 7.2 to 9.0	35 – 84.9(13.4) 37 to 101	35 – 165.8(27.9) 75 to 204	35 – 299.7(41.4) 169 to 347
7 (5 m)	42 – 15.26(8.50) 2.3 to 29.5	41 – 7.89(3.00) 2.1 to 13.6	41 – 76.93(28.58) 19.4 to 136	42 – 2.0(2.2) 0 to 11	43 – 8.03(0.33) 7.1 to 9.0	43 – 88.0(11.3) 55 to 103	43 – 176.4(34.2) 107 to 243	43 – 311.1(44.0) 223 to 381

means, typically the case for water quality data. The base 10 was used for convenience.

Logarithmic transformation is used with positive integers which cover a wide range. It cannot be used directly for zero,

Table 2.—Continued.

Station and Depth	Nitrate (as N)	Nitrite (as N)	Ammonia (as N)	Organic Nitrogen (as N)	Total Nitrogen	Chloride	Total Phosphorus (as P)	Soluble Orthophosphate (as P)
1 (0 m)	45 — 1.811(1.711) 0.01 to 5.23	45 — 0.141(0.110) 0.01 to 0.51	45 — 0.108(0.060) 0.04 to 0.28	45 — 0.359(0.207) 0.02 to 1.1	45 — 2.418(1.749) 0.26 to 5.60	45 — 23.67(5.22) 16.5 to 45.0	45 — 0.172(0.099) 0.06 to 0.61	45 — 0.030(0.032) <0.01 to 0.12
1 (2 m)	37 — 2.090(1.689) 0.01 to 4.99	37 — 0.145(0.119) 0.02 to 0.53	37 — 0.095(0.065) 0.03 to 0.35	37 — 0.302(0.140) 0.06 to 0.56	37 — 2.632(1.673) 0.48 to 5.25	37 — 23.31(5.70) 16.4 to 45.0	37 — 0.187(0.098) 0.07 to 0.62	37 — 0.030(0.037) <0.01 to 0.22
1 (5 m)	43 — 1.823(1.727) 0.01 to 4.94	43 — 0.136(0.115) 0.01 to 0.54	43 — 0.089(0.057) 0.02 to 0.28	41 — 0.317(0.151) 0.06 to 0.70	43 — 2.351(1.723) 0.27 to 5.20	43 — 23.82(5.75) 13.0 to 47.0	43 — 0.195(0.075) 0.08 to 0.44	43 — 0.034(0.051) <0.01 to 0.26
1 (7 m)	33 — 2.293(1.752) 0.01 to 4.99	33 — 0.151(0.120) 0.01 to 0.52	33 — 0.084(0.046) 0.03 to 0.24	31 — 0.342(0.146) 0.06 to 0.74	33 — 2.849(1.768) 0.38 to 5.75	33 — 23.49(6.57) 11.5 to 47.0	33 — 0.258(0.122) 0.08 to 0.64	33 — 0.030(0.038) <0.01 to 0.19
2 (0 m)	42 — 1.824(1.684) 0.01 to 4.99	42 — 0.139(0.124) 0.01 to 0.50	42 — 0.081(0.046) 0.02 to 0.24	42 — 0.388(0.230) 0.09 to 1.2	42 — 2.431(1.655) 0.28 to 5.40	42 — 24.13(5.95) 16.8 to 50.0	42 — 0.148(0.052) 0.05 to 0.25	42 — 0.028(0.035) <0.01 to 0.17
2 (2 m)	34 — 2.182(1.688) 0.01 to 4.94	34 — 0.153(0.129) 0.01 to 0.47	34 — 0.096(0.061) 0.03 to 0.29	34 — 0.319(0.157) 0.04 to 0.87	34 — 2.749(1.682) 0.38 to 5.30	34 — 24.16(6.48) 14.0 to 47.0	34 — 0.147(0.050) 0.04 to 0.26	34 — 0.021(0.019) <0.01 to 0.07
2 (5 m)	42 — 1.825(1.693) 0.01 to 4.99	42 — 0.143(0.126) 0.01 to 0.47	42 — 0.086(0.050) 0.02 to 0.25	42 — 0.330(0.152) 0.03 to 0.76	42 — 2.384(1.692) 0.38 to 5.30	42 — 24.38(6.11) 17.5 to 47.0	42 — 0.148(0.059) 0.05 to 0.29	41 — 0.025(0.027) <0.01 to 0.12
2 (8 m)	32 — 2.214(1.681) 0.01 to 4.99	32 — 0.170(0.159) 0.01 to 0.74	32 — 0.128(0.123) 0.04 to 0.50	32 — 0.322(0.258) 0.01 to 1.6	32 — 2.834(1.678) 0.56 to 5.30	32 — 24.32(6.97) 17.7 to 50.0	32 — 0.245(0.254) 0.07 to 1.5	32 — 0.027(0.023) <0.01 to 0.07
3 (0 m)	45 — 1.755(1.722) 0.01 to 4.99	45 — 0.143(0.119) 0.01 to 0.50	45 — 0.080(0.045) 0.02 to 0.22	45 — 0.298(0.113) 0.09 to 0.52	45 — 2.275(1.728) 0.38 to 5.55	45 — 24.72(6.56) 16.8 to 52.0	45 — 0.160(0.064) 0.04 to 0.38	45 — 0.028(0.027) <0.01 to 0.12
3 (5 m)	45 — 1.782(1.736) 0.01 to 4.99	45 — 0.154(0.140) 0.01 to 0.57	45 — 0.088(0.059) 0.02 to 0.27	45 — 0.312(0.123) 0.07 to 0.54	45 — 2.335(1.782) 0.25 to 5.70	45 — 24.69(6.40) 17.2 to 52.0	45 — 0.160(0.058) 0.06 to 0.39	45 — 0.028(0.028) <0.01 to 0.13
3 (10 m)	45 — 1.747(1.699) 0.01 to 4.99	45 — 0.153(0.181) 0.01 to 1.05	45 — 0.183(0.308) 0.02 to 1.8	45 — 0.326(0.113) 0.02 to 0.55	45 — 2.409(1.708) 0.38 to 5.65	45 — 24.55(6.13) 18.1 to 50.0	45 — 0.176(0.083) 0.04 to 0.40	45 — 0.023(0.021) <0.01 to 0.09
3 (12 m)	33 — 1.757(1.737) 0.0 to 4.94	33 — 0.207(0.265) 0.03 to 1.13	33 — 0.359(0.559) 0.04 to 2.3	32 — 0.397(0.248) 0.01 to 1.3	33 — 2.708(1.747) 0.45 to 5.80	33 — 24.67(7.99) 17.2 to 56.0	33 — 0.271(0.177) 0.04 to 0.86	33 — 0.031(0.057) <0.01 to 0.31
4 (0 m)	45 — 1.797(1.739) 0.01 to 5.10	45 — 0.130(0.106) 0.01 to 0.47	45 — 0.088(0.059) 0.02 to 0.26	44 — 0.315(0.132) 0.05 to 0.57	44 — 2.359(1.754) 0.37 to 5.65	45 — 24.67(6.03) 16.8 to 48.0	45 — 0.202(0.110) 0.05 to 0.69	45 — 0.038(0.087) <0.01 to 0.57
4 (2 m)	37 — 2.114(1.764) 0.01 to 5.15	37 — 0.138(0.107) 0.02 to 0.46	37 — 0.078(0.054) 0.03 to 0.25	36 — 0.337(0.135) 0.12 to 0.74	37 — 2.658(1.770) 0.45 to 5.55	37 — 24.40(6.40) 16.8 to 50.0	37 — 0.233(0.115) 0.10 to 0.66	37 — 0.030(0.036) <0.01 to 0.16
4 (5 m)	45 — 1.830(1.792) 0.01 to 5.20	45 — 0.152(0.145) 0.01 to 0.54	45 — 0.081(0.058) 0.02 to 0.27	45 — 0.352(0.176) 0.05 to 0.95	45 — 2.415(1.810) 0.33 to 5.60	45 — 24.54(6.30) 16.8 to 52.0	45 — 0.226(0.113) 0.06 to 0.63	45 — 0.028(0.044) <0.01 to 0.29
5 (0 m)	45 — 1.781(1.739) 0.01 to 5.10	45 — 0.130(0.106) 0.01 to 0.45	45 — 0.079(0.049) 0.03 to 0.22	44 — 0.342(0.157) 0.06 to 0.73	45 — 2.324(1.748) 0.32 to 5.80	45 — 24.27(6.60) 16.8 to 54.0	45 — 0.190(0.077) 0.07 to 0.48	45 — 0.029(0.029) <0.01 to 0.17
5 (2 m)	37 — 2.119(1.767) 0.01 to 5.15	37 — 0.145(0.125) 0.03 to 0.59	37 — 0.081(0.048) 0.03 to 0.25	37 — 0.332(0.115) 0.11 to 0.51	37 — 2.677(1.763) 0.52 to 5.75	37 — 24.15(6.61) 17.2 to 47.0	37 — 0.199(0.088) 0.07 to 0.48	37 — 0.032(0.032) <0.01 to 0.16
7 (0 m)	43 — 2.341(2.287) 0.01 to 6.53	43 — 0.138(0.125) 0.01 to 0.53	43 — 0.074(0.049) 0.02 to 0.28	43 — 0.424(0.236) 0.11 to 1.5	43 — 2.976(2.361) 0.32 to 7.75	43 — 24.10(7.00) 5.0 to 48.0	43 — 0.258(0.173) 0.04 to 0.90	43 — 0.053(0.071) <0.01 to 0.12
7 (2 m)	35 — 2.854(2.284) 0.01 to 6.63	35 — 0.156(0.129) 0.02 to 0.52	35 — 0.079(0.045) 0.01 to 0.21	35 — 0.401(0.208) 0.11 to 1.1	35 — 3.489(2.322) 0.48 to 7.29	35 — 23.79(7.51) 12.9 to 50.0	35 — 0.278(0.216) 0.04 to 1.0	35 — 0.066(0.097) <0.01 to 0.47
7 (5 m)	43 — 2.308(2.283)	43 — 0.154(0.137)	43 — 0.101(0.068)	42 — 0.414(0.219)	43 — 3.009(2.349)	43 — 24.08(6.35)	43 — 0.284(0.172)	43 — 0.058(0.085)

and when some of the values are less than 10, it yields undesirable results. To avoid these problems, 1 is added to each number prior to taking the logarithm, as in transformed Y = $\log_{10}$ (Y + 1). Two assumptions required of many statistical

Station and Depth	Turbidity (JTU)	Total Iron	Soluble Iron	Sulfate (as S)	Total Organic Carbon	Particulate Organic Carbon	Dissolved Organic Carbon	Silica (as SiO_2)
1 (0 m)	45 – 21.0(14.7)	45 – 0.626(0.375)	45 – 0.055(0.049)	45 – 50.85(11.44)	44 – 18.56(7.66)	44 – 9.57(7.21)	44 – 8.99(5.29)	44 – 3.35(1.53)
	5 to 80	0.15 to 1.9	0.01 to 0.27	24.7 to 72.1	4.2 to 33.8	0.2 to 24.5	2.5 to 31.7	0.3 to 6.6
1 (2 m)	37 – 21.0(15.2)	37 – 0.725(0.547)	37 – 0.046(0.038)	37 – 50.29(14.11)	35 – 16.77(6.06)	35 – 9.82(5.70)	35 – 6.95(3.68)	36 – 3.26(1.50)
	5 to 78	0.19 to 3.3	0.0 to 0.16	26.7 to 81.8	2.0 to 30.2	0.3 to 20.4	0.8 to 19.6	0.4 to 6.6
1 (5 m)	43 – 25.6(15.2)	43 – 0.815(0.424)	43 – 0.076(0.107)	43 – 49.03(12.05)	40 – 16.54(6.68)	40 – 7.92(7.19)	40 – 8.60(5.57)	39 – 3.61(1.26)
	5 to 63	0.15 to 2.0	0.0 to 0.62	27.7 to 76.8	4.9 to 32.4	0.2 to 24.6	1.8 to 31.9	0.9 to 5.6
1 (7 m)	33 – 31.8(20.1)	33 – 1.27(0.638)	33 – 0.052(0.059)	33 – 50.51(11.84)	30 – 15.41(4.55)	30 – 7.10(5.07)	30 – 8.34(3.84)	30 – 3.45(1.48)
	5 to 74	0.22 to 2.9	0.0 to 0.29	27.7 to 71.0	4.6 to 23.0	0.4 to 19.0	2.0 to 17.6	0.8 to 6.4
2 (0 m)	42 – 18.8(12.1)	42 – 0.528(0.263)	42 – 0.038(0.031)	42 – 52.43(12.23)	40 – 11.68(5.73)	40 – 2.64(2.35)	40 – 9.04(5.61)	41 – 3.41(1.69)
	5 to 59	0.13 to 1.3	0.0 to 0.13	31.4 to 78.4	3.7 to 32.8	0.2 to 9.4	0.0 to 29.2	0.8 to 7.3
2 (2 m)	34 – 18.2(14.0)	34 – 0.538(0.283)	34 – 0.040(0.044)	34 – 55.20(14.14)	33 – 11.97(4.13)	33 – 3.56(3.22)	33 – 8.41(3.81)	31 – 3.58(2.48)
	5 to 74	0.19 to 1.3	0.0 to 0.19	31.4 to 95.1	3.8 to 22.1	0.2 to 10.5	2.2 to 20.1	0.2 to 9.7
2 (5 m)	42 – 20.7(13.0)	42 – 0.584(0.281)	42 – 0.046(0.050)	42 – 52.92(11.74)	41 – 11.01(5.71)	41 – 3.40(2.35)	41 – 7.62(5.30)	41 – 3.53(1.35)
	5 to 66	0.15 to 1.4	0.0 to 0.21	35.1 to 83.4	2.0 to 32.0	0.2 to 11.7	1.4 to 29.0	0.8 to 7.0
2 (8 m)	32 – 25.5(18.6)	32 – 0.969(0.764)	32 – 0.045(0.040)	32 – 52.79(13.51)	29 – 11.15(6.82)	29 – 3.88(4.90)	29 – 7.26(3.71)	29 – 3.43(1.84)
	6 to 76	0.36 to 4.2	0.0 to 0.16	27.4 to 83.4	3.5 to 41.3	0.4 to 26.5	2.3 to 16.0	0.7 to 7.3
3 (0 m)	45 – 17.9(10.4)	45 – 0.527(0.325)	45 – 0.31(0.24)	45 – 51.48(13.04)	43 – 10.43(5.93)	43 – 2.39(3.12)	43 – 8.01(4.56)	43 – 3.36(1.70)
	5 to 59	0.14 to 1.7	0.0 to 0.10	27.4 to 81.8	2.0 to 31.8	0.1 to 17.4	1.4 to 27.1	0.2 to 7.1
3 (5 m)	45 – 20.0(12.2)	45 – 0.571(0.330)	45 – 0.039(0.031)	45 – 51.00(13.07)	44 – 9.18(5.50)	44 – 2.11(2.18)	44 – 7.07(4.91)	43 – 3.35(1.48)
	6 to 73	0.16 to 1.7	0.0 to 0.11	28.4 to 83.4	1.9 to 31.1	0.2 to 9.4	1.2 to 30.9	0.6 to 7.3
3 (10 m)	45 – 23.5(14.0)	45 – 0.844(0.671)	45 – 0.033(0.028)	45 – 50.62(15.79)	44 – 11.34(5.77)	44 – 3.39(2.13)	44 – 7.96(5.32)	44 – 3.79(1.69)
	6 to 70	0.16 to 3.9	0.0 to 0.12	15.7 to 96.8	3.5 to 34.0	0.4 to 7.8	0.8 to 32.4	0.6 to 6.8
3 (12 m)	33 – 45.5(54.0)	33 – 1.59(1.27)	33 – 0.038(0.039)	33 – 46.09(15.41)	31 – 10.93(4.70)	31 – 3.70(2.58)	31 – 7.23(3.76)	32 – 4.30(2.28)
	8 to 300	0.22 to 5.0	0.0 to 0.17	8.3 to 83.4	4.0 to 25.2	0.2 to 12.6	0.7 to 16.3	0.9 to 9.0
4 (0 m)	45 – 25.9(16.9)	45 – 0.825(0.384)	45 – 0.035(0.029)	45 – 50.83(12.21)	44 – 10.41(5.32)	44 – 2.59(2.20)	44 – 7.82(4.96)	44 – 3.58(1.42)
	7 to 85	0.29 to 2.2	0.0 to 0.13	22.0 to 74.1	3.2 to 31.4	0.1 to 9.4	0.9 to 28.9	0.7 to 7.7
4 (2 m)	37 – 26.6(18.3)	37 – 0.938(0.428)	37 – 0.042(0.032)	37 – 52.13(14.17)	36 – 9.56(4.26)	36 – 2.15(1.84)	36 – 7.41(3.47)	35 – 3.99(1.98)
	7 to 76	0.36 to 2.4	0.0 to 0.13	24.7 to 76.8	4.5 to 22.3	0.1 to 9.2	2.8 to 18.1	0.6 to 11.7
4 (5 m)	45 – 31.2(18.5)	45 – 1.12(0.591)	45 – 0.043(0.043)	45 – 50.98(12.90)	43 – 10.25(5.45)	43 – 1.91(1.78)	43 – 8.34(4.77)	44 – 3.45(1.66)
	7 to 92	0.28 to 2.7	0.0 to 0.20	24.3 to 84.1	1.7 to 31.4	0.1 to 8.4	1.4 to 29.9	0.6 to 7.0
5 (0 m)	45 – 23.9(14.1)	45 – 0.770(0.415)	45 – 0.052(0.046)	45 – 51.35(12.67)	42 – 10.40(6.03)	42 – 2.52(2.61)	42 – 7.88(5.06)	42 – 3.13(1.67)
	5 to 60	0.19 to 2.3	0.0 to 0.20	29.4 to 83.4	2.2 to 31.9	0.2 to 15.8	0.8 to 30.0	0.2 to 7.2
5 (2 m)	37 – 23.3(15.8)	37 – 0.852(0.475)	37 – 0.055(0.053)	37 – 52.39(13.60)	36 – 9.55(4.84)	36 – 2.31(2.76)	36 – 7.25(3.42)	36 – 2.88(1.56)
	5 to 68	0.20 to 2.4	0.0 to 0.28	30.4 to 83.4	2.2 to 28.2	0.2 to 13.6	0.9 to 14.6	<0.1 to 6.0
7 (0 m)	43 – 32.7(38.6)	43 – 1.04(1.16)	43 – 0.055(0.050)	43 – 45.45(15.33)	40 – 9.58(5.76)	40 – 4.24(2.80)	40 – 5.34(6.04)	41 – 4.08(2.63)
	5 to 230	0.23 to 5.2	0.0 to 0.22	4.7 to 76.8	2.2 to 29.2	0.3 to 12.6	0.2 to 27.5	0.2 to 11.6
7 (2 m)	35 – 34.1(32.1)	35 – 1.32(1.69)	35 – 0.054(0.099)	35 – 44.59(13.76)	34 – 9.44(5.98)	34 – 3.19(3.00)	34 – 6.25(4.37)	33 – 4.54(2.55)
	5 to 140	0.16 to 8.0	0.0 to 0.60	17.4 to 76.8	2.1 to 29.9	0.2 to 14.8	0.3 to 20.4	1.1 to 10.6
7 (5 m)	43 – 37.3(26.3)	43 – 1.38(1.47)	43 – 0.070(0.095)	43 – 42.44(14.03)	41 – 10.79(5.42)	41 – 4.62(2.69)	41 – 6.17(5.48)	41 – 3.64(2.09)
	5 to 110	0.22 to 7.0	0.0 to 0.50	4.3 to 72.1	2.1 to 29.0	0.5 to 13.3	0.8 to 26.9	0.3 to 9.0

tests are that experimental errors be independently and normally distributed and that variance be homogeneous (data are homoscedastic). These assumptions are generally invalid for water quality measurements, but the regular heterogeneity of variance displayed by these data may be approximately normalized by transformation.

Model I linear regressions for three of the most influential variables (water temperature, dissolved oxygen, and turbidity) were performed on pooled data from stations 1 (0 and 5 m), 3 (0, 5, and 10 m), 5 (0 m), and 7 (0 and 5 m). In the resulting equations, the relationship between the two variables in each equation is only a functional one, not actually a cause-and-effect one.

Each of the equations in Table 9 represents the best fit of Y on X. For each pair of variables, the linear regression and four forms of curvilinear regression ($Y = a + b \log X$; $Y = a + b \operatorname{antilog} X$; $Y = a + b X^2$; and $\log Y = a + b \log X$) were calculated. Tests of significance were performed on each of these curvilinear regressions. The five equations were compared to determine which function of X best accounted for the variation in Y. Equations in Table 9 are significant at the 0.001 level.

RESULTS AND DISCUSSION

HOMOGENEITY IN THE WATER COLUMN

Lake Sangchris is a reasonably shallow impoundment: in the main channel of the cold-water arm the lake is 7–10 m deep; in the vicinity of the dam it is approximately 15 m deep; the warmwater arm, however, is generally more shallow, ranging from 5 to 8 m in depth. The overall shallowness throughout most of the lake combined with the velocity created by the flow of water through the power plant keep the lake water well mixed. With the exception of those measured at Station 3, 5 or fewer of 24 physical and chemical variables analyzed demonstrated any significant differences (0.05 level) as depth varied (Table 3).

Dissolved oxygen, both as concentration and percentage of saturation, exhibited significant differences with depth at all stations except Station 5, the point of discharge from the power plant. Concentrations at corresponding depths among stations were remarkably similar. Even though the lake water was well mixed, the photic zone was generally less than 2 m deep. Consequently, the concentration of

Lake Sangchris and Kincaid Generating Station in 1979, after the construction of a new stack.

Table 3.—Relationships among 3-year mean concentrations of physical and chemical variables at several depths at stations in Lake Sangchris. Any two or more means underscored by the same line are not significantly different by the modified new Duncan multiple-range test (0.05 level).

Variable[a]	n	Station 1			
		0 m	2 m	5 m	7 m
Dissolved oxygen	151	10.1	8.3	7.2	6.8
Dissolved oxygen (percent of saturation)	151	97.8	83.1	70.2	66.0
Total phosphorus (as P)	158	0.172	0.187	0.195	0.258
Turbidity (JTU)	158	21	21	26	32
Total iron	158	0.63	0.73	0.82	1.27
		Station 2			
		0 m	2 m	5 m	8 m
Dissolved oxygen	144	9.9	9.2	8.1	6.2
Dissolved oxygen (percent of saturation)	144	96.0	91.2	77.6	59.4
Hydrogen ion concentration (*p*H)	150	8.05	8.01	7.94	7.84
Total phosphorus (as P)	150	0.148	0.147	0.148	0.245
Total iron	150	0.53	0.54	0.58	0.97
		Station 3			
		0 m	5 m	10 m	12 m
Dissolved oxygen	153	9.7	7.5	6.1	4.6
Dissolved oxygen (percent of saturation)	153	96.6	73.9	58.3	45.7
Free carbon dioxide	162	1.6	1.9	3.5	5.5
Hydrogen ion concentration (*p*H)	168	8.08	7.98	7.82	7.74
Total alkalinity (as $CaCO_3$)	168	88	89	93	98
Ammonia (as N)	168	0.08	0.09	0.18	0.36
Organic nitrogen (as N)	167	0.30	0.31	0.33	0.40
Total phosphorus (as P)	168	0.160	0.160	0.176	0.271
Turbidity (JTU)	168	18	20	24	46
Total iron	168	0.53	0.57	0.84	1.59
		5 m	0 m	10 m	12 m
Particulate organic carbon	162	2.1	2.4	3.4	3.7
		Station 4			
		0 m	2 m	5 m	
Dissolved oxygen	124	9.6	8.2	7.0	
Dissolved oxygen (percent of saturation)	124	101.0	89.2	69.8	
Free carbon dioxide	125	1.7	1.5	2.3	
Hydrogen ion concentration (*p*H)	127	8.01	7.97	7.88	
Total iron	127	0.83	0.94	1.12	
		Station 7			
		0 m	2 m	5 m	
Dissolved oxygen	116	10.3	9.3	7.9	
Dissolved oxygen (percent of saturation)	116	102.0	93.3	76.9	

[a] Shown as mg liter except where other units are indicated

dissolved oxygen decreased with depth as oxygen was consumed in decomposition processes and respiration without corresponding oxygen production. It has been estimated that as much as 50–90 percent of the available dissolved oxygen may be taken up by sediments as a result of chemical and bacteriological decomposition activities (Golterman 1975).

Total phosphorus and total iron demonstrated significant differences with depth at stations 1, 2, and 3 and 1, 2, 3, and 4, respectively. In general, the top layer of water was significantly distinct from the deepest depth sampled. Since the main channel is more narrow and deep in the cold-water arm than it is the warmwater arm of the lake (a function of the basin morphology), sediment particles settled to these deep sites but did not settle out completely because of the water velocity. Concentrations of total phosphorus and total iron paralleled the distribution of suspended solids, as reflected by turbidity values.

Station 3, the broadest and deepest portion of Lake Sangchris, exhibited significant differences for 11 variables with depth. Most were those which one would expect to exhibit such differences because of their relationships to vertical gradients of dissolved oxygen or to the differential settling of sediment particles: turbidity, total phosphorus, ammonia, organic nitrogen, total iron, free carbon dioxide, and total alkalinity, in addition to dissolved oxygen. Both dissolved oxygen and hydrogen ion concentration (*p*H) decreased with depth, while concentrations of the remaining variables increased with depth.

At Station 3, the upper 10 m were statistically homogeneous for free carbon dioxide, total alkalinity, turbidity, total phosphorus, ammonia, organic nitrogen, and total iron. Of these, all but total alkalinity were significantly different from the 12-m sample. For hydrogen ion concentration (*p*H) the water column at Station 3 was divided into two significantly different layers: the surface –5 m and 10 m – 12 m. While dissolved oxygen, both as concentration and percentage of saturation, was significantly higher at the surface, concentrations, although decreasing with depth, were still interrelated. As percentage of saturation, however, the surface and 5-m depths were significantly different from the 10-m–12-m layer.

3-YEAR CHANGES IN LAKE LIMNOLOGY

As there were obvious climatological differences among study years (Larimore & Tranquilli 1981), water quality data from selected stations were analyzed by study year to determine if any variables appeared to be dependent upon climatological cycles or if the concentrations of any variables functioned independently of variations in overall temperature regime or precipitation. Of 24 variables examined (those summarized in Table 2), 15 demonstrated some significant differences among study years (Table 4).

Some of the variables exhibiting differences among years were observed at only a single station. These included dissolved oxygen (percentage of saturation), total phosphorus, sulfate, particulate organic carbon, and dissolved organic carbon. As no trend was apparent from the pattern of occurrence among stations, these differences very likely resulted from changes occurring at limited areas in the lake and did not have an apparent overall impact which could be attributed to any climatological differences among years.

Variables which varied significantly among years at two or more of the stations analyzed, however, were considered to be representative of more generalized phenomena and could have been related to the observed variations in climate.

Annual mean concentrations for Year 1 were significantly lower than those of years 2 and 3 for several variables. For total alkalinity, turbidity, molybdate-reactive silica, and total

Table 4.—Summary of variables showing significant differences among study years at four representative stations in Lake Sangchris. Year 1 was September 1973–August 1974; Year 2, September 1974–August 1975; and Year 3, September 1975–April 1976. Any two means underscored by the same line are not significantly different by the modified new Duncan multiple-range test (0.05 level). Data are presented only for those years and variables showing significant differences.

Variable	Station 2 (0 m)				Station 3 (0 m)				Station 4 (0 m)				Station 7 (0 m)			
	n	Year 1	Year 2	Year 3	n	Year 1	Year 2	Year 3	n	Year 1	Year 2	Year 3	n	Year 1	Year 2	Year 3
Dissolved oxygen (percent of saturation)									44	104.0	101.7	90.9				
Total alkalinity (as $CaCO_3$)	42	86	93	92	45	85	93	91	45	86	93	90				
Total dissolved ionizable solids (as NaCl)	42	302	335	367	45	299	334	370	45	308	333	371				
EDTA hardness (as $CaCO_3$)	42	170	198	230	45	167	196	230	45	168	199	231	43	152	193	224
Turbidity (JTU)	42	12	27	26	45	12	26	24	45	16	43	31	43	23	57	31
Total phosphorus (as P)					45	0.182	0.132	0.133								
Soluble orthophosphate (as P)	42	0.041	0.012	0.017	45	0.037	0.016	0.018								
Nitrate (as N)	42	2.55	1.49	0.33	45	2.33	1.50	0.34	45	2.41	1.50	0.32	43	2.96	2.16	0.42
Total nitrogen (as N)	42	3.09	2.25	0.90	45	2.81	2.11	0.85	44	2.89	2.24	0.86	43	3.59	2.86	0.98
Sulfate (as S)	42	59.6	41.6	48.9												
Particulate organic carbon													40	5.1	3.7	2.4
Dissolved organic carbon													40	2.1	9.5	10.0
Molybdate-reactive silica (as SiO_2)					43	2.93	3.67	4.15	44	3.13	3.97	4.31				
		Year 1	Year 3	Year 2												
Total organic carbon	40	9.7	12.4	14.9	43	8.3	13.7	12.2	44	8.5	13.1	12.2	40	7.2	13.2	12.4
						Year 1	Year 3	Year 2		Year 1	Year 3	Year 2				
Ammonia (as N)					45	0.07	0.07	0.11	45	0.07	0.07	0.13				

organic carbon, the annual mean concentrations observed for Year 1 were significantly lower than for either Year 2 or 3 at two or three stations. For soluble orthophosphate, however, Year 1 was significantly higher than the other 2 study years. In 1973, rainfall was approximately 33 cm above normal, and it was over 13 cm above normal for 1974. Overall, there would be a diluting effect if lake levels were high. For soluble orthophosphate, however, the opposite could be true. Higher runoff rates would ultimately increase soluble orthophosphate concentrations in the surface runoff.

Lower-than-normal precipitation during 1976 had a significant impact upon nitrogen concentrations in the lake. Mean annual concentrations of nitrate and total nitrogen for Year 3 were significantly lower than for years 1 and 2. Although field portions of the study terminated in April, drought conditions experienced through late spring and summer, 1976, would not have increased the nitrogen concentrations substantially. Since nitrogen transport to water is bound with the cycle of rainfall, nitrogen delivery to Lake Sangchris from non-point sources would decrease with decreases in total annual precipitation.

The annual mean concentrations observed for total dissolved ionizable solids and EDTA hardness were statistically distinct from one another for the 3 study years. With excess precipitation for 1973, Year 1 values would be low as a result of dilution, with Year 2 values closely approximating the "normal" cycle, and those for Year 3 representing only two-thirds of a yearly cycle during a period of below-average precipitation. Annual mean concentrations of ammonia for Year 2 were significantly higher than for years 1 and 3. Dilution from high water levels was a contributing factor in Year 1, and the time of year represented by Year 3 corresponded to the time of year when nitrate predominates in Lake Sangchris. Ammonia and organic nitrogen concentrations increase during late summer.

RELATIONSHIPS AMONG VARIABLES

Eight variables in the Model I one-way analysis of variance exhibited no significant differences among stations and depths. These included total alkalinity, EDTA hardness, total dissolved ionizable solids, nitrate, nitrite, total nitrogen, chloride, and molybdate-reactive silica (Table 5). With the possible exception of water temperature, depth and location in the Lake Sangchris basin rather than any thermal effect appeared to influence the concentrations of variables showing significant differences among stations. Variables where depth seemed to be the determining factor included dissolved oxygen, both as concentration and expressed as percentage of saturation; free carbon dioxide; hydrogen ion concentration; turbidity; total phosphorus; total iron; and forms of organic carbon. Concentrations of most other variables remained at reasonably constant levels throughout the year.

Forms of nitrogen followed a predictable annual cycle in Lake Sangchris (Fig. 2 and 3). Total nitrogen remained reasonably constant through autumn, increasing in winter during January and February. Nitrate, the principal nitrogen form throughout the year except in late summer and autumn, fell to barely detectable concentrations during late September, October, and November, coincident with the late summer-early autumn population peaks of blue-green algae. During this period organic nitrogen was the principal nitrogen form in Lake Sangchris. This phenomenon was observed in 1973 with populations of *Oscillatoria geminata* and *Raphidiopsis curvata* and was repeated in 1974 with populations of *O. geminata* and *Agmenellum quadruplicatum*. When populations of algae had decreased to winter lows by December, nitrate concentrations began to increase at most stations. Releases of nitrogen from declining phytoplankton populations were not entirely responsible for the observed winter increases in nitrogen concentrations. Since nitrogen is readily leached from soil by percolation and runoff, increases in nitrogen concentration during late winter and spring are normal in lakes surrounded by agricultural land.

Nitrogen contributions to Lake

Table 5.—Relationships among 3-year mean concentrations of physical and chemical variables at stations in Lake Sangchris, September 1973–April 1976. Any two or more means underscored by the same line are not significantly different (0.05 level). The number of observations for each variable at each station is shown in Table 2. Where station numbers and depths are not given, read those for the preceding variable.

Variable	Station and Depth											
	3 (10 m)	1 (0 m)	2 (0 m)	7 (5 m)	2 (5 m)	1 (5 m)	7 (0 m)	3 (5 m)	3 (0 m)	4 (5 m)	4 (0 m)	5 (0 m)
Temperature (C)	14.97	15.23	15.26	15.26	15.40	15.63	16.33	16.57	16.80	17.48	19.90	21.67
	3 (10 m)	4 (5 m)	1 (5 m)	3 (5 m)	7 (5 m)	2 (5 m)	5 (0 m)	4 (0 m)	3 (0 m)	2 (0 m)	1 (0 m)	7 (0 m)
Dissolved oxygen	6.13	6.98	7.18	7.49	7.89	8.09	9.49	9.62	9.66	9.92	10.13	10.32
	3 (10 m)	4 (5 m)	1 (5 m)	3 (5 m)	7 (5 m)	2 (5 m)	2 (0 m)	3 (0 m)	1 (0 m)	4 (0 m)	5 (0 m)	7 (0 m)
Dissolved oxygen (percent of saturation)	58.32	69.79	70.22	73.87	76.93	77.59	95.96	96.64	97.79	101.0	101.8	102.0
	3 (0 m)	4 (0 m)	5 (0 m)	3 (5 m)	7 (0 m)	2 (0 m)	7 (5 m)	1 (5 m)	4 (5 m)	1 (0 m)	2 (5 m)	3 (10 m)
Free carbon dioxide	1.6	1.7	1.7	1.9	2.0	2.0	2.0	2.2	2.3	2.3	2.3	3.5
	3 (10 m)	4 (5 m)	2 (5 m)	1 (5 m)	1 (0 m)	3 (5 m)	5 (0 m)	4 (0 m)	7 (5 m)	2 (0 m)	3 (0 m)	7 (0 m)
Hydrogen ion concentration (*p*H)	7.82	7.88	7.94	7.94	7.95	7.98	8.00	8.02	8.03	8.05	8.08	8.11
	1 (0 m)	1 (5 m)	2 (0 m)	2 (5 m)	3 (0 m)	3 (5 m)	3 (10 m)	4 (0 m)	4 (5 m)	5 (0 m)	7 (0 m)	7 (5 m)
Total alkalinity (as $CaCO_3$)	89.1	89.3	89.1	89.0	88.4	88.6	93.2	88.5	88.6	89.0	86.4	88.0
EDTA hardness (as $CaCO_3$)	182.6	183.9	189.1	188.2	186.0	186.5	187.4	187.4	185.4	184.3	174.0	176.4
	1 (0 m)	1 (5 m)	2 (0 m)	2 (5 m)	3 (0 m)	3 (5 m)	3 (10 m)	4 (0 m)	4 (5 m)	5 (0 m)	7 (0 m)	7 (5 m)
Total dissolved ionizable solids (as NaCl)	314.6	312.3	323.8	321.5	321.2	322.3	321.2	326.0	321.6	325.2	305.7	311.1
Nitrate (as N)	1.811	1.823	1.824	1.825	1.755	1.782	1.747	1.797	1.830	1.781	2.341	2.308
Nitrite (as N)	0.141	0.136	0.139	0.143	0.143	0.154	0.153	0.130	0.152	0.130	0.138	0.154
	7 (0 m)	5 (0 m)	3 (0 m)	5 (2 m)	2 (0 m)	2 (5 m)	3 (5 m)	4 (0 m)	1 (5 m)	7 (5 m)	1 (0 m)	3 (10 m)
Ammonia (as N)	0.074	0.079	0.080	0.081	0.081	0.086	0.088	0.088	0.089	0.101	0.108	0.183
	3 (0 m)	3 (5 m)	4 (0 m)	1 (5 m)	3 (10 m)	2 (5 m)	5 (0 m)	4 (5 m)	1 (0 m)	2 (0 m)	7 (5 m)	7 (0 m)
Organic nitrogen (as N)	0.298	0.312	0.315	0.317	0.326	0.330	0.342	0.352	0.359	0.388	0.414	0.424
Total nitrogen	2.275	2.335	2.359	2.351	2.409	2.384	2.324	2.415	2.418	2.431	3.009	2.976

Sangchris from nonpoint sources were estimated to be 250,975 kg N yr⁻¹, 99.49 percent of the total nitrogen load (U.S. Environmental Protection Agency 1975*a*). Römkens, Nelson, & Mannering (1973) examined the nitrogen and

Table 5.—Continued.

Variable	Station and Depth											
	1 (0 m)	1 (5 m)	2 (0 m)	2 (5 m)	3 (0 m)	3 (5 m)	3 (10 m)	4 (0 m)	4 (5 m)	5 (0 m)	7 (0 m)	7 (5 m)
Chloride	23.67	23.82	24.13	24.38	24.72	24.69	24.55	24.67	24.54	24.27	24.10	24.08
	2 (0 m)	2 (5 m)	3 (0 m)	3 (5 m)	1 (0 m)	3 (10 m)	5 (0 m)	1 (5 m)	4 (0 m)	4 (5 m)	7 (0 m)	7 (5 m)
Total phosphorus (as P)	0.148	0.148	0.160	0.160	0.172	0.176	0.190	0.195	0.202	0.226	0.258	0.284
	3 (10 m)	2 (5 m)	4 (5 m)	3 (0 m)	2 (0 m)	3 (5 m)	5 (0 m)	1 (0 m)	1 (5 m)	4 (0 m)	7 (5 m)	7 (0 m)
Soluble orthophosphate (as P)	0.023	0.025	0.028	0.028	0.028	0.028	0.029	0.030	0.034	0.038	0.058	0.053
	3 (0 m)	2 (0 m)	3 (5 m)	2 (5 m)	1 (0 m)	3 (10 m)	5 (0 m)	1 (5 m)	4 (0 m)	4 (5 m)	7 (0 m)	7 (5 m)
Turbidity (JTU)	17.93	18.81	20.00	20.67	20.96	23.53	23.93	25.65	25.93	31.22	32.70	37.26
	3 (0 m)	2 (0 m)	3 (5 m)	2 (5 m)	1 (0 m)	5 (0 m)	1 (5 m)	4 (0 m)	3 (10 m)	7 (0 m)	4 (5 m)	7 (5 m)
Total iron	0.527	0.528	0.571	0.584	0.626	0.770	0.815	0.825	0.844	1.04	1.12	1.38
	3 (0 m)	3 (10 m)	4 (0 m)	2 (0 m)	3 (5 m)	4 (5 m)	2 (5 m)	5 (0 m)	1 (0 m)	7 (0 m)	7 (5 m)	1 (5 m)
Soluble iron	0.031	0.033	0.035	0.038	0.039	0.043	0.046	0.052	0.055	0.055	0.070	0.076
	7 (5 m)	7 (0 m)	1 (5 m)	3 (10 m)	4 (0 m)	1 (0 m)	4 (5 m)	3 (5 m)	5 (0 m)	3 (0 m)	2 (0 m)	2 (5 m)
Sulfate (as S)	42.44	45.45	49.03	50.62	50.83	50.85	50.98	51.00	51.35	51.48	52.43	52.92
	3 (5 m)	7 (0 m)	4 (5 m)	5 (0 m)	4 (0 m)	3 (0 m)	7 (5 m)	2 (5 m)	3 (10 m)	2 (0 m)	1 (5 m)	1 (0 m)
Total organic carbon	9.18	9.58	10.25	10.40	10.41	10.43	10.79	11.01	11.34	11.68	16.54	18.56
	4 (5 m)	3 (5 m)	3 (0 m)	5 (0 m)	4 (0 m)	2 (0 m)	3 (10 m)	2 (5 m)	7 (0 m)	7 (5 m)	1 (5 m)	1 (0 m)
Particulate organic carbon	1.91	2.11	2.39	2.52	2.59	2.64	3.39	3.40	4.24	4.62	7.92	9.57
	7 (0 m)	7 (5 m)	3 (10 m)	2 (5 m)	4 (0 m)	5 (0 m)	3 (5 m)	3 (0 m)	4 (5 m)	1 (5 m)	1 (0 m)	2 (0 m)
Dissolved organic carbon	5.34	6.17	7.96	7.62	7.82	7.88	7.07	8.01	8.34	8.60	8.99	9.04
Molybdate-reactive silica (as SiO_2)	4.08	3.64	3.79	3.53	3.58	3.13	3.35	3.36	3.45	3.61	3.35	3.41

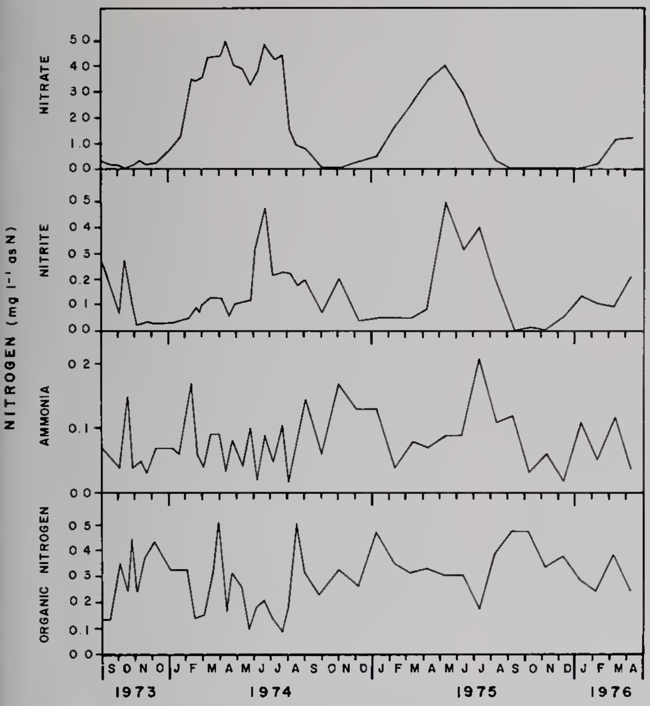

Fig. 2.—Concentrations of nitrogen in various forms observed at Station 3 (0 m) in Lake Sangchris.

phosphorus composition of surface runoff as affected by tillage methods. They compared five tillage-planting systems: coulter-plant, till-plant, chisel-plant, disk and coulter-plant, and conventional plant. The authors observed that the coulter and chisel systems controlled soil loss (reflected as turbidity or suspended solids in Lake Sangchris), but runoff contained high levels of soluble nitrogen

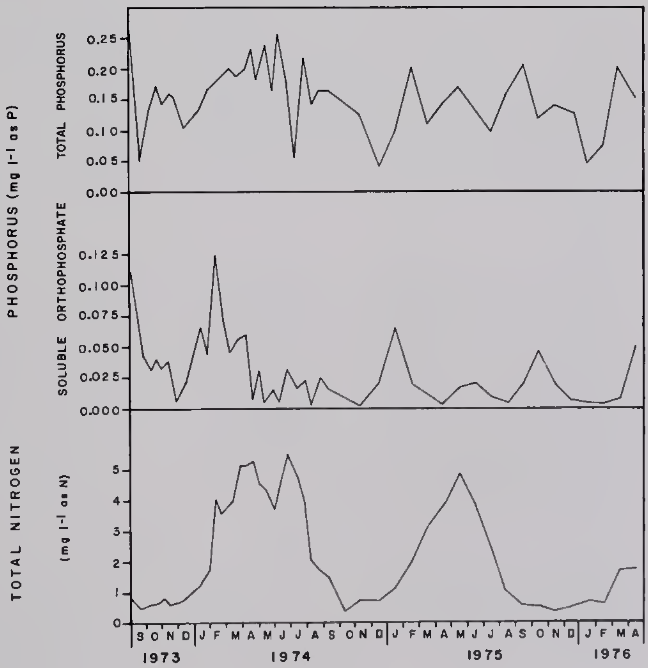

Fig. 3.—Forms of phosphorus and total nitrogen observed at Station 3 (0 m) in Lake Sangchris.

and phosphorus from surface-applied fertilizer. The disk and till systems were less effective in controlling soil erosion, but concentrations of soluble nitrogen and phosphorus were lower in runoff. Conventional tillage, in which fertilizers were plowed under, had the greatest soil and water losses but low losses of soluble nitrogen and phosphorus. However, high percentages of all nutrients removed by runoff were components of the sediments from all treatments.

They concluded that the differences in the nitrogen and phosphorus concentrations in the runoff sediments of the various tillage systems were due primarily to selective soil erosion, i.e., small colloidal particles were removed preferentially to the larger silt- and sand-sized particles. It would appear that nutrient input control in Lake Sangchris from nonpoint agricultural sources would be a double-edged sword: agricultural methods to control soil erosion would still contribute high concentrations of nitrogen and phosphorus, while nutrients would be controlled by methods which would not curtail soil erosion.

Concentrations of total phosphorus and total iron, which reflect the amount of suspended matter in the water, paralleled turbidity levels in Lake Sangchris. Concentrations of total phosphorus and soluble orthophosphate appeared to be quite similar within the cooling loop stations (stations 1 through 5), but concentrations for Station 7 on each corresponding date were frequently greater.

Total phosphorus concentrations appeared to increase gradually around the cooling loop from the intake arm (Station 1) to the point of discharge (Station 5). Superimposed upon this relationship are the higher concentrations observed at the deeper sampling depths and the concentrations observed at Station 7, which receives the Tovey municipal waste water (Table 2). The contribution of phosphorus from this effluent was estimated to be 35 kg P yr^{-1} or 0.9 percent of the total phosphorus load to Lake Sangchris (U.S. Environmental Protection Agency 1975*a*). The Kincaid Generating Station treatment plant was estimated to contribute 22 kg P yr^{-1} or 0.6 percent of the total phosphorus budget. To place these loadings in perspective, direct precipitation was estimated to contribute 4.8 percent of the total phosphorus budget, 190 kg P yr^{-1}.

These known point sources of phosphorus (Tovey and Kincaid Generating Station) contributed to the higher concentrations observed at stations 7 and 5, respectively. However, turbidity relationships (Table 5) followed the same general pattern as did phosphorus, suggesting that concentrations of suspended solids are of greater importance in predicting total phosphorus concentrations at various points in the lake than is the proximity to the known point sources.

Nonpoint agricultural sources contributed an estimated 3,915 kg P yr^{-1} to Lake Sangchris (U.S. Environmental Protection Agency 1975*a*, Table 6). This was 98.4 percent of the total phosphorus load. Römkens & Nelson (1974), in analyzing the phosphorus relationships in runoff from fertilized soils, concluded that the relation of the phosphorus addition rate to the soluble orthophosphate or sediment-extractable phosphorus level in runoff was approximately linear for the soils they tested. Their experimental design simulated the conditions commonly occurring in the spring in central Illinois: bare, wet soil subjected to the highly erosive potential of rainstorms.

Migratory waterfowl use Lake Sangchris as a rest and feeding area during autumn and winter. Sanderson & Anderson (1981) estimated that an average of 2.43 kg N (as N_2) and 1.37 kg P (as P_2O_5) per acre was contributed to the lake by these birds while in residence (October through March). Expressed as a concentration, 0.13 mg N $liter^{-1}$ and 0.03 mg P $liter^{-1}$ could be contributed to the lake by waterfowl.

Waterfowl are more abundant on the slag pond than on any other part of the lake. Excluding the nitrogen and phosphorus contributions added to the slag pond, the concentrations derived from waterfowl in the rest of Lake Sangchris could be 0.08 mg N liter^{-1} and 0.02 mg P liter^{-1}.

The impact of contributions of phosphorus and nitrogen from migratory waterfowl is difficult to isolate because the contributions occur when inputs are highest from fertilizer leaching and surface runoff (Fig. 3). The concentrations of 0.08 mg N and 0.02 mg P liter^{-1} would not be noticeable at that time of year. However, these contributions from migratory waterfowl would add approximately 5,425 kg N yr^{-1} and 1,320 kg P yr^{-1} to the lake.

Using the loading and accumulation data presented in Table 6, waterfowl contributions represent a 95.2-percent increase in P loading (to 2,707 kg yr^{-1}) and a 4.4-percent increase in N loading (to 128,500 kg yr^{-1}).

As discussed above, except at Station 5 (the discharge point), dissolved oxygen values, both as concentration and percentage of saturation, were significantly different with depth at all stations. These vertical gradients in dissolved oxygen were generally temporary and of short duration.

To illustrate this point, dissolved oxygen isopleths were drawn, using dissolved oxygen profile data from Station 3, the deepest portion of the lake and the site where chemical stratification would be most likely to occur. These isopleths are shown in Fig. 4.

Dissolved oxygen concentrations were occasionally below 5 mg liter^{-1} (for convenience, a heavier line in Fig. 4) from 1973 through 1975. These were generally of short duration, and concentrations below 3 mg liter^{-1} were rare. In May 1976, however, the combined effects of the power plant's being shut down and drought conditions appeared to have an effect upon the dissolved oxygen profiles. Lake Sangchris dissolved oxygen stratified at Station 3 in May 1976 and remained stratified through August 1976. While this stratification had been observed to some extent in previous years, low concentrations did not appear as early nor persist uninterrupted for so long.

It would appear that as long as the power plant is in operation, or at least

Table 6.—Annual total phosphorus and nitrogen loading to Lake Sangchris calculated for an average year (summarized from U.S. Environmental Protection Agency 1975*a*).

	Phosphorus		Nitrogen	
	kg P/Year	Percent of Total	kg N/Year	Percent of Total
Inputs				
Tributaries (nonpoint load)				
Clear Creek (eastern)	850	21.4	47,450	18.8
Unnamed creek	140	3.5	17,950	7.1
Unnamed creek	400	10.0	28,070	11.1
Clear Creek (western)	1,070	26.9	52,330	20.7
Minor tributaries and immediate drainage	1,265	31.8	93,375	37.0
Treatment plants				
Kincaid Generating Station	22[a]	0.6	705	0.3
Tovey pumphouse	35	0.9	400	0.2
Septic tanks	5	0.1	185	<0.1
Direct precipitation	190	4.8	11,800	4.7
Total from all sources	3,977	100.0	252,265	100.0
Outputs				
Clear Creek (lake outlet)	2,590		129,190	
Net annual accumulation	*1,387*		*123,075*	

[a] The contribution of Kincaid Generating Station's sewage treatment facility to the point source loading of Lake Sangchris should be 22 kg P/yr. Figures contained in the U.S. Environmental Protection Agency's (1975a) document are in error.

mechanically pumping and circulating the lake water, there will be vertical gradients in dissolved oxygen, especially in the deeper portions of the lake, but that those will be of short duration. Data for 1974 illustrate this point (Fig. 4). Concentrations changed rapidly and frequently. There were no long periods when the dissolved oxygen concentration in a substantial portion of the water mass was below 5 mg liter^{-1}.

WATER TEMPERATURE

The dispersion and elimination of waste heat from the Kincaid Generating Station and the effect of plant operation upon the annual water temperature regime is of particular interest in Lake

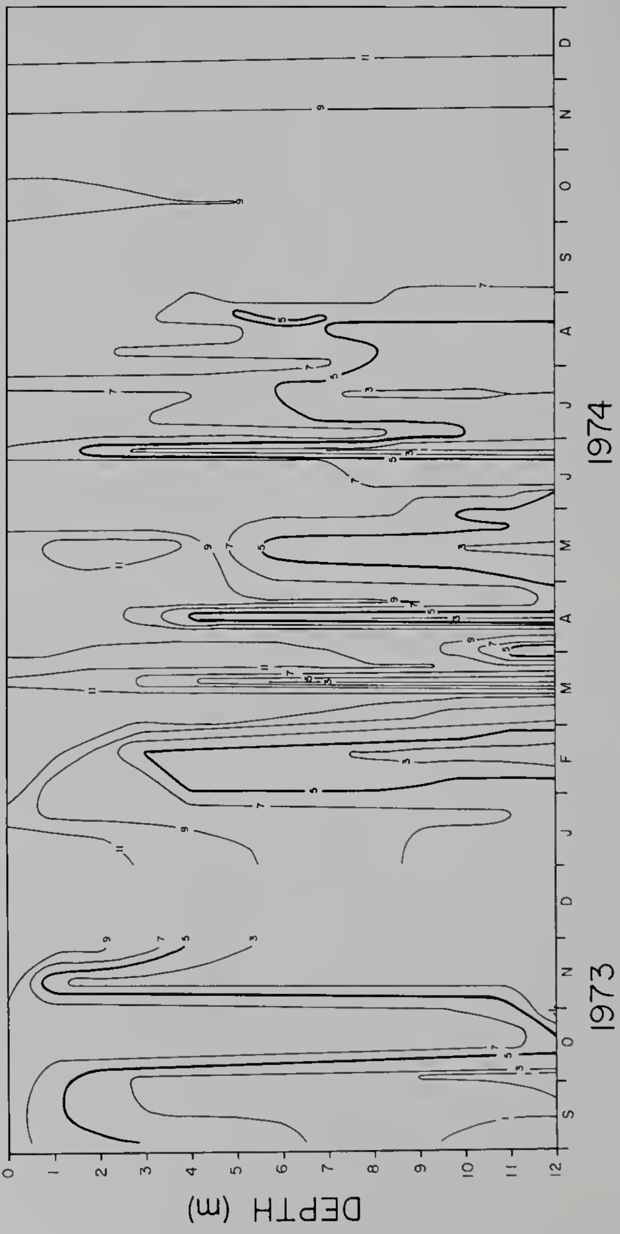

Fig. 4.—Isopleths of dissolved oxygen (mg liter^{-1}) at Station 3 in Lake Sangchris.

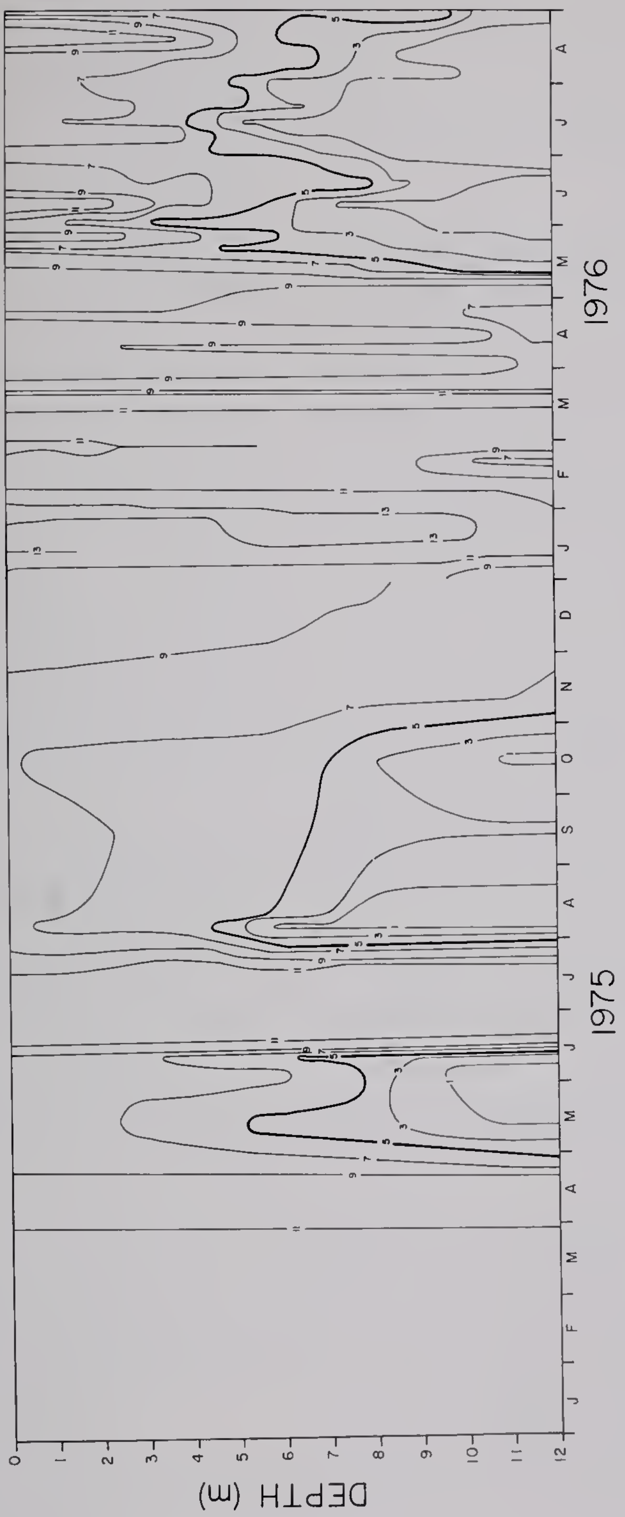

Fig. 4.—Continued.

Sangchris. One unusual aspect of power plant operation has been the general lack of thermal stratification in the lake during winter and summer. While vertical temperature gradients often occur, they are of short duration and do not correspond to true thermal stratification.

Thermal stratification is a phenomenon which implies *stability* while the lake is stratified, generally in summer and winter in Illinois. The thermocline, a region or layer where the temperature change is extremely rapid, prevents complete vertical mixing and separates the water column into two distinct layers: an epilimnion, which circulates throughout the ice-free period, and a hypolimnion, a cool bottom layer that can gradually become anoxic in eutrophic lakes.

An important consideration in determining whether thermal stratification can occur is the ratio between the depth of the water which can be mixed by the wind and the total depth. The depth of wind mixing is determined by surface area and the amount of exposure to wind (Golterman 1975). Once thermal stratification has become established, the stability is so great that no storm can disrupt it. This stability is the result of the density differences between the warm surface water and the cool subsurface water.

The vertical homogeneity of water temperature in Lake Sangchris is illustrated in Table 7. Only Station 4 demonstrated any significant temperature differences with depth. At all other sites sampled no significant differences were observed with depth for the 3-year period.

Inverse stratification occurred at Station 7 in the control arm during the period of ice cover. At most stations in Lake Sangchris, however, thermal stratification through winter was absent, and only temporary gradients were apparent.

Fig. 5 graphically illustrates surface water temperature relationships among sampling stations in the cooling loop of Lake Sangchris from the source of the heated water (Station 5) to the plant intake (Station 1) from September 1973 through September 1976. One hundred forty sets of water temperature profiles were taken during this period and were included in the figure. Stations are located vertically on the figure proportional to their distances from one another. Lines shown represent increases above the intake (ambient) water temperature (°C).

Several aspects of the water temperature regime are readily apparent from the figure. First, increases in water temperature were of greater magnitude during the first year (September 1973 through August 1974) than in subsequent years. During September, January through April, and June through August of the first year, there were considerable

Table 7.—Relationships among 3-year mean water temperatures (°C), illustrating significant differences with depth. Any two or more means underscored by the same line are not significantly different (0.05 level).

Station	n	0 m	1 m	2 m	3 m	4 m	5 m	6 m	7 m	8 m	9 m	10 m	11 m	12 m
1	1,052	16.3	16.3	16.2	16.2	16.3	16.1	15.9	15.6	8.9				
2	1,219	16.7	16.9	16.8	16.7	16.5	16.4	16.4	16.2	16.0	14.7	8.9	3.0	
3	1,683	17.6	17.9	17.8	17.6	17.4	17.2	17.0	16.7	16.3	15.8	15.4	14.9	14.7
A	1,308	18.7	18.8	18.5	18.1	17.7	17.4	17.0	16.7	16.4	16.2	13.4		
4	924	20.5	20.6	20.3	19.6	18.6	18.0	16.9	12.7	6.0				
B	593	21.7	21.9	21.8	21.7	20.7								
5	530	22.1	22.4	22.4	22.4	21.9	17.5							
7	973	16.5	17.1	16.9	16.7	16.5	16.2	15.5	15.5	12.6				

areas of the lake (to Station 4, Fig. 5) where observed water temperatures were greater than or equal to 9°C above intake water temperatures. Furthermore, there were intervals when water temperatures during September 1973 and January through April 1974 exceeded 11°C above intake water temperature. By comparison, throughout the remaining 2 years of study, there were only three occasions when discharge temperatures at Station 5 were 10°C or more above the intake water temperature. Increases of from 7° to 9°C above the intake water temperature were common.

As a result of scheduled maintenance and downtime, power plant operation was an on-off, off-on phenomenon during May, June, and portions of September, October, and November 1975 and roughly from February 1976 through the end of the study period

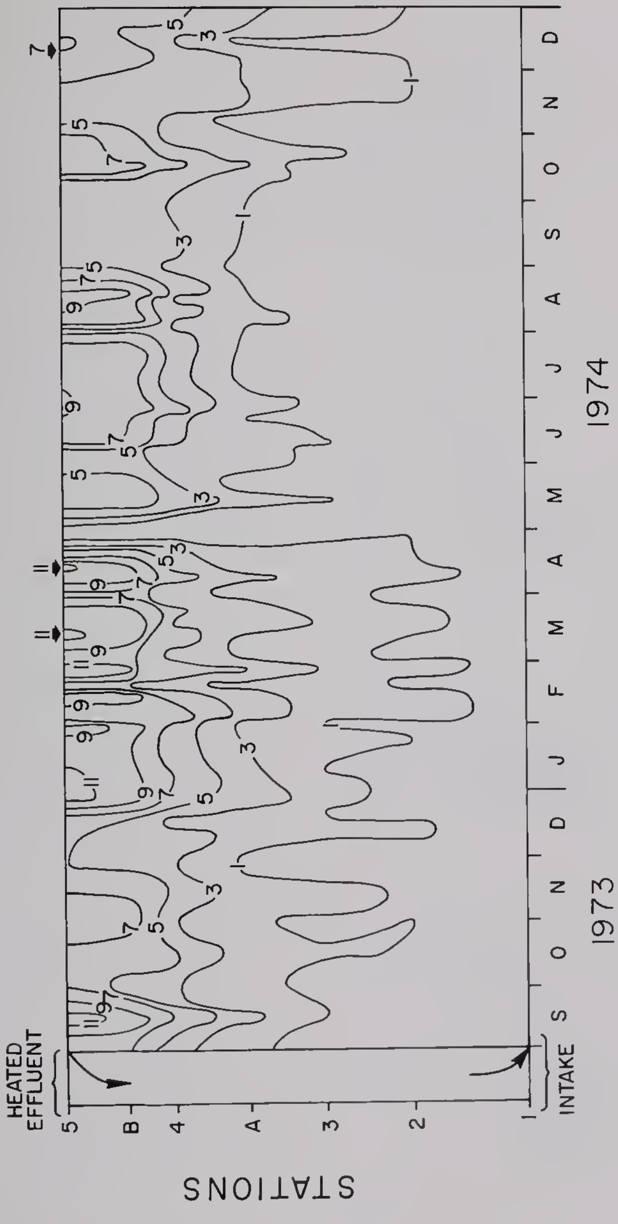

Fig. 5.—Surface water temperature relationships (ºC) among stations in Lake Sangchris.

(Larimore & Tranquilli 1981: Fig. 2). Although the plant was in operation during much of the 1976 spring, rapid changes in the isopleths reflect that this was not the

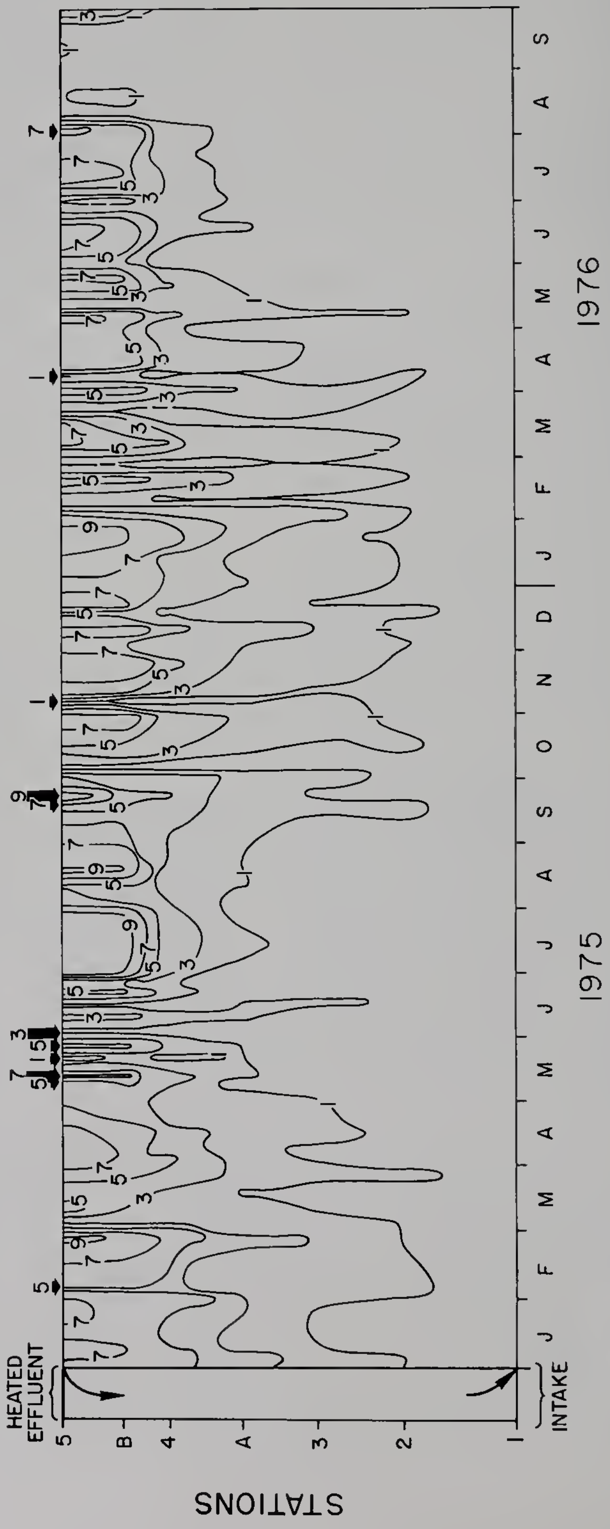

Fig. 5—Continued.

result of continuous operation as had occurred during the comparable time period in 1974. Finally, in late July 1976 heat additions to Lake Sangchris were stopped for the remainder of the summer.

Since May 1975 then, the thermal patterns in Lake Sangchris have been disrupted as a result of the off-on nature of plant operation, as illustrated by the 1 °C line. The 1 °C line (separating the areas greater than from those less than 1 °C above intake water temperature) moves from Station 5 in November 1975 to Station 2 by late November 1975 and back to Station 5 by late Feburary 1976. It bounces back and forth around the entire cooling loop, reflecting the interrupted nature of plant operation. Data interpretation during this period for any thermal effect would be very difficult.

Linear regressions with 0.001-level confidence intervals were calculated for the mean water temperature at each station (Y) against the mean intake water temperature (X) for the period September 1973 through August 1976 to determine whether there was any predictive value in the data. Could the water temperature at the plant intake be related to ambient water temperature?

Table 8 summarizes the equations derived from the linear regressions of mean water temperatures from stations 2 through 7 on that at Station 1. Fig. 6 illustrates the slopes and intercepts of the lines derived for the cooling-loop stations.

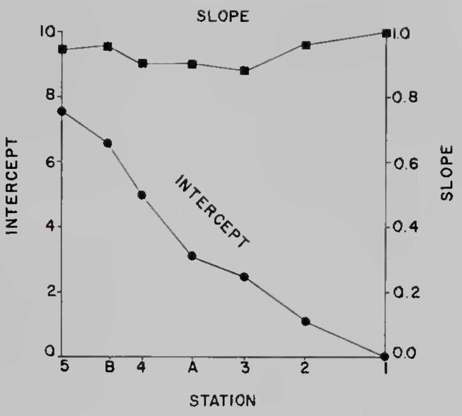

Fig. 6.—Slopes and intercepts of linear regressions of mean water temperatures at stations 1 through 5 on the mean water temperature at Station 1 in Lake Sangchris, September 1973–August 1976.

Proceeding around the cooling loop from plant intake to plant discharge, the observed water temperatures become less dependent upon intake or "ambient" water temperature. It therefore becomes increasingly difficult, based upon intake water temperature, to calculate the water temperature precisely as one proceeds around the cooling loop from Station 2 to Station 5.

Table 8.—Equations derived from linear regressions of mean water temperatures (°C) at stations 2 through 7 on the mean water temperature at Station 1.

Stations	Sept. 1973—Aug. 1976
1 & 2	Y = 0.961X + 1.07
1 & 3	Y = 0.878X + 2.51
1 & A	Y = 0.906X + 3.10
1 & 4	Y = 0.901X + 4.94
1 & B	Y = 0.954X + 6.58
1 & 5	Y = 0.934X + 7.45
1 & 7	Y = 1.062X − 1.34

The line relating the intercepts derived for the 3 years of water temperature data for the sampling stations (Fig. 6) in a simple, general way illustrates the cooling efficiency of Lake Sangchris. Based upon the equations derived from the 140 profiles taken over the 3-year period, approximately 66 percent of the added heat may be dissipated by the time the water mass moves approximately 57 percent of the distance around the cooling loop. Using the area of the cooling loop of Lake Sangchris without the areas of the bays (about 344 ha), the intercepts from the regression equations were plotted against cumulative lake area from Station 5 to the individual stations. Cooling efficiency appeared to be comparable to that derived by distance, reflecting the rather uniform channel that the cooling loop circuit travels. By the time the heated water mass had flowed through 50 percent of the cooling loop channel area, 66 percent of the heat had been dissipated.

These percentages are a general extraction from the entire water temperature data set for Lake Sangchris compiled over 3 years, including that period when power plant operation was disrupted, as has been described. The isopleths in Fig. 5 indicate the areas or distances that were required to cool water to the various temperatures above the intake (ambient) water temperature at any specific time period. While the area required for cooling at any one time is dependent upon power plant operating conditions and climatic conditions, in general most of the added heat is dissipated at least by the time the water mass has arrived near the vicinity of stations A or 3.

That only 50–60 percent of the cooling loop circuit might actually be needed for heat dissipation is further illustrated by the relationships existing among the 3-year mean concentrations for water temperature presented in Table 5. Station 4 appears to be the location which is an intergrade area. It is not distinct from the discharge point (Station 5), but the water has cooled somewhat so that Station 4 is not entirely distinct statistically from Station 3.

FUNCTIONAL RELATIONSHIPS AMONG WATER QUALITY VARIABLES

Each of the equations in Table 9 represents the best fit of Y on X for water temperature, dissolved oxygen (both as concentration and percentage of saturation), free carbon dioxide, hydrogen ion concentration (*p*H), total alkalinity, total dissolved ionizable solids, EDTA hardness, turbidity, and nitrate. These variables were selected to represent commonly performed field and laboratory procedures and to include the important variables in the lake. Each of these equations is significant at the 0.001 level.

EDTA hardness and nitrate each could be used to predict the concentrations of 13 other variables; total alkalinity, 11; and total dissolved ionizable solids, 10. The remaining variables could be used to predict the concentrations of seven or fewer variables.

Equations were developed for all 24 variables included in the data set. Based upon the 32-month data set for stations 1, 2, 4, and 7 (0 and 5 m), Station 5 (0 and 2 m), and Station 3 (0, 5, and 10 m), concentrations of the 24 variables could be predicted from hardness (13), water temperature (5), nitrate (3), total alkalinity (1), total dissolved ionizable solids (1), and turbidity (1), for example. Other combinations could be developed, however. As it is, most variables could be predicted from several equations. Any of six variables could be used to predict total phosphorus concentrations, for example.

The type of functional relationships developed varied importantly among the variables used to develop the equations. The equations developed using water temperature and dissolved oxygen as concentration were virtually all logarithmic, while the equations using dissolved oxygen (percentage of saturation), total alkalinity, total dissolved ionizable solids, EDTA hardness, and turbidity were all linear. Virtually all equations developed using free carbon dioxide and hydrogen ion concentration (*p*H) were exponential.

Equations were developed using the pooled data from the six stations identified above, and a calculated concentration would represent a likely concentration to be expected at any point in the lake. In more specific circumstances, equations could be developed for individual sites in Lake Sangchris or seasons to identify the probable outcome of various management strategies, such as the impact of raising or lowering lake water temperature upon dissolved oxygen. Even though the equations developed are functional, not cause-and-effect, relationships, the difference which might occur as a result of such a change could be predicted.

The value of this procedure is that a particular variable can be calculated from a number of other variables. For example, water temperature could be calculated from dissolved oxygen, free carbon dioxide, hydrogen ion concentration (*p*H), or EDTA hardness.

Table 9.—Significant regressions (0.001 level) from data pooled from stations 1 (0 and 5 m), 3 (0, 5, and 10 m), 5 (0 and 2 m), and 7 (0 and 5 m) in Lake Sangchris, September 1973 – April 1976.

Water Temperature

Dissolved oxygen: $Y = -0.219 \log X + 0.982$
Free carbon dioxide: $Y = -0.431 \log X + 0.484$
Hydrogen ion concentration (*p*H): $Y = 0.015 \log X + 0.951$
EDTA hardness: $Y = -0.069 \log X + 2.269$
Nitrite: $Y = 0.069 \log X + 0.046$
Chloride: $Y = -0.052 \log X + 1.398$
Molybdate-reactive silica: $Y = -0.126 \log X + 0.636$
where X = water temperature = $\log (X + 1)$
Y = variable = $\log (Y + 1)$

Dissolved Oxygen

Water temperature: $Y = 1.802 - 0.230\, e^{X}$
Dissolved oxygen (percentage of saturation): $Y = 0.708 \log X + 1.956$
EDTA hardness: $Y = 0.058 \log X + 2.263$
Total dissolved ionizable solids: $Y = 0.033 \log X + 2.502$
where X = dissolved oxygen = $\log (X + 1)$
Y = variable = $\log (Y + 1)$

Dissolved Oxygen (percentage of saturation)

Dissolved oxygen: $Y = 0.720\, X - 0.416$
EDTA hardness: $Y = 0.061\, X + 2.142$
where X = dissolved oxygen (percentage of saturation) = $\log (X + 1)$
Y = variable = $\log (Y + 1)$

Free Carbon Dioxide

Water temperature: $Y = -0.356\, e^{X} + 1.750$
Hydrogen ion concentration (*p*H): $Y = -0.029\, e^{X} + 0.999$
Ammonia: $Y = 0.020\, e^{X} + 0.007$
Total iron: $Y = -0.00006 \log X + 0.245$
Molybdate-reactive silica: $Y = 0.068\, e^{X} + 0.507$
where X = free carbon dioxide = $\log (X + 1)$
Y = variable = $\log (Y + 1)$

Hydrogen Ion Concentration (*p*H)

Water temperature: $Y = 1.728\, e^{X} - 3.293$
Free carbon dioxide: $Y = -3.862\, e^{X} + 10.44$
where X = hydrogen ion concentration (*p*H) = $\log (X + 1)$
Y = variable = $\log (Y + 1)$

Total Alkalinity

EDTA hardness: $Y = 0.794\, X + 0.712$
Total dissolved ionizable solids: $Y = 0.644\, X + 1.242$
Nitrate: $Y = -2.186\, X + 4.636$
Ammonia: $Y = 0.117\, X - 0.191$
Total nitrogen: $Y = -1.665\, X + 3.728$
Chloride: $Y = 0.881\, X - 0.326$
Total phosphorus: $Y = -0.189\, X + 0.445$
Soluble orthophosphate: $Y = -0.097\, X + 0.204$
Total iron: $Y = -0.709\, X + 1.620$
Soluble iron: $Y = -0.100\, X + 0.214$
Dissolved organic carbon: $Y = 1.209\, X - 1.492$
where X = total alkalinity = $\log (X - 1)$
Y = variable = $\log (Y + 1)$

LAKE SANGCHRIS AND THE NATIONAL EUTROPHICATION SURVEY

In its report on Lake Sangchris, the U.S. Environmental Protection Agency National Eutrophication Survey (1975*a*) concluded that Lake Sangchris ranked sixth among 31 lakes in overall trophic quality based upon a combination of six water quality variables (total phosphorus, dissolved phosphorus, inorganic nitrogen, chlorophyll *a*, Secchi disk

Table 9.—Continued.

EDTA Hardness

Water temperature: $Y = -0.924 X + 3.277$
Dissolved oxygen: $Y = 0.747 X - 0.738$
Dissolved oxygen (percentage of saturation): $Y = 0.582 X + 0.583$
Total alkalinity: $Y = 0.404 X + 1.037$
Total dissolved ionizable solids: $Y = 0.601 X + 1.141$
Nitrate: $Y = -1.162 X + 2.996$
Total nitrogen: $Y = -0.937 X + 2.597$
Chloride: $Y = 0.527 X + 0.200$
Total phosphorus: $Y = -0.179 X + 0.480$
Soluble orthophosphate: $Y = -0.081 X + 0.197$
Total iron: $Y = -0.455 X + 1.266$
Soluble iron: $Y = -0.062 X + 1.603$
Dissolved organic carbon: $Y = 1.037 X - 1.478$
where X = EDTA hardness = $\log (X + 1)$
Y = variable = $\log (Y + 1)$

Total Dissolved Ionizable Solids

Dissolved oxygen: $Y = 0.478 X - 0.246$
Total alkalinity: $Y = 0.373 X + 1.019$
EDTA hardness: $Y = 0.683 X + 0.554$
Nitrate: $Y = -1.273 X + 3.552$
Total nitrogen: $Y = -1.038 X + 3.074$
Chloride: $Y = 0.481 X + 0.191$
Total phosphorus: $Y = -0.134 X + 0.411$
Total iron: $Y = -0.409 X + 1.260$
Particulate organic carbon: $Y = -0.748 X + 2.430$
Dissolved organic carbon: $Y = 0.832 X - 1.210$
where X = total dissolved ionizable solids = $\log (X + 1)$
Y = variable = $\log (Y + 1)$

Nitrate

Total alkalinity: $Y = -0.010 \log X + 1.933$
EDTA hardness: $Y = -0.015 \log X + 2.234$
Total dissolved ionizable solids: $Y = -0.013 \log X + 2.477$
Nitrite: $Y = 0.011 \log X + 0.074$
Organic nitrogen: $Y = -0.008 \log X + 0.113$
Total nitrogen: $Y = 0.538 e^{X} - 0.333$
Chloride: $Y = -0.113 e^{X} + 1.562$
Total phosphorus: $Y = 0.030 e^{X} + 0.030$
Turbidity: $Y = 0.164 e^{X} + 1.073$
Total iron: $Y = 0.138 e^{X} + 0.028$
Soluble iron: $Y = 0.014 e^{X} - 0.002$
Total organic carbon: $Y = -0.033 \log X + 0.989$
Dissolved organic carbon: $Y = -0.057 \log X + 0.769$
where X = nitrate = $\log (X + 1)$
Y = variable = $\log (Y + 1)$

Turbidity

Nitrate: $Y = 0.251 X + 0.039$
Total nitrogen: $Y = 0.241 X + 0.161$
Chloride: $Y = -0.106 X + 1.532$
Total phosphorus: $Y = 0.047 X + 0.013$
Total iron: $Y = 0.224 X - 0.060$
Sulfate: $Y = -0.146 X + 1.884$
Molybdate-reactive silica: $Y = 0.326 X + 0.184$
where X = turbidity = $\log (X + 1)$
Y = variable = $\log (Y + 1)$

transparency, and dissolved oxygen profiles). Results of their chemical analyses were consistent with concentrations obtained during this investigation (Tables 10 and 11).

The profile of Lake Sangchris which emerged when the results from the 31 lakes investigated in Illinois were compared is that of a rather turbid, nitrogen-rich, phosphorus-limited lake.

Table 10.—The position of Lake Sangchris compared with 30 Illinois lakes for selected variables sampled in 1973 by the National Eutrophication Survey. Lakes are ranked by the eutrophication index, with the most eutrophic at the top (modified from U.S. Environmental Protection Agency 1975a).

Lake	Median Total Phosphorus	Median Inorganic Nitrogen	500 - Mean Secchi	Mean Chlorophyll a	15 - Minimum Dissolved Oxygen	Median Dissolved Ortho-phosphate
Cedar Lake	0.029	0.170	400.333	5.767	12.800	0.013
Baldwin Lake	0.044	0.140	461.167	11.333	13.200	0.007
Coffeen Lake	0.032	0.260	456.222	7.700	14.900	0.012
Rend Lake	0.071	0.210	471.500	23.533	12.700	0.012
East Loon Lake	0.076	0.120	450.000	22.300	14.900	0.018
Lake Sangchris	0.050	1.970	475.417	19.292	14.500	0.009
Lake Wematuk	0.069	1.770	466.333	7.967	14.500	0.031
Crab Orchard Lake	0.082	0.200	482.222	59.867	13.800	0.013
Lake Carlyle	0.084	1.270	477.889	17.367	11.000	0.032
Lake Shelbyville	0.062	3.290	461.333	17.161	14.800	0.019
Lake Story	0.072	2.510	459.333	17.250	14.800	0.021
Raccoon Lake	0.106	0.310	484.333	19.217	13.800	0.020
Lake Vandalia	0.116	0.480	478.111	11.278	14.800	0.023
Horseshoe Lake	0.127	0.705	482.833	182.250	6.800	0.018
Lake Marie	0.098	0.370	467.667	39.533	14.700	0.057
Lake Bloomington	0.050	5.730	464.667	26.200	14.800	0.020
Lake Springfield	0.108	3.265	483.385	13.013	10.800	0.059
Pistakee Lake	0.203	0.370	485.667	75.867	7.000	0.062
Lake Holiday	0.167	3.135	485.167	51.217	7.200	0.046
Grass Lake	0.301	0.820	481.000	83.500	5.900	0.093
Lake Lou Yaeger	0.186	1.600	489.583	10.662	11.400	0.076
Old Ben Mine Reservoir	0.930	0.205	478.333	31.433	11.200	0.575
Silver Lake (Highland)	0.226	0.970	489.500	5.822	14.800	0.057
Vermilion Lake	0.109	4.695	481.500	31.150	14.200	0.050
Lake Charleston	0.160	4.680	490.667	12.000	8.400	0.065
Fox Lake	0.219	0.375	486.167	63.850	8.800	0.083
Slocum Lake	0.865	0.200	487.333	221.100	5.800	0.362
Lake Decatur	0.129	3.750	479.571	43.000	14.500	0.062
Long Lake	0.704	1.190	482.667	49.333	8.800	0.398
Wonder Lake	0.426	0.890	486.000	98.533	7.800	0.132
Depue Lake	0.438	4.050	490.000	58.833	7.600	0.276

Of the 31 lakes studied, 26 lakes had higher median total phosphorus than Lake Sangchris, 29 had higher median dissolved orthophosphate, 9 had higher median inorganic nitrogen, 20 had greater mean Secchi disk transparencies, 17 had greater chlorophyll *a* concentrations, and only 8 had lower dissolved oxygen concentrations (Tables 10 and 12).

While these results were an important consideration in evaluating Lake Sangchris, results of algal assays yielded more pertinent information (U.S. Environmental Protection Agency 1975*a*). Despite the high total phosphorus loading (3,977 kg P yr^{-1}, Table 6), Lake Sangchris was described as phosphorus limited. Assayists obtained a significant increase in the yield of the assay alga *Selenastrum capricornutum* with the addition of phosphorus. The addition of nitrogen alone did not result in a significant difference in yield compared to that of the control. Their conclusions were substantiated by N:P ratios of 35:1 or greater. Consequently, while considerable phosphorus is present in Lake Sangchris (mean total phosphorus concentration in the lake of 0.205 ± 0.128 mg $liter^{-1}$; soluble orthophosphate, 0.035 ± 0.063 mg $liter^{-1}$), it does not appear to be abundant in a form that can be used directly by algae.

Lake Sangchris was estimated to have a net annual phosphorus accumulation of 1,387 kg and a net annual nitrogen accumulation of 123,075 kg (Table 6).

For comparison, Lake Springfield, used for cooling by the city-owned Lakeside Power Plant, has a net annual phosphorus accumulation of 7,430 kg and a net nitrogen accumulation of 376,595 kg (U.S. Environmental

Table 11.—Results of water quality sampling conducted by the staff of the National Eutrophication Survey at Lake Sangchris during 1973 (U.S. Environmental Protection Agency 1975a).

	7 May 1973			10 August 1973			18 October 1973		
Variable[a]	Range	Mean[b]	Median	Range	Mean[b]	Median	Range	Mean[b]	Median
Water temperature (°C)	16.5 – 18.9	17.8	18.3	24.3 – 32.2	29.4	29.2	18.8 – 22.4	20.6	20.2
Dissolved oxygen	7.8 – 8.8	8.4	8.2	0.5 – 8.4	6.0	6.9	7.2 – 8.8	7.6	7.4
Specific conductance (μmho/cm)	335 –380	371	380	353 –454	424	424	380 –418	399	399
Hydrogen ion concentration (pH)	8.0 – 8.1	8.0	8.0	7.2 – 8.9	8.3	8.3	7.9 – 8.4	8.0	8.0
Total alkalinity (as $CaCO_3$)	64 – 79	74	77	93 –105	98	97	88 – 94	91	91
Total phosphorus (as P)	0.079– 0.156	0.113	0.109	0.021– 0.134	0.045	0.042	0.035– 0.065	0.047	0.044
Soluble orthophosphate (as P)	0.023– 0.042	0.028	0.025	0.005– 0.011	0.007	0.006	0.005– 0.012	0.009	0.008
Nitrite + nitrate (as N)	4.25 – 4.51	4.31	4.30	1.67 – 2.00	1.89	1.91	0.10 – 0.32	0.27	0.29
Ammonia (as N)	0.07 – 0.14	0.09	0.08	0.03 – 0.39	0.08	0.05	0.03 – 0.06	0.04	0.04
Total Kjeldahl nitrogen (as N)	0.40 – 0.70	0.53	0.50	0.60 – 1.20	0.84	0.80	0.40 – 0.90	0.59	0.60
Inorganic nitrogen (as N)	4.33 – 4.60	4.40	4.39	1.88 – 2.06	1.97	1.97	0.14 – 0.36	0.31	0.33
Total nitrogen (as N)	4.65 – 5.01	4.84	4.84	2.54 – 3.00	2.73	2.73	0.68 – 1.19	0.86	0.82
Chlorophyll a (μg/liter)	2.5 – 4.3	3.2	3.1	26.6 – 48.8	39.0	40.3	12.4 – 22.3	15.6	13.9
Secchi depth (m)	0.1 – 0.3	0.2	0.2	0.7 – 0.9	0.8	0.9	0.9 – 0.9	0.9	0.9

[a] Shown as mg/liter unless other units are indicated.

[b] n = 4.

Table 12.—The percent of Illinois lakes sampled by the National Eutrophication Survey with higher concentrations or values than those of Lake Sangchris, followed by the number of lakes with higher concentrations or values (in parentheses). Lakes are ranked by eutrophication index, with the most eutrophic at the top (modified from U.S. Environmental Protection Agency 1975*a*).

Lake	Median Total Phosphorus	Median Inorganic Nitrogen	500 - Mean Secchi	Mean Chlorophyll a	15 - Minimum Dissolved Oxygen	Median Dissolved Ortho-phosphate	Index Number
Cedar Lake	100(30)	93(28)	100(30)	100(30)	50(15)	85(25)	528
Baldwin Lake	93(28)	97(29)	87(26)	80(24)	47(14)	100(30)	504
Coffeen Lake	97(29)	77(23)	93(28)	93(28)	2 (0)	92(27)	454
Rend Lake	77(23)	80(24)	70(21)	50(15)	53(16)	92(27)	422
East Loon Lake	70(21)	100(30)	97(29)	53(16)	2(0)	77(23)	399
Lake Sangchris	88(26)	30(9)	67(20)	57(17)	30(8)	97(29)	369
Lake Wematuk	80(24)	33(10)	77(23)	90(27)	30(8)	57(17)	367
Crab Orchard Lake	67(20)	90(27)	43(13)	20(6)	42(12)	85(25)	347
Lake Carlyle	63(19)	40(12)	63(19)	63(19)	63(19)	53(16)	345
Lake Shelbyville	83(25)	17(5)	83(25)	70(21)	13(2)	73(22)	339
Lake Story	73(22)	27(8)	90(27)	67(20)	13(2)	63(19)	333
Raccoon Lake	57(17)	73(22)	30(9)	60(18)	42(12)	68(20)	330
Lake Vandalia	47(14)	60(18)	60(18)	83(25)	13(2)	60(18)	323
Horseshoe Lake	43(13)	57(17)	37(11)	3(1)	93(28)	80(24)	313
Lake Marie	60(18)	68(20)	73(22)	37(11)	23(7)	42(12)	303
Lake Bloomington	88(26)	0(0)	80(24)	47(14)	13(2)	68(20)	296
Lake Springfield	53(16)	20(6)	33(10)	73(22)	67(20)	37(11)	283
Pistakee Lake	27(8)	68(20)	23(7)	13(4)	90(27)	32(9)	253
Lake Holiday	33(10)	23(7)	27(8)	27(8)	87(26)	50(15)	247
Grass Lake	17(5)	53(16)	50(15)	10(3)	97(29)	17(5)	244
Lake Lou Yaeger	30(9)	37(11)	7(2)	87(26)	57(17)	23(7)	241
Old Ben Mine Reservoir	0(0)	83(25)	57(17)	40(12)	60(18)	0(0)	240
Silver Lake (Highland)	20(6)	47(14)	10(3)	97(29)	13(2)	42(12)	229
Vermilion Lake	50(15)	3(1)	47(14)	43(13)	37(11)	47(14)	227
Lake Charleston	37(11)	7(2)	0(0)	77(23)	77(23)	27(8)	225
Fox Lake	23(7)	63(19)	17(5)	17(5)	72(21)	20(6)	212
Slocum Lake	3(1)	87(26)	13(4)	0(0)	100(30)	7(2)	210
Lake Decatur	40(12)	13(4)	53(16)	33(10)	30(8)	32(9)	201
Long Lake	7(2)	43(13)	40(12)	30(9)	72(21)	3(1)	195
Wonder Lake	13(4)	50(15)	20(6)	7(2)	80(24)	13(4)	183
Depue Lake	10(3)	10(3)	3(1)	23(7)	83(25)	10(3)	139

Protection Agency 1975*b*). As Lake Springfield is approximately 50 km from Lake Sangchris, the comparisons should be appropriate.

CONCLUSIONS

The general shallowness throughout most of the lake combined with the flow created by the pumping of water through the power plant kept the lake well mixed. At each sampling station except Station 3, five or fewer of the 30 physical and chemical variables analyzed demonstrated any significant differences (0.05 level) with depth.

Station 3, the broadest and deepest portion of Lake Sangchris, exhibited significant differences for 12 variables with depth. Most of these variables were those which one would expect to show such differences because of their relationships to vertical gradients of dissolved oxygen or to the differential settling of sediment particles.

Forms of nitrogen followed a predictable annual cycle in Lake Sangchris, with nitrate as the principal nitrogen form throughout the year except in late summer and autumn. At these times organic nitrogen predominated. This predominance was coincident with high population densities of blue-green algae. Winter increases in nitrogen in the lake were the result of declining phytoplankton populations and contributions from the watershed during times of high precipitation.

Nitrogen contributions to the lake from nonpoint sources were estimated to be approximately 250,000 kg N yr^{-1} or nearly 99.5 percent of the total nitrogen load.

Nonpoint agricultural sources contributed an estimated 3,915 kg P yr^{-1} or nearly 98.5 percent of the total phosphorus load. Point source contributions to the lake were minimal, represented chiefly by the Tovey and Kincaid Generating Station treatment plants.

Nutrient input control in Lake Sangchris from nonpoint agricultural sources would be difficult; agricultural methods to control soil erosion would still contribute high concentrations of nitrogen and phosphorus, while nutrients could be controlled by methods which would not curtail soil erosion.

With the possible exception of water temperature, depth and location in the Lake Sangchris basin rather than any thermal effect appeared to influence the concentrations of variables that showed significant differences among stations.

As long as the power plant is in operation, or at least mechanically pumping and circulating the lake water, there will be vertical gradients in dissolved oxygen, especially in the deeper portions of the lake, but these will be of short duration.

Of 31 lakes investigated by the U.S. Environmental Protection Agency National Eutrophication Survey, 26 lakes had higher median total phosphorus than Lake Sangchris had, 29 had higher median dissolved orthophosphate, 9 had higher median inorganic nitrogen, 20 had greater mean Secchi disk transparencies, 17 had greater mean chlorophyll *a* concentrations, and only 8 had lower dissolved oxygen concentrations. Data were collected during 1973.

Despite the high total phosphorus loading to the lake (nearly 4,000 kg P yr^{-1}), the National Eutrophication Survey concluded that Lake Sangchris was phosphorus limited. While there is considerable phosphorus in the lake, it does not appear to be abundant in a form that can be used directly by algae.

Increases in water temperature (above the ambient or intake water temperature) were of greater magnitude during the first study year (September 1973 through August 1974) than in subsequent years. Scheduled maintenance and downtime contributed to the on-off, off-on nature of heat additions to the lake during the last 2 study years.

During the first year of study, there were considerable areas of the lake where observed water temperatures were greater than or equal to 9°C above intake water temperatures. Furthermore, there were intervals when water temperatures during September 1973 and January through March 1974 exceeded 11°C above intake water temperature. In comparison, throughout the remaining 2 years of study, there were only three occasions when discharge water temperatures were 10°C or more above the intake water temperature. Increases of from 7° to 9°C above intake water temperature were common.

REFERENCES CITED

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1971. Standard methods for the examination of water and wastewater. 13th ed. American Public Health Association, Washington, D.C. 874 p.

Golterman, H. L. 1975. Physiological limnology. Elsevier Scientific Publishing Company, New York. 489 p.

Kramer, C. Y. 1956. Extension of multiple range tests to group means with unequal numbers of replications. Biometrics 12:307–310.

Larimore, R. W., and J.A. Tranquilli. 1981. The Lake Sangchris project. Pages 279–289 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

Römkens, M. J. M., and D. W. Nelson. 1974. Phosphorus relationships in runoff from fertilized soils. Journal of Environmental Quality 3(1):10–13.

———, ———, and J. V. Mannering. 1973. Nitrogen and phosphorus composition of surface runoff as affected by tillage method. Journal of Environmental Quality 2(2):292–295.

Sanderson, G. C., and W. L. Anderson. 1981. Waterfowl studies at Lake Sangchris, 1973–1977. Pages 656–690 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

U.S. Environmental Protection Agency. 1975*a*. Report on Sangchris Lake Christian County Illinois EPA Region V. U.S. Environmental Protection Agency Working Paper No. 314. Corvallis Environmental Research Laboratory, Corvallis. n. p.

———, 1975*b*. Report on Lake Springfield Sangamon County Illinois EPA Region V. U.S. Environmental Protection Agency Working Paper No. 317. Corvallis Environmental Research Laboratory, Corvallis. n. p.

Phytoplankton Dynamics in a Cooling-Water Reservoir

Robert L. Moran

ABSTRACT

Lake Sangchris is an 876-ha reservoir built between 1963 and 1966 as a cooling-water supply for a 1,232-megawatt coal-fired electric generating station. The constant circulation of water around the cooling loop of the lake prevented permanent stratification and maintained a high degree of spatial homogeneity in the phytoplankton. Condenser passage did not produce any differences among the phytoplankton communities in the intake and discharge canals although primary productivity was temporarily depressed when temperatures exceeded 30°C. The control arm had significantly higher productivity rates than the other two arms had and usually had the highest concentrations of phytoplankters, probably a result of the higher phosphorus concentrations in that area resulting from the effluent from the Tovey sewage treatment plant. A cluster analysis of the phytoplankton in the cooling loop, control arm, and five bays indicated that the entire lake was well mixed and quite homogeneous in the phytoplankters that it contained.

INTRODUCTION

Lake Sangchris is an 876-ha reservoir built between 1963 and 1966 as a cooling-water supply for Commonwealth Edison's 1,232-megawatt coal-fired Kincaid Generating Station. The lake is composed of three arms with a general north-south orientation (Fig. 1). The electric generating station lies between the western and middle arms and is connected to them by canals. The middle arm, receiving the thermal effluent, has been designated the discharge arm and contains stations 4, B, and 5. The western arm, which supplies the cooling-water intake, is referred to as the intake arm and contains stations 1 and 2. Together, these two arms and the main body of the lake, with stations A and 3, form the cooling loop. Complete circulation of the water mass can be accomplished within 11 days if all circulating water pumps are operating. The third, eastern, arm is not directly involved in the cooling loop flow; it has been named the control arm and contains Station 7.

The purpose of this study was to document the composition and dynamics of the phytoplankton in this reservoir and to determine what effects the operation of the Kincaid Generating Station and its thermal discharge had upon this community.

METHODS

SAMPLE COLLECTION AND PREPARATION

Samples of the phytoplankton were collected at stations 1, 2, 3, 4, 5, and 7 during the first 2 years and at stations 2, 4, and 7 during the third year. Samples were obtained with a 4.2-liter Kemmerer-style polyvinyl chloride (PVC) bottle and were returned to the lab in 1-gallon (3.785-liter) plastic bottles and kept under refrigeration overnight. Samples for microscopic examination during the first year of study were concentrated by settling 1-liter samples in 1-percent Lugol's solution for a minimum of 5 days. The supernatant was siphoned off with a J-shaped tube until 50–80 ml remained with the sediments. The sediments were further concentrated by centrifugation, and then the volumes

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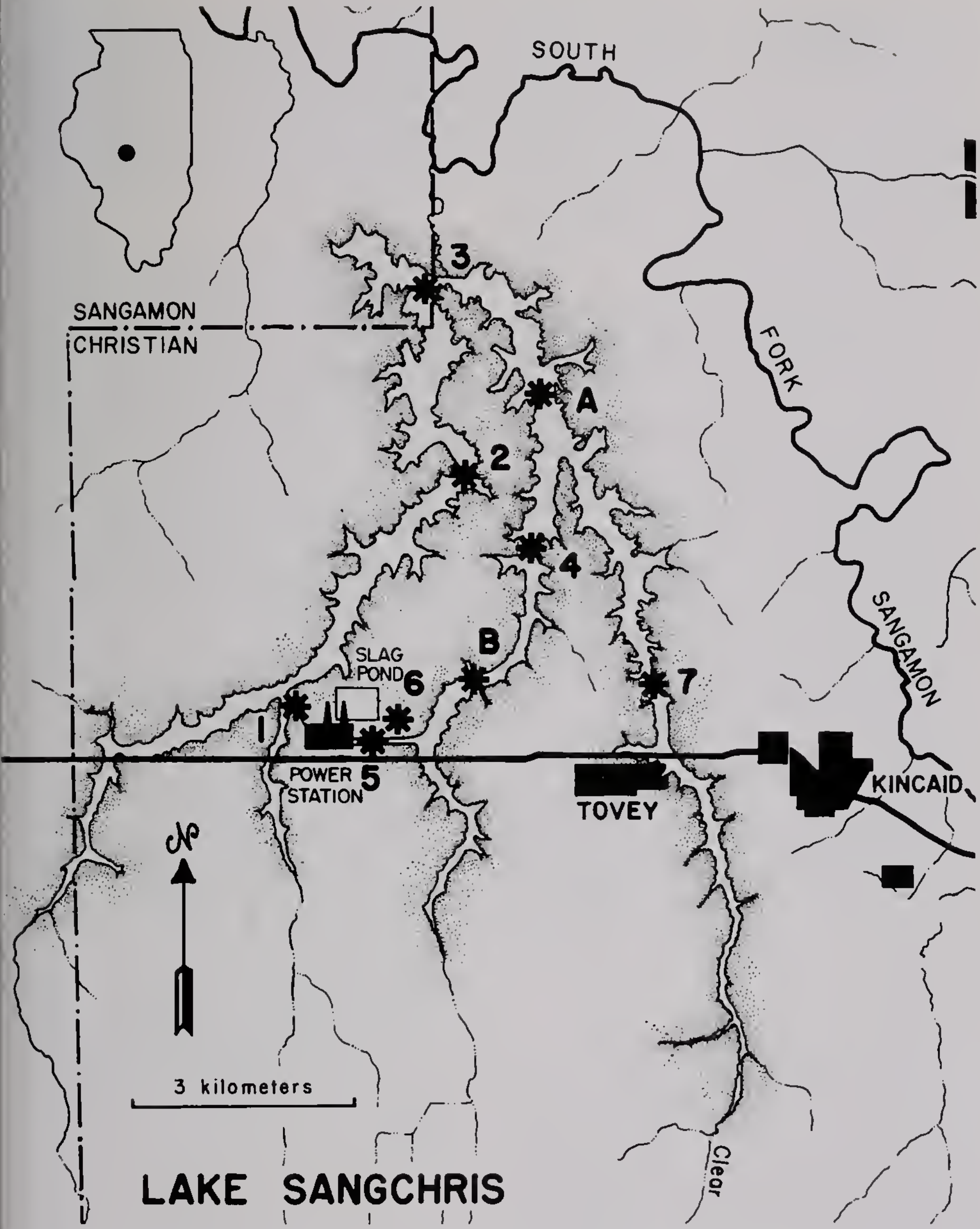


Fig. 1.—Lake Sangchris, a cooling lake in central Illinois, and its sampling stations.

were adjusted to an appropriate amount. During the second and third years, samples were concentrated by means of a Foerst centrifuge.

EXAMINING, COUNTING, AND IDENTIFYING SAMPLES

Samples were examined with a circular plankton counting chamber 0.6 mm deep, covered by a no. 1 cover slip. Counting and identification of the algae were accomplished with a Zeiss microscope using both bright field light and Nomarski differential interference contrast. All large phytoplankters that lay within two transects of the counting chamber under 160 X magnification were counted. Under 400 X magnification, all nanoplankton that lay within 20 visual fields was counted. If the count of the most common taxon did not total 100 individuals, 10 more random fields were examined. A unit or clump counting system, in which unicellular and colonial organisms were tallied as single units with equal numerical weight, was employed. Filamentous algae were counted in 50-micron units of length.

Total numbers of organisms per milliliter of lake water were than calculated from these counts. Diatoms were recorded separately at Centrales, *Melosira* spp., or Pennales during the initial counting. Final identifications were completed at 1,000 X magnification after the frustules were cleared, cleaned, and mounted in hyrax. The percentage composition for each species was determined, and the total number per milliliter was calculated. This method was based upon the procedures recommended in Palmer (1962) and Weber (1973). Beginning in May 1976, an improved system of counting was instituted following the procedure of Woelkerling et al. (1976). This method involved counting two optical fields or Whipple grids on each of 12 separately prepared slides. If 100 individuals of the most common taxon were not tallied, 10 more optical fields or Whipple grids were counted.

DETERMINING BIOVOLUMES

Biovolumes were determined by direct measurement of most of the phytoplankton species and by applying the appropriate formulas for the volumes of spheres, cylinders, cones, and cubes (Findenegg 1974). The volumes of species present too infrequently to permit the measurement of several individuals were calculated from the mean dimensions given in the taxonomic literature or as given by Nauwerck (1963) and Evans & Stockner (1972); $10^9\ \mu^3$ is equal to 1 μl.

PHOTOSYNTHETIC RATES

Photosynthetic rates were determined under natural conditions by using the ΔpH-CO_2 method (Verduin 1956) and the ΔO_2 method (Ryther 1956). Light-dark bottle experiments were performed, utilizing these two methods as well as the ^{14}C method (Vollenweider 1969). Two 300-ml glass stoppered BOD light bottles were suspended horizontally at each sampled depth along with a lightproof dark bottle.

CLUSTER ANALYSIS

A cluster analysis was performed on a collection of 64 samples taken 26 July 1976, when 20 mid-channel lake stations were sampled at 1 and 5 meters (or bottom), a total of 39 lake samples. Five bays, one in each major portion of the lake, each had five samples taken (25 bay samples) at a depth of 1 meter on a transect from the mouth of the bay inward. All samples were analyzed for patterns of distribution with a modified Jaccard coefficient of similarity (J. O. Church, Institute of Paper Chemistry, Appleton, WI, personal communication) and were graphically illustrated by a dendrogram.

LIGHT ATTENUATION

Light attenuation profiles and determinations of the light compensation point were made with a Montedoro-Whitney portable underwater solar illuminance meter, model LMD-8A.

EDDY DIFFUSION

Eddy diffusion coefficients were determined by measuring heat transported across a reference plane and applying the transport equation (Ruttner 1963):

$$S = A\,s'$$

Where

S = the heat (calories) transported through 1 cm^2 of the reference plane

s′ = the gradient (calories/cm) across the reference plane

A = the coefficient of eddy diffusion, cm^2/sec

Eddy diffusion was determined at 1-m intervals through the entire vertical water column.

SPECIES DIVERSITY

Species diversity (H′) was determined by using the Shannon-Wiener Index (Shannon & Weaver 1949), as recommended by Pielou (1975). The form of the expression used was:

$$H' = -\Sigma pi \ln pi$$

Where

pi = the proportion of the ith species to the total number of individuals in the community

An increase in the number of taxa or in the evenness of distribution of individuals among taxa will result in an increase in the index value.

The evenness of the species distributions (J) was also analyzed by the ratio of the species diversity indices (H′) to the maximum value possible for a community of the same size, such that:

$$J = H'/\ln S$$

Where

S = the total community size

This expression removes the effects of sample size upon the index value (Pielou 1975).

Relationships among parameters were determined through the use of the Student-Newman-Keuls multiple-range test (Zar 1974) modified to accept uneven group sizes. Significance was determined at the 0.05 level, and where "significance" is claimed, $P = 0.05$ level unless another level is indicated. Unless otherwise stated, the physical-chemical data are from Brigham (1981).

RESULTS AND DISCUSSION

PHOTIC ZONE

As a routine part of primary productivity measurements, the light compensation point was determined at those stations where current velocity did not preclude use of the submarine photometer. In all, 36 measurements were made at stations 2, 3, 4, and 7 (Table 1). The mean depth of the photic zone was 2.41 m, with Station 2 being somewhat more clear. The shallow photic zone at Station 7 was confirmed by the water chemistry data (Brigham 1981) which showed this station to have the highest 3-year mean turbidity level.

Table 1.—Mean light compensation point ($D_{0.01}$) in meters at four stations in Lake Sangchris. The numbers of samples are in parentheses.

Discharge- and Control-Arm Stations		Mean	Main-Body and Intake-Arm Stations	
4	7		3	2
1.85 (6)	2.16 (5)	2.41 (36)	2.42 (18)	3.09 (7)

EDDY DIFFUSIVITY

Measurements of eddy-diffusion coefficients (A) (Fig. 2) showed that within the upper 3 m the mean rates ranged from 1.65 to 9.01 cm^2/sec. Station 4 had the highest mean rates, while those of stations 2 and 7 were similar. Below 3 m Station 2 had the highest mean rates and Station 7 the lowest. Eddy diffusion coefficients of 0.02 – 0.15 cm^2/sec are typical of a thermocline (Csanady 1964 and Sweers 1970). In Lake Sangchris the lowest mean rate was 0.25 cm^2/sec, indicating that stable stratification of the water column did not develop. The constant circulation

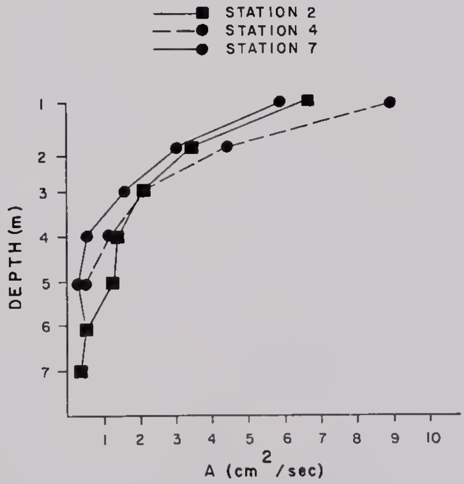


Fig. 2.—Eddy diffusion coefficients in the vertical water column at three stations in Lake Sangchris. Each point is the mean of seven to nine measurements taken during the spring, summer, and autumn of 1974, 1975, and 1976.

of water by the power plant was, undoubtedly, the most important factor in preventing seasonal stratification from developing.

SEASONAL PERIODICITY

In Lake Sangchris the seasonal abundance of phytoplankton generally followed a bimodal pattern, with late winter or spring pulses of diatoms and a late summer pulse of blue-green algae (Fig. 3 and 4 and Table 2). The periods separating these pulses were composed of mixed communities of green algae, diatoms, and sometimes blue-greens. The bimodal pattern of phytoplankton periodicity is typical of lakes experiencing nutrient depletion during the summer (Fogg 1975).

The first diatom pulse in this study occurred in April 1974 when *Melosira distans* v. *alpigena* and *M. italica* achieved concentrations of 5,000–7,000 units/ml and constituted about 50–60 percent of the phytoplankton community. *M. distans* v. *alpigena* declined more rapidly, so that by the end of April, *M. italica* was the principal species. The mean biovolume during this period was 1.1 µl/l.

In January–February 1975, *Synedra tenera* bloomed with concentrations as high as 16,800 units/ml. This pulse was of a magnitude similar to that of the previous *Melosira* pulse. The mean biovolume, however, was slightly higher, 1.4 µl/l, than in the *Melosira* bloom in April 1974.

In the January–April 1976 period, a pulse of a minute centric diatom, *Cyclotella pseudostelligera,* occurred with concentrations at times as high as 36,000 units/ml, accounting for as much as 75 percent of the total phytoplankton community. This species, in addition to being quite small, had very lightly silicified frustules. The mean biovolume during this period was about 1.4 µl/l.

In the late summer of each year the blue-green algae produced pulses with mean concentrations as high as 82,000 units/ml. Even though the average unit size was less than that of the other major groups, these blooms usually produced the seasonal biomass maximum.

At the beginning of this study, October 1973, a blue-green bloom was in decline, and the principal component at that time was *Oscillatoria geminata.* The average density was about 6,000

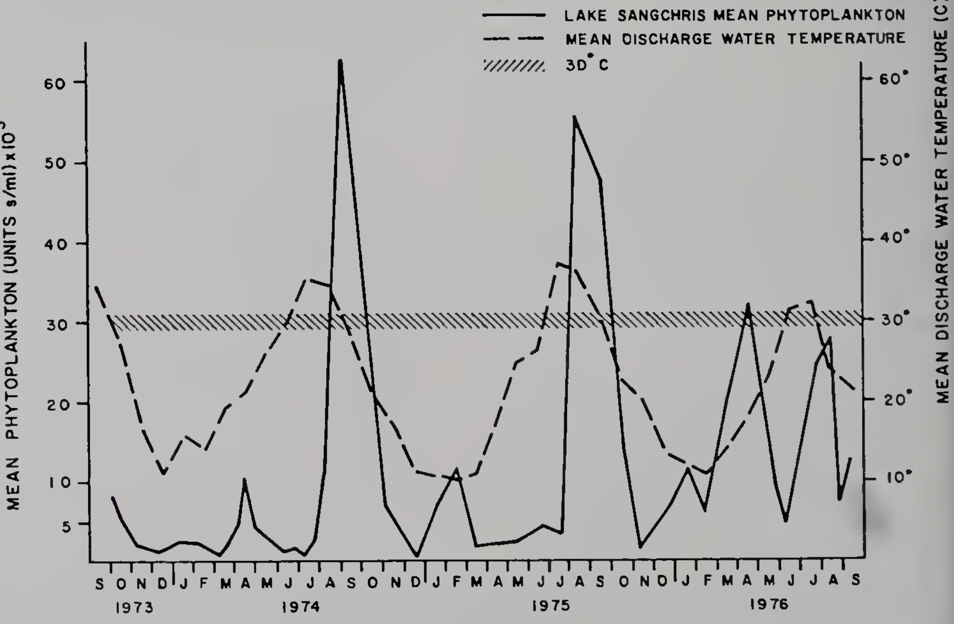


Fig. 3.—Mean numbers of phytoplankters (units/ml) and mean temperatures in the discharge arm in Lake Sangchris, 9 October 1973—9 September 1976.

units/ml, and the mean biovolume was about 1.2 µl/l. The following year, August–October 1974, the pulse (22,804 units/ml) was initially composed primarily of *O. geminata* and *Raphidiopsis curvata*, 70 and 20 percent, respectively, with the biovolume being 2.9 µl/l. In September–October the

Table 2.—Phytoplankton communities in Lake Sangchris, October 1973–August 1976.

Period	Type	Mean Density (No./ml)	Mean Biovolume (µl/1)	Major Components	Percent
October 1973	Diatom-Blue-green	5,946	1.2	*Melosira distans* var. *alpigena*	20.7
				Oscillatoria geminata	12.8
				Synedra tenera	3.8
				Cyclotella pseudostelligera	1.4
				Synedra acus	1.3
				Melosira granulata var. *angustissima*	1.2
				Nitzschia sp.	0.9
November 1973–March 1974	Green-Diatom	1,826	0.2	*Monoraphidium contortum*	34.0
				Melosira distans var. *alpigena*	26.9
				M. italica	9.3
				Selenastrum westii	8.2
April 1974	Diatom	6,475	1.1	*Melosira italica*	60.5
				M. distans var *alpigena*	37.1
				Cyclotella pseudostelligera	7.7
May–July 1974	Diatom	1,904	0.5	*Nitzschia kuetzingiana*	13.1
				Melosira italica	12.4
				M. distans var. *alpigena*	7.3
				Nitzschia sp.	4.8
				N. palea	4.5
				Stephanodiscus astrea var. *minutula*	4.3
				Synedra tenera	3.7
				Cyclotella pseudostelligera	2.3
				Nitzschia acicularis	1.6
August 1974	Blue-green	22,804	2.9	*Oscillatoria geminata*	70.2
				Raphidiopsis curvata	19.7
				Nitzschia sp.	0.9
September October 1974	Blue-green	43,634	3.6	*Agmenellum quadruplicatum*	42.2
				Oscillatoria geminata	36.8
				O. limnetica	4.8
				Raphidiopsis curvata	3.2
				Synedra tenera	2.2

mean density increased to 43,634 units/ml. The dominant species changed to *Agmenellum quadruplicatum* and *O. geminata,* 42 and 37 percent, respectively, and the biovolume increased to 3.6 µl/l.

In August–October 1975, the pulse began with *O. geminata, R. curvata,* and

Table 2.—Continued.

Period	Type	Mean Density (No./ml)	Mean Biovolume (µl/1)	Major Components	Percent
November–December 1974	Transitional	3,931	0.4	*Agmenellum quadruplicatum*	49.9
				Monoraphidium contortum	10.3
				Synedra tenera	9.8
				Anacystis marina	5.8
				Melosira distans var. *alpigena*	3.6
				Nitzschia acicularis	2.0
				Nitzschia sp.	1.2
				N. palea	0.6
January–February 1975	Diatom-Green	8,997	1.4	*Synedra tenera*	65.4
				Monoraphidium irregulare	26.2
				Synedra sp.	2.5
March 1975	Green-Diatom	1,854	0.1	*Monoraphidium contortum*	60.7
				Synedra tenera	3.2
				Melosira distans var. *alpigena*	2.5
				M. italica	1.7
April–July 1975	Diatom	3,148	0.6	*Melosira distans* var. *alpigena*	23.3
				Monoraphidium contortum	5.2
				Nitzschia acicularis	4.4
				Synedra tenera	4.0
				Nitzschia palea	2.2
				Nitzschia sp.	0.8
				Cyclotella pseudostelligera	0.6
August 1975	Blue-green	55,372	5.8	*Oscillatoria geminata*	52.8
				Raphidiopsis curvata	29.2
				Agmenellum quadruplicatum	2.5
September–October 1975	Blue-green	30,786	0.9	*Agmenellum quadruplicatum*	80.0
				Anacystis incerta	3.0
November–December 1975	Transitional	4,189	1.4	*Cyclotella pseudostelligera*	47.8
				Monoraphidium contortum	15.6
				Anacystis incerta	6.3
				Stephanodiscus astrea var. *minutula*	3.4
				Synedra tenera	2.0
				Cyclotella stelligera	1.4

A. quadruplicatum, 50, 29, and 2.5 percent, respectively. The mean density during August was 55,372 units/ml, and the mean biovolume was 5.8 μl/l. Again *A. quadruplicatum* became the most common species in September, accounting for about 82 percent of the phytoplankton community and for about

Period	Type	Mean Density (No./ml)	Mean Biovolume (μl/1)	Major Components	Percent
				Melosira distans var. *alpigena*	1.4
				Nitzschia tryblionella var. *victoriae*	1.4
				Agmenellum quadruplicatum	0.5
				Trachelomonas volvocina	0.5
				Scenedesmus quadricauda	0.3
January–April 1976	Diatom-Green	18,440	1.4	*Cyclotella pseudostelligera*	65.5
				Cyclotella sp.	6.2
				Monoraphidium contortum	3.0
				Nitzschia acicularis	2.0
				Melosira distans var. *alpigena*	1.3
May–June 1976	Transitional	6,887	2.6	*Anacystis incerta*	16.5
				Synedra tenera	11.9
				Oscillatoria limnetica	8.5
				Cyclotella stelligera	5.9
				Melosira distans var. *alpigena*	5.6
				Cyclotella pseudostelligera	4.8
				Monoraphidium contortum	2.4
				Nitzschia acicularis	1.6
				Monoraphidium dybowskii	1.5
				Stephanodiscus astrea var. *minutula*	1.4
				Nitzschia kuetzingiana	1.3
				N. tryblionella var. *victoriae*	1.1
July–12 August 1976	Blue-green	26,082	3.1	*Raphidiopsis curvata*	26.9
				Oscillatoria geminata	26.3
				Synedra tenera	8.7
				Anacystis incerta	4.9
				Oscillatoria limnetica	3.6
				Nitzschia acicularis	0.9
24 August–9 September 1976	Blue-green	9,722	0.9	*Agmenellum quadruplicatum*	21.3
				Raphidiopsis curvata	16.5
				Oscillatoria geminata	10.7
				Synedra tenera	4.4
				Oscillatoria limnetica	2.7
				Nitzschia cf. *gracilis*	2.2
				Cyclotella atomus	1.7
				Melosira distans var. *alpigena*	0.7
				Lyngbya contorta	0.5

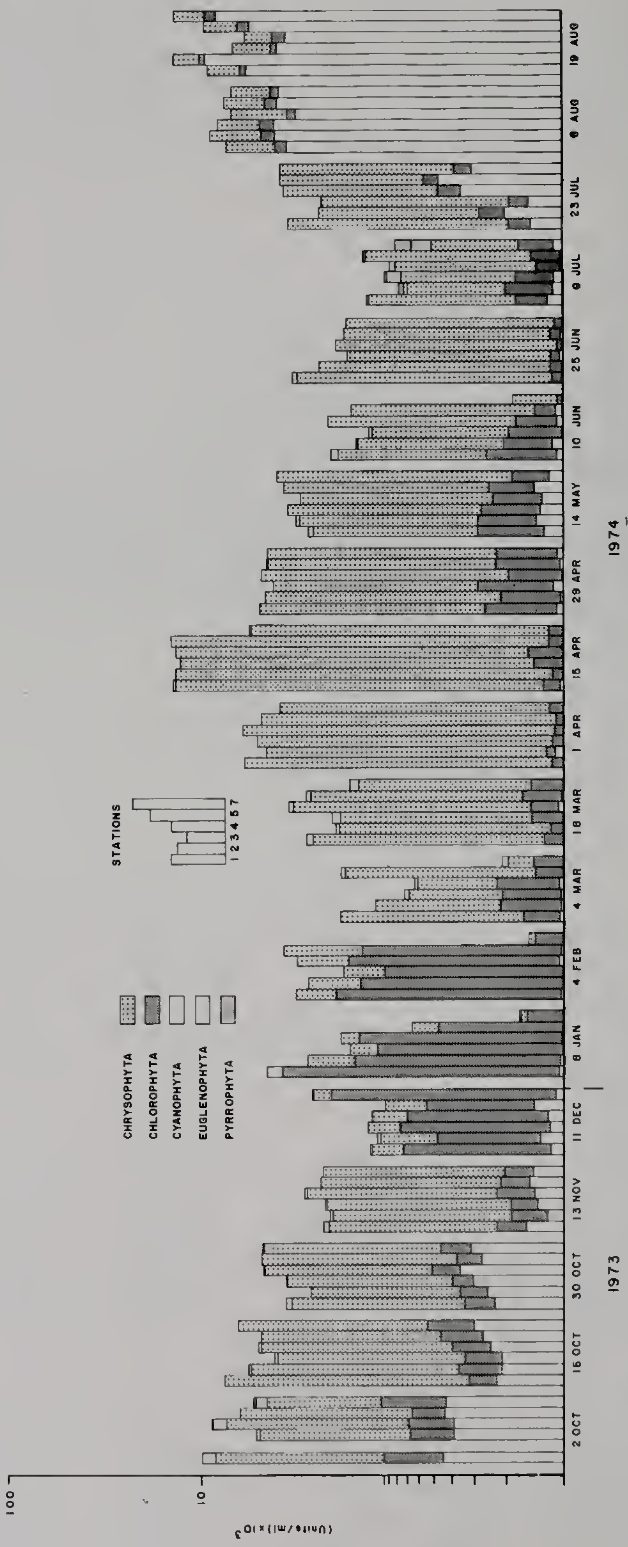
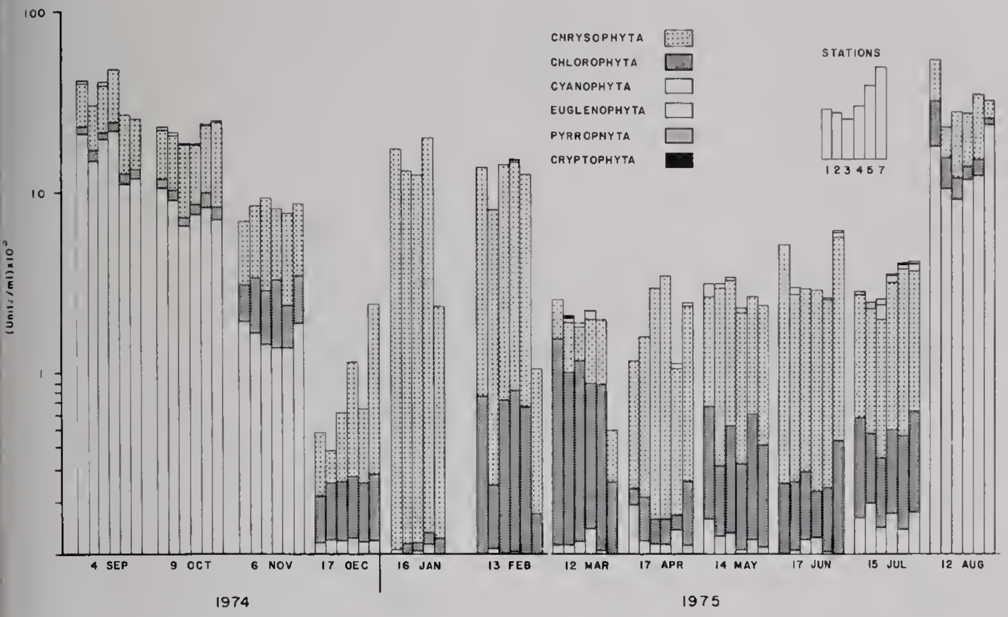


Fig. 4.—Phytoplankton in Lake Sangchris as units/ml and percentage composition by division, 2 October 1973–9 September 1976.



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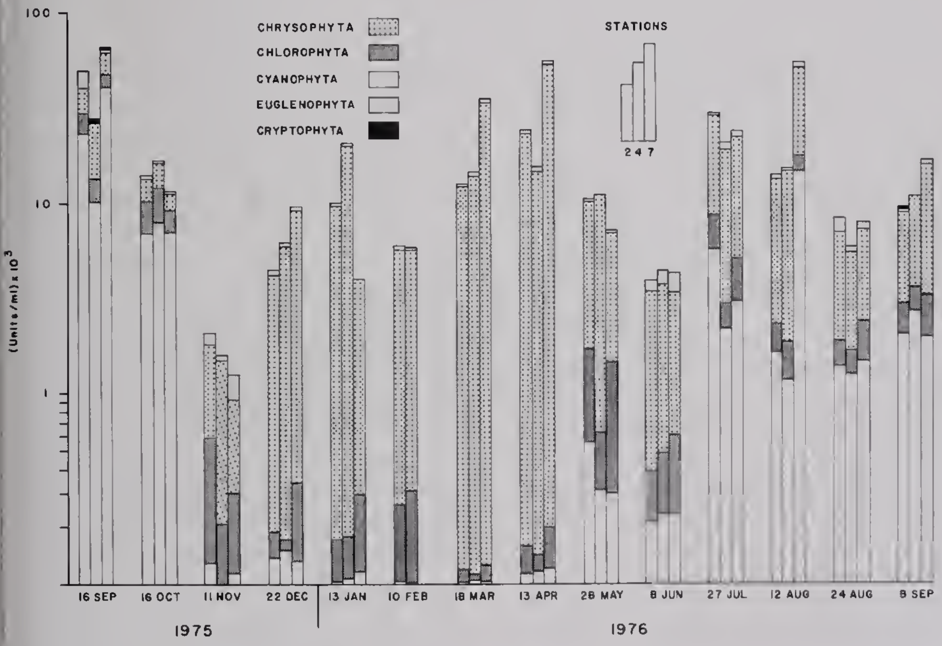

Fig. 4.—Continued.

68 percent in October. However, the mean density declined to 30,786 units/ml, and the mean biovolume declined to 0.9 μl/l.

In 1976 the blue-green pulse began in late July when *R. curvata* accounted for about 38 percent and *Anacystis incerta* about 10 percent of the community of about 25,000 units/ml. By 12 August the cooling loop mean had dropped to about 14,500 units/ml with the major species being *R. curvata,* 32 percent; *O. geminata,* 13 percent; *Nitzschia acicularis,* 5 percent; and *Synedra tenera,* 5 percent. In the control arm the pulse had continued to increase to a mean concentration of almost 54,000 units/ml with *O. geminata* and *R. curvata* accounting for 66 and 8 percent, respectively, of the total. The mean biovolume for this period was 3.1 µl/l. By 24 August the cooling loop phytoplankton had dropped to about 7,000 units/ml and the control arm phytoplankton to 7,800 units/ml, with the blue-greens still dominant. The mean biovolume was about 0.9 µl/l. On 9 September the cooling loop mean had increased to about 10,000 units/ml, and in the control arm the mean had increased to 16,000 units/ml. The dominants were *A. quadruplicatum,* 25 percent; *O. geminata,* 11 percent; and *R. curvata,* 16 percent of the total. The phytoplankton communities at all stations were similar in composition. By mid-September the phytoplankton had returned to concentrations typical of the season, about 40,000–50,000 units/ml (Coutant 1977).

The green algae were most common in periods between the pulses of the diatoms and blue-green algae. The communities in which this group formed a significant part were always small, usually 2,000 units/ml or less, and usually less than 1.0 µl/l in biovolume.

During November 1973–March 1974, *Monoraphidium contortum* and *Selenastrum westii* composed 34 and 8 percent, respectively, of the phytoplankton community, which was 90 percent chlorophycean and had a mean biovolume of 0.2 µl/l.

In March 1975 *M. contortum* was the dominant species with about 61 percent of the total community (biovolume 0.1 µl/l), and in November 1975 *M. contortum* made up about 34 percent of the total. Through the spring and summer of 1976, *M. contortum* periodically appeared as a common species, and in February was about 22 percent of the total.

The Euglenophyta, Cryptophyta, and Pyrrophyta were never important in Lake Sangchris. They were generally more common during the warmer months, but the entire assemblage only once accounted for as much as 8 percent of the total community.

STATION COMPARISONS

The annual mean total phytoplankters at each station fell into the range of 8,415.4 units/ml at Station 3 to 12,995.1 units/ml at Station 7 (Table 3). Phytoplankters at Station 7 (control arm) were significantly more abundant than at the cooling-loop stations, and within the cooling loop, the population at Station 2 (intake arm) was significantly greater than at the other stations. At Station 3 the phytoplankton population was significantly lower, an artifact introduced by the lower populations in the 10-m samples. The higher concentrations in the control arm were probably due to the significantly higher total phosphorus concentrations there, rather than to increased mortality within the cooling loop.

The winter months, December through February, were usually marked by a diatom pulse and concentrations of about half the annual mean. While an analysis of variance indicated significant differences among the stations, the Student-Newman-Keuls test was unable to detect them. The analysis did suggest that the populations at stations 5 and 7 were significantly lower than the others.

In the spring months, March through May, the phytoplankton was dominated by diatoms and green algae. The population at Station 7 was significantly highest, while within the cooling loop, populations at stations 2 and 4 were significantly higher than those at stations 1, 3, and 5. This result was an artifact of a third-year diatom pulse which was numerically quite large, but was only sampled at stations 2, 4, and 7.

In the summer months, June and July, the phytoplankton populations at stations 2, 4, and 7 were again significantly higher than those at stations 1, 3, and 5. Again, in the third year a large bloom

Table 3.—Mean phytoplankton concentrations, units/ml, at stations 1, 2, 3, 4, 5, and 7 in Lake Sangchris, October 1973 through August 1976. Relationships among station phytoplankton concentrations were determined by the Student-Newman-Keuls multiple range test, modified for unequal group sizes. Means underscored by the same line are not significantly different at the 0.05 level.

Annual Concentrations at Stations

3	5	4	1	2	7
8,415.4	9,255.2	9,681.1	10,096.9	10,762.3	12,995.1

December–February Concentrations at Stations

7	5	2	3	1	4
3,226.4	3,649.6	5,185.6	5,297.0	5,411.5	6,168.6

March–May Concentrations at Stations

3	1	5	4	2	7
3,400.4	3,560.9	3,999.7	6,385.8	6,749.6	10,104.4

June–July Concentrations at Stations

3	5	1	4	7	2
1,689.7	2,281.2	2,819.0	4,873.0	5,630.6	5,661.0

August–November Concentrations at Stations

4	3	2	5	1	7
18,113.4	18,835.3	21,466.5	21,532.8	23,157.4	25,455.5

occurred (the blue-green pulse started in July 1976, a month earlier than in the 2 previous years), and since only stations 2, 4, and 7 were sampled, their means reflected the increased concentration. When the July 1976 samples were discarded from the analysis, all stations were similar.

In the late summer and autumn months, August through November, the blue-green algae dominated. All of the cooling-loop stations were similar, but Station 7 had significantly higher concentrations. If the 12 August 1976 Station 7 sample was discarded (that period when the cooling-loop populations had collapsed, but the control-arm pulse continued), all stations were then similar.

Examination of the data indicated that on a seasonal or annual basis there was no consistent significant difference in phytoplankton concentrations between the intake canal (Station 1), the discharge canal (Station 5), and the discharge arm (Station 4). Station 3 was significantly lower, reflecting the effect of the 10-m sample on the station mean. Within the cooling loop, the higher annual mean concentration at Station 2 reflects the large third-year diatom pulse not included at stations 1, 3, and 5 rather than any real increase in phytoplankton concentration. Evidently, condenser passage, with the accompanying thermal rises experienced during this study, was not fatal to the phytoplankton.

SPECIES DIVERSITY AND EVENNESS

The species-diversity index, H , was determined for the surface collection at each station and date during this study. Since all stations were similar, only the mean of the cooling-loop stations and of Station 7 were presented (Fig. 5). While the index number has no absolute meaning, it is a valuable tool for comparing collections within a study. The evenness index, J,'looks only at the evenness of the distribution of species and is not affected by the sample size, as is H′. While the Shannon-Wiener Index usually falls within a range of 0 to about 4, the evenness component has a range of 0–1. In both indexes, the higher the number, the more even the species

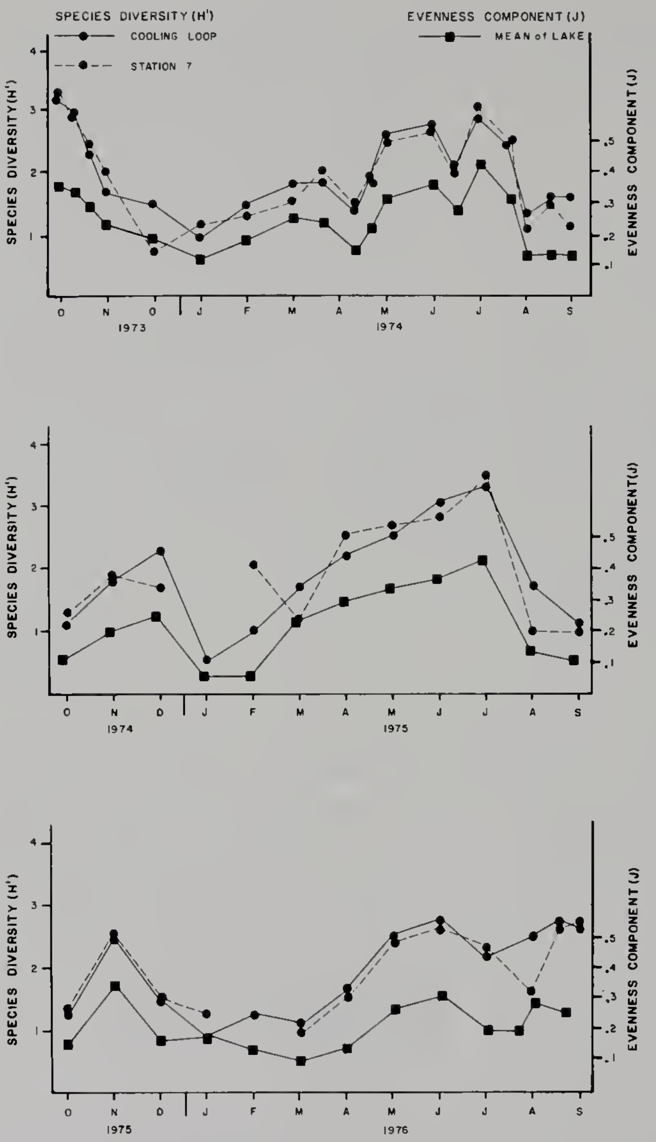

Fig 5.—Species diversity and evenness indices of the phytoplankton community in Lake Sangchris, 9 October 1973–9 September 1976.

distribution. The evenness component was calculated from the lakewide mean.

All 3 years presented the same general pattern, a species diversity value near 1 during the winter-spring diatom bloom and a steady increase to a maximum value of around 3 in the early summer, prior to the blue-green bloom. With the blue-green pulse, the diversity index dropped rapidly to a value near 1. In November and December, the diversity rose toward 2.5, as the phytoplankton became a mixed community of diatoms, greens, and blue-greens, and then dropped again with the winter diatom pulse.

The evenness component ranged from a low of 0.06 in January–February 1975 to a high of 0.42 in July of 1974 and 1975. These low values indicate that even when the phytoplankton community had diversity indexes of 3 or more, the distribution of species was not exceptionally even. Since the evenness index paralleled the diversity index throughout the study, uneven distribution of species was the common situation.

CLUSTER ANALYSIS

A cluster analysis technique using a modified Jaccard similarity index was applied to an extensive collection taken on 26 July 1976. The purpose was to test for any station- or depth-related distribution patterns among the phytoplankton within the main lake and bays (Fig. 6). The results were presented in the form of a computer-generated dendrogram (Fig. 7) which was divided into six clusters, designated A through F.

The most striking feature of the analysis is the high degree of similarity among all stations (0.8559 or higher) with 97 percent of the comparisons having a similarity index above 0.900. No relationship between bay location and clustering was evident. The lake samples (designated by the prefix L in the station code) generally clustered with the cooling-loop stations (L011 through L151) in groups A, B, and C and the control-arm stations (L161 through L204) in groups C, D, and F. The lake samples taken from the lower depths (designated by the last number of the station code) were generally distributed through all of the cluster groups.

Thus, while some patterns were displayed by the analysis, the overall level of similarity was quite high. The similarity of the bay and lake samples indicated that their waters were in intimate contact with one another. Using a similar cluster analysis on the zooplankton data, Waite (1977) found that the zooplankton clusters were separated primarily by season. Within

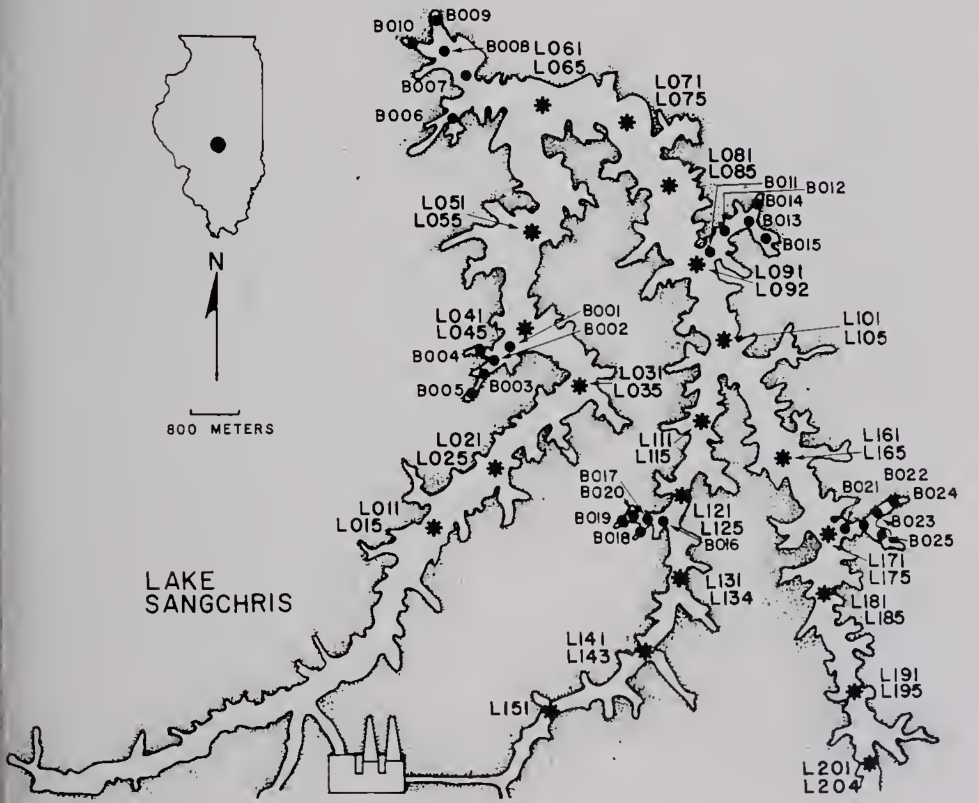

Fig 6.—Stations sampled for phytoplankton cluster analysis, 26 July 1976. Lake stations are marked by an asterisk and the station code prefix L. Bay stations are marked by a dot and the station code prefix B. The first two integers of the station code are the sample number, and the third is the depth in meters at which the sample was collected.

sample dates the bays (littoral areas) and limnetic areas were usually quite similar in phytoplankton. However, during the winter months Station 7 zooplankton

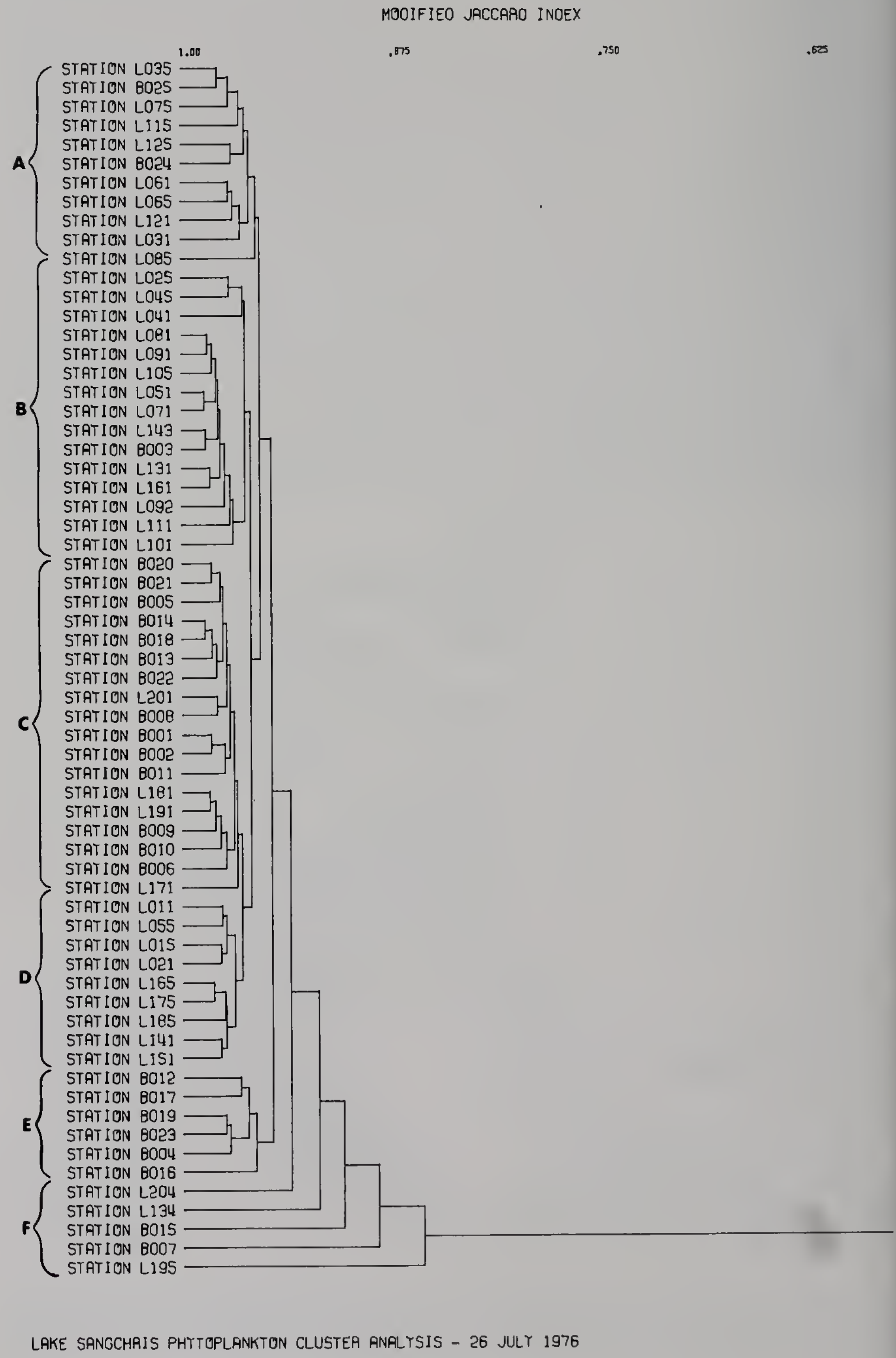

Fig. 7.—Cluster analysis of 64 phytoplankton samples from Lake Sangchris, 26 July 1976.

communities differed from those of the cooling loop. The similarity of the phytoplankton of the control arm to that of the cooling loop also suggested that this area was quite similar to the cooling loop as a habitat for phytoplankton.

WATER TEMPERATURE

In Lake Sangchris the occurrences of the major algal communities were correlated with water temperature. Diatoms were most common from autumn through spring when water temperatures ranged from 6° to 15°C. The green algae were most abundant in spring and summer when water temperatures were within the 15°–25°C range. The blue-greens bloomed in the late summer when water temperatures were above 30°C and declined when temperatures were within the 15°–25°C These temperature ranges generally agree with the observations of Cairns (1956) and others.

The interruption of the blue-green pulse when the generating station shut down on 9 August 1976 (but continued pumping water intermittently) was probably related to the substantial drop in water temperature experienced immediately following the shutdown (Table 4 and Brigham 1981). During July and August of 1974 and 1975, the mean discharge-arm temperature was 36.04°C, and the mean control-arm surface temperature was 30.46°C. The year 1976 was cooler than normal, and the July discharge-arm water temperature was 3.51°C cooler than it was in the 2 previous years. Similarly, the water of the control arm was 2.71°C cooler than it was in the 2 previous years. However, both stations at 32.50°C and 27.47°C, respectively, were still near the optimal temperature range for the blue-green algae, and by 26 July 1976 a blue-green algal pulse had started. When the generating plant shut down, the mean cooling-loop temperature fell to about 24°C within 2 days. This sudden drop in water temperature below the optimal range for the blue-green algae probably caused the collapse of the blue-green population in the cooling loop.

In the control arm, however, 2 days after the shutdown the temperature had dropped only 2.3°C to 26.7°C, possibly explaining why the pulse continued at this station. However, by 24 August the control-arm temperature (24.63°C) was similar to that of the cooling loop (24.70°C), and the blue-green bloom had collapsed. By 9 September 1976 a slight increase in the phytoplankton was observed at all stations, and by mid-September the population was similar to the previous year's at that time (Coutant 1977).

NUTRIENTS

In fresh waters, nitrogen and phosphorus are regarded as the nutrients most likely to be limiting to algal growth. The forms of nitrogen most readily used by algae are nitrate and ammonia (Stewart 1974). In Lake Sangchris the mean concentration of nitrate nitrogen was 1.993 ± 1.820 mg/l, and that of ammonia nitrogen, 0.105 ± 0.155 mg/l. Nitrate nitrogen concentrations of less than 0.02 mg/l have been reported to be limiting to algae (Prowse & Talling 1958). In Lake Sangchris, nitrate nitrogen fell to 0.01 mg/l in the autumn of each year (Brigham 1981). With the exception of 1975, these periods were quite brief and the concentration of ammonia was great enough to raise the readily available nitrogen to 0.06 mg/l or more. During these times, the plankton was dominated by nonheterocystous (non-nitrogen-

Table 4.—Water temperature variations (°C) in the discharge and control arms of Lake Sangchris during July and August 1974, 1975, and 1976, derived from Brigham's data (1981).

	Station 4 (Discharge Arm)		Station 7 (Control Arm)	
	1 July–8 Aug.	9–31 Aug.	1 July–8 Aug.	9–31 Aug.
Mean, 1974 & 1975	36.01	36.07	30.18	30.74
Mean, 1976	32.50	24.70	27.47	24.63
Difference	− 3.51	− 11.37	− 2.71	− 6.11

fixing) blue-green algae. Thus, it is doubtful if the phytoplankton population was ever limited by nitrogen.

Phosphorus is generally regarded as the single most important algal nutrient in temperate waters and the nutrient most likely to be limiting. The single most common aspect of cultural eutrophication of waters is the increase in phosphorus levels and the resultant increase in algal biomass. In Lake Sangchris the mean concentration of total phosphate phosphorus was 0.205 ± 0.128 mg/l and 0.035 ± 0.063 mg/l as soluble orthophosphate phosphorus. The maximum recorded levels of each were 1.51 and 1.12 mg/l, and the minimums were 0.036 and 0.0 mg/l, respectively. At Station 7 the soluble orthophosphate concentration, 0.076 ± 0.178 mg/l, was significantly higher than concentrations in the rest of the lake (Brigham 1981), probably due to the effluent from the Tovey sewage treatment plant. Since Station 7 also had significantly higher mean phytoplankton concentrations, it appeared that the phytoplankton abundance was correlated with soluble orthophosphate concentrations.

Sawyer (1947) reported that concentrations of 0.02 mg P/l were enough to support nuisance-algal growths, while Chu (1943 *in* Kuhl 1962) stated that concentrations of 0.05 mg P/l or less were limiting to such growths. Since the phosphorus requirements vary with different species, this discrepancy is not unusual, and it does give a general idea of the range in which phosphorus may become limiting. On only three occasions did total phosphorus levels approach what may have been phytoplankton-growth-limiting concentrations: on 9 July 1974 (0.053 mg P/l) immediately prior to a blue-green algal pulse, 17 December 1974 (0.039 mg P/l) prior to a winter diatom pulse, and 13 January 1976 (0.044 mg P/l) with a diatom community. All of these periods were characterized by transitional phytoplankton communities of low density.

The N-to-P ratio expresses the relationship of nitrogen and phosphorus concentrations in waters. The ratio in protoplasm is about 8, and this may be regarded as the optimal ratio for nutrient media to promote growth (Verduin 1967). A higher ratio indicates insufficient phosphorus to utilize fully the available nitrogen; a lower ratio indicates insufficient nitrogen to utilize fully the available phosphorus.

In Lake Sangchris the N-to-P ratio based upon the mean concentrations of total phosphate phosphorus and the combined concentrations of ammonia and nitrate nitrogen was 13.11, slightly phosphorus limited. Since the abundances of these elements varied through the year, the N-to-P ratio was not constant and ranged from less than 1 to more than 80 (Fig. 8). From August of one year through January of the next the ratio was usually less than 8, and the concentration of available nitrogen approached phytoplankton-limiting levels. This period was characterized by a blue-green algal community.

From February through July the N-to-P ratio was usually greater than 8, and the phosphate phosphorus concentrations averaged about 0.15–0.20 mg/l, dropping below 0.05 mg P/l for brief periods. Diatoms and green algae were the dominant plants during this time of year. An algal bioassay by the U.S. Environmental Protection Agency (1975) concluded that Lake Sangchris was phosphorus limited, because additions of phosphorus produced a significant increase in yield of *Selenastrum capricornutum*. The reported N-to-P ratio was 35, and from the water chemistry data accompanying the report (Brigham 1981) it seems that the water sample used for the bioassay was taken in May, a period when the N-to-P ratio is normally high (phosphorus is limiting).

Because algae are able to store nutrients and use these reserves to support several cell divisions when environmental concentrations of nutrients are at limiting levels, instances of nutrient supply limiting a plankton

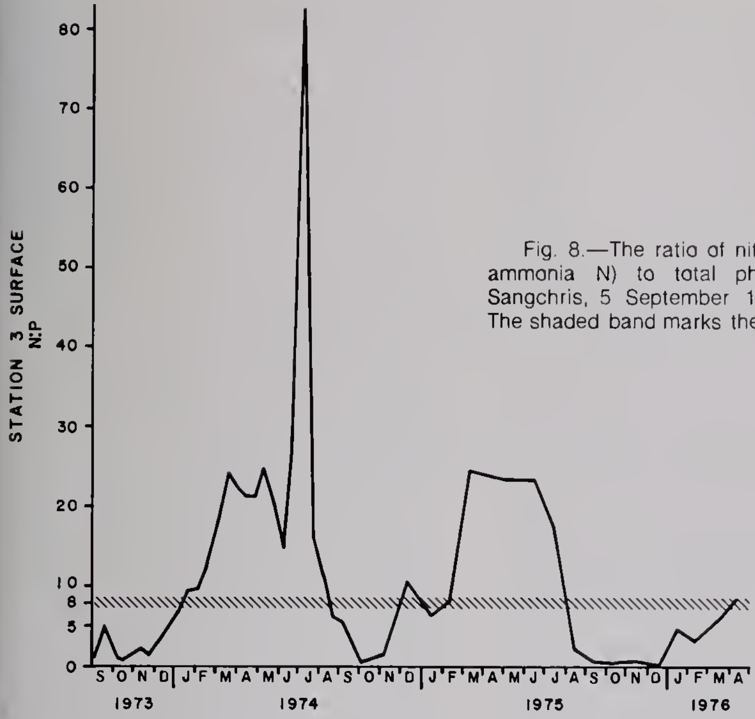

Fig. 8.—The ratio of nitrogen (nitrate N + ammonia N) to total phosphorus in Lake Sangchris, 5 September 1973–13 April 1976. The shaded band marks the optimal ratio of 8.

pulse are often not evident. However, instances of silica limitation upon diatom growth have been documented. Lund (1950) found evidence that *Asterionella formosa* decreases coincided with drops in dissolved silica concentrations to below 0.5 mg SiO_2/l. Pearsall (1932) also found that a silica concentration of about 0.5 mg SiO_2/l was critical to diatom multiplication. Lewin & Guillard (1963) found the growth-limiting concentrations to be 0.1 mg SiO_2/l.

In Lake Sangchris dissolved silica concentrations had a mean annual concentration of 3.573 mg/l and were generally in excess of 2 mg/l with the exceptions of November–December 1973 and March 1974, when concentrations dropped to 0.7–0.8 mg/l (Fig. 9). Pulses of *Melosira distans* v. *alpigena* and *M. italica* occurred at those times, and the heavily silicified frustules of these species may have drained the silica supply to nearly limiting levels. The decline of this pulse was followed by an increase in silica to levels of 3 mg/l or more.

In the following winter another pulse of diatoms, primarily *Synedra tenera*, occurred, and this pulse was accompanied by a drop in silica to about 2 mg/l. The decline of this pulse was accompanied by an increase of silica to more than 4 mg/l.

In March–April 1976 a pulse of a minute diatom, *Cyclotella pseudostelligera*, was accompanied by a drop in silica, but water chemistry data acquisition terminated at this point; so the extent of the drop is not known. The frustules of this species were so small and lightly silicified, however, that it seems unlikely that silica concentrations were reduced to limiting levels.

The ratio of silica and phosphorus has been suggested as possibly explaining some diatom dynamics. Schelske (1975) reported that the mass ratio of SiO_2 to P in *Asterionella* ranged between 170 and 500. Unpolluted tributaries of the Great Lakes have ratios greater than 500, and Tarapchak & Stoermer (1976) suggest a ratio of 200 as being optimal for diatom growth. In Lake Sangchris the mean SiO_2-to-P ratio was 17.4, suggesting that the phosphate concentration was capable of supporting diatom growth to the point

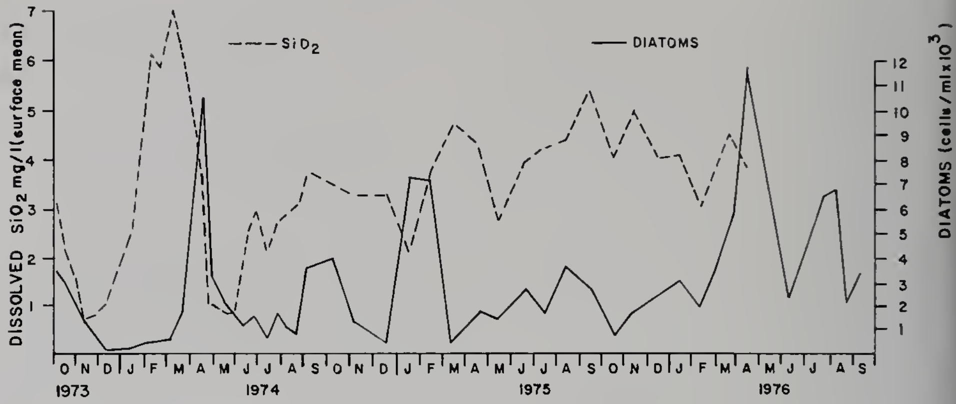

Fig. 9.—Dissolved silica (mg SiO_2/l) and diatoms in Lake Sangchris, 2 October 1973–9 September 1976. Diatom concentrations during the period December 1975–April 1976 were modified (0.43X) to adjust for the extremely small cell size of the dominant phytoplankter.

where silica would become limiting, thus removing diatoms from nutrient competition and allowing for increased growths of green and blue-green algae.

The ratios of silica and total phosphate were examined before, during, and after three major diatom pulses (Table 5). As expected, the ratios of silica to phosphorus declined during each pulse. In May 1974 the silica concentrations approached what may have been a phytoplankton-growth-limiting concentration of silica (0.8 mg/l), and the SiO_2-to-P ratio was 4.4. This pulse of *Melosira* spp. may have been limited by silica depletion. However, the diatoms were not replaced in importance by any other group; so other factors may have been responsible for the decline rather than silica depletion. The other pulses were composed of the small, lightly silicified cells of *Synedra tenera* and *Cyclotella pseudostelligera,* and the ratio did not drop below 20.4. At these times the mean surface water concentrations of dissolved silica were in excess of 2.14 mg/l, and the total phosphate phosphorus concentrations were in excess of 0.10 mg/l. In general, it appeared that neither silica nor phosphorus depletions were responsible for the decline of diatom pulses.

PRIMARY PRODUCTIVITY

During this study several techniques were employed to estimate primary production. Since each method measured a different reaction in the photosynthetic process, their combined use gave a good estimate of photosynthetic activity in the lake.

The $^{\Delta}$pH-CO_2 and $^{\Delta}O_2$ methods were used to measure photosynthesis under natural conditions while light-dark bottle experiments were being conducted. The light-dark bottle experiments used the $^{\Delta}$pH-CO_2, $^{\Delta}O_2$, or the ^{14}C methodology. The mean $^{\Delta}O_2$-determined photosynthetic rate was 5.34 mmol O_2/m^3·hr, and the mean of the $^{\Delta}$pH-CO_2-determined rates was 6.77 mmol CO_2/m^3· hr. The overall mean was 5.52 mmol CO_2/m^3· hr. For comparative purposes, the oxygen

Table 5.—Ratios of silica to total phosphate phosphorus (SiO_2:P) before, during, and after diatom pulses in Lake Sangchris.

Period	Pulsing Species	Before Pulse	During Pulse	After Pulse
Mar.–May 1974	*Melosira distans* v. *alpingena*	32.2	15.2	4.4
Jan.–Mar. 1975	*Synedra tenera*	85.4	20.4	42.1
Mar.–May 1976	*Cyclotella pseudostelligera*	40.3	24.0	. . .

production rates were converted to CO_2 uptake rates by a factor of 0.80 × (Ryther 1956).

The ^{14}C data, while showing the same trends as the other methods, yielded much lower carbon uptake rates. Generally, the ^{14}C data lowered the mean photosynthetic rates by about 12 percent during the cool-water periods and 30 percent during the warmwater periods.

The data were divided into two periods based upon discharge water temperatures (Table 6). When discharge temperatures equalled or exceeded 30°C at Station 5, the period was classified as a warmwater period, and when temperatures were less than 30°C at the discharge, it was considered a cool-water period.

During the warmwater period (June–September) the mean rate, 4.18 mmol $CO_2/m^3 \cdot$ hr, was about 11 percent higher than the mean for the cool-water period, 3.77 mmol $CO_2/m^3 \cdot$ hr. During the cool-water period, the photosynthetic rate at Station 4 in the discharge arm was similar to those of stations 2 and 3 in the intake arm and main body of the lake. Productivity at stations 1 and 5 was significantly lower than it was at the other cooling-loop stations and may have been depressed by the increased water velocity, turbulence, and turbidity. During condenser passage, the thermal rise seemed to have a stimulatory effect upon net photosynthesis at Station 5 (in the discharge canal), which was significantly greater than it was at Station 1.

Table 6.—Summary of primary productivity, mmol $CO_2/m^3 \cdot hr$ (standard deviation in parentheses), in the photic zone of Lake Sangchris from 16 October 1973 through 14 September 1976. Means underscored by the same line are not significantly different at the 0.05 level (after the Student-Newman-Keuls multiple range test).

Station	Station 5 at or above 30°C (June–September)	Station 5 below 30°C (October–May)
1	4.49 (4.19)	0.92 (2.88)
2	4.84 (5.48)	3.79 (4.62)
3	5.00 (3.54)	3.40 (8.70)
4	1.69 (35.34)	3.51 (5.35)
5	1.73 (2.76)	2.58 (3.48)
7	6.28 (9.16)	4.67 (7.64)
Mean	*4.18*	*3.77*
Number of samples	173	416

October–May Rates at Stations

1	5	3	4	2	7
0.92	2.58	3.40	3.51	3.79	4.67

June–September Rates at Stations

4	5	1	2	3	7
1.69	1.73	4.49	4.84	5.00	6.28

During the warmwater period, photosynthesis rates were similar at stations 1, 2, and 3, but at stations 4 and 5 they were significantly lower than they were in the rest of the lake. Evidently, the mean thermal rise of 6.77°C, when water temperatures were already in excess of 30°C, inhibited photosynthesis. The inhibition was temporary, however, and photosynthetic capability was restored by the time the water mass reached Station 3. A similar effect was described for a steam electric station on Chesapeake Bay (Morgan & Stross 1969).

There were significantly higher rates of primary production at Station 7 in the control arm than there were in the rest of the lake during both periods. It is probable that the significantly higher concentrations of phosphorus at this station were the primary reason. The high turbidity and shallow photic zone at Station 7 were evidently offset by the increased phosphorus supply and the well mixed water column which kept algal cells in constant circulation.

SUMMARY AND CONCLUSIONS

1.—Seasonal periodicity was bimodal, with a large cyanophycean pulse in early autumn and a diatom pulse in winter and spring. The annual mean concentration of phytoplankters ranged between 8,000 and 13,000 units per ml with peaks in excess of 80,000 units per ml during the blue-green blooms.

2.—The control arm (Station 7) had a significantly higher mean concentration of phytoplankters than had the cooling-loop stations on an annual basis as well as during the spring and autumn periods. The significantly higher soluble orthophosphate phosphorus concentrations in the control arm may have been a contributing factor.

3.—Species diversity (H′) seldom exceeded a value of 3 and was 1 or less during the blue-green and diatom blooms. Evenness of the species distribution (J) did not exceed a value of 0.42, indicating that the highest species diversities were due to the population size rather than the evenness of species distribution.

4.—Distribution of phytoplankters throughout the lake and bays was uniform, indicating that the turbulent flow and side arm circulation in the bays kept the lake water well mixed.

5.—A 1-month shutdown of the generating station in August 1976 resulted in water temperatures being 6°–11°C below the seasonal norm and caused the temporary collapse of a blue-green algal pulsed during that period.

6.—The mean N-to-P ratio was 13.11 and varied from less than 1 in the autumn to more than 80 in the spring. Nitrogen approached phytoplankton-growth-limiting levels in the autumn, and phosphorus concentrations approached limiting levels on a few occasions but did not appear responsible for limiting any phytoplankton blooms.

7.—The annual mean concentration of silica was 3.573 mg/l, and the mean SiO_2-to-P ratio was 17.4. Silica limitation may have been responsible for the termination of a *Melosira* spp. bloom in 1974, and while later blooms of other diatom species caused some decline in silica levels, the silica concentrations did not approach limiting levels.

8.—Primary productivity was significantly higher in the control arm than it was in the cooling loop. Productivity in the warmwater periods (summer) was greater than it was in the cool-water periods. The mean net photosynthetic rate, excluding the ^{14}C data, was 5.52 mmol $CO_2/m^3 \cdot$ hr, indicating that the lake was moderately productive.

9.—When discharge water temperatures exceeded 30°C, primary productivity was significantly reduced in the discharge canal and discharge arm. The inhibition was temporary, and photosynthetic capability was restored by the time the water mass had reached the Station 3 area, half way around the cooling loop.

10.—The operation of the Kincaid Generating Station was generally not deleterious to the phytoplankton. The constant circulation of water around the cooling loop prevented permanent stratification and maintained a high degree of spatial homogeneity in the phytoplankton. Condenser passage did not produce any differences among the phytoplankton communities in the intake and discharge canals although primary productivity was temporarily depressed when discharge water temperatures exceeded 30°C. The control arm had significantly higher productivity rates and usually had the highest concentrations of phytoplankters, probably a result of the higher soluble orthophosphorus concentrations in that area.

REFERENCES CITED

Brigham, A. R. 1981. Water quality in a cooling water reservoir. Pages 290–319 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

Cairns, J., Jr. 1956. Effects of increased temperatures on aquatic organisms. Industrial Wastes 1:150–152.

Coutant, L. 1977. Algal dynamics of Lake Sangchris and Lake Shelbyville. Pages 5-1–5-44 *in* Evaluation of a cooling lake fishery. Vol. 4. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

Csanady, G. T. 1964. Turbulence and diffusion in the Great Lakes. Pages 326–329 *in* University of Michigan Great Lakes Research Division Publication 11.

Evans, D., and J.G. Stockner. 1972. Attached algae on artificial and natural substrates in Lake Winnipeg, Manitoba. Canada Fisheries Research Board Journal 29:31–44.

Findenegg, I. 1974. Expressions of populations. Pages 16–18 *in* R. A. Vollenweider, ed., A manual on methods for measuring primary production in aquatic environments. Blackwell Scientific Publications. London 225 p.

FOGG, G. E. 1975. Algal cultures and phytoplankton ecology. 2nd ed. University of Wisconsin Press, Madison. 175 p.

KUHL, A. 1962. Inorganic phosphorus uptake and metabolism. Pages 211–229 *in* R. A. Lewin, ed., Physiology and biochemistry of algae. Academic Press, New York.

LEWIN, J. C., and R. R. L. GUILLARD. 1963. Diatoms. Annual Review of Microbiology 17:373–414.

LUND, J. W. G. 1950. Studies on *Asterionella formosa* Hass. II. Nutrient depletion and the spring maximum. Journal of Ecology 38:1–14, 15–35.

MORGAN, R. P., and R. G. STROSS. 1969. Destruction of phytoplankton in the cooling water supply of a steam electric station. Chesapeake Science 10(3–4):165–171.

NAUWERCK, A. 1963. Die Beziehungen zwischer zooplankton und phytoplankton in See Erken. Symbolae Botanicae Upsalienses 17(5):93–154.

PALMER, C. 1962. Algae in water supplies. Public Health Service Publication 657. Robert A. Taft Sanitary Engineering Center, Cincinnati. 88 p.

PEARSALL, W. H. 1932. Phytoplankton in the English lakes. 2. The composition of the Phytoplankton in relation to dissolved substances. Journal of Ecology 20:241–262.

PIELOU, E. C. 1975. Ecological diversity. J. Wiley & Sons, New York. 165 p.

PROWSE, G. A., and J. F. TALLING. 1958. The seasonal growth and succession of plankton algae in the White Nile. Limnology and Oceanography 3:222–238.

RUTTNER, F. 1963. Fundamentals of limnology. University of Toronto Press. xi + 242 p.

RYTHER, J. H. 1956. The measurement of primary production. Limnology and Oceanography 1:72–84.

SAWYER, C. N. 1947. Fertilization of lakes by agricultural drainage. New England Water Works Association Journal 61:109–127.

SCHELSKE, C. L. 1975. Silica and nitrate depletion as related to rate of eutrophication in Lakes Michigan, Huron, and Superior. Pages 277–298 *in* A.D. Hasler, ed., Coupling of land and water systems. Ecological Studies. Vol. 10. Springer-Verlag, New York.

SHANNON, C. E., and W. WEAVER. 1949. The mathematical theory of communication. University of Illinois Press. Urbana. 117 p.

STEWART, W. D. P., ed. 1974. Algal physiology and biochemistry. Botanical Monographs. Vol. 10. University of California Press, Berkeley. 989 p.

SWEERS, H. E. 1970 Vertical diffusivity coefficient in a thermocline. Limnology and Oceanography 15:273–280.

TARAPCHAK, S. T. and E. F. STOERMER. 1976. Environmental status of the Lake Michigan region. Vol. 4. Phytoplankton of Lake Michigan. Argonne National Laboratory, Argonne, IL. 21 p.

U.S. ENVIRONMENTAL PROTECTION AGENCY. 1975. Report on Sangchris Lake, Christian County, Illinois. Working Paper No. 314. Corvallis Environmental Research Laboratory. Corvallis, OR.

VERDUIN, J. 1956. Primary productivity in lakes. Limnology and Oceanography 1:85–91.

———. 1967. Reservoir management problems created by increased phosphorus levels of surface waters. Pages 200–206 *in* Reservoir fishery resources symposium. American Fisheries Society, Southern Division, Washington D.C. viii + 569 p.

VOLLENWEIDER, R. A. 1974. Methods of measuring production rates. Pages 51–152 *in* R.A. Vollenweider, ed., A manual on methods for measuring primary production in aquatic environments. Blackwell Scientific Publications, London 225 p.

WAITE, S. W. 1977. Zooplankton dynamics of Lake Sangchris, October 1975 through October 1976. Pages 2.1–2.24 *in* Annual report for fiscal year 1976, Lake Sangchris Project. Illinois Natural History Survey, Urbana.

WEBER, C. ed. 1973. Plankton. Pages 1–20 *in* Biological field and laboratory methods for measuring the quality of surface waters and effluents. U. S. Environmental Protection Agency Publication EPA 670l/4-73-001. Cincinnati, OH.

WOELKERLING, W. J., R. R. KOWAL, and S. B. GOUGH. 1976. Sedgwick-Rafter cell counts: a procedural analysis. Hydrobiologia 48:95–107.

ZAR J. H. 1974. Biostatistical analysis. Prentice-Hall, New Jersey. 620 p.

Effects of Cooling Lake Perturbations upon the Zooplankton Dynamics of Lake Sangchris

Stephen W. Waite

ABSTRACT

The limnoplankton of power plant cooling lakes are subject to many atypical environmental conditions.

The purpose of this investigation was to determine the effects of entrainment on the density of zooplankters and of heated discharge water on the seasonal periodicity, composition, diversity, and standing crop of these organisms in Lake Sangchris, a cooling lake in central Illinois.

An analysis of water chemistry data showed that no chemical limitations were imposed on the zooplankters during the study.

While most zooplankton records from this lake are typical of midwestern lentic systems, several typically common species, including *Leptodora kindtii* and *Diaptomus pallidus,* were noticeably absent from Lake Sangchris.

Several traditionally dicyclic species became monocyclic in the heated system, indicating that possibly the interrelated biological and physicochemical parameters in Lake Sangchris favored continual growth and reproduction for these forms. The lifetime for some Lake Sangchris zooplankters (especially rotifers) appeared to increase or decrease depending upon the temperature preference of the individual species; these increased growing periods probably resulted in greater fecundity and total production. The number of zooplankton species in the cooling loop was relatively constant throughout the year, a trend unlike that recorded for the control arm or for Lake Shelbyville. Species diversity index values of zooplankton in Lake Sangchris were highly variable, with differences and similarities attributed to seasonality and erratic power plant discharge conditions. There was no evidence of significant differences (0.05 level) of the diversity of zooplankton populations in the intake and discharge canals.

The standing crop of zooplankters in Lake Sangchris was highest during early spring, decreasing through late spring and summer. This trend was unlike that in unheated lakes, where biomass is generally highest during late spring or summer. In June and July, secondary production in all Lake Sangchris cove stations was well within or above the range of open lake values (0.4–0.6 kcal m^{-3}), but in late autumn and winter, cove production decreased to levels below those in all nearby lake stations. A comparison of autumn and early winter zooplankton production of the open-water regions at Lake Sangchris and Lake Shelbyville indicated generally higher values in the former, with production in Lake Sangchris significantly higher in November.

Generally, the addition of heat in Lake Sangchris provided a potential enhancement for zooplankton communities during autumn, winter, and spring, but in late summer, thermal loading resulted in an obvious reduction in numbers and biomass.

INTRODUCTION

Both plant and animal constituents of the limnoplankton inhabiting electrical power plant cooling reservoirs are subject to a wide variety of artificially induced environmental alterations. While some

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result from the addition of chlorine and other biocides, others are mechanical forces acting within the plant itself; these include turbulence, pressure, vacuum, and physical contact with the various screens, pumps, and tubes (Kedl & Coutant 1976). One factor posing a threat to the plankton in a cooling lake is the heat discharged via large volumes of condenser cooling water. Depending on thermal loading, discharge volume, and current velocity, and the cooling-lake morphology, the energy supplement from the waste heat is reflected in most limnoplankton populations at a particular level, thus identifying certain thermal conditions that may be detrimental or beneficial to the ecosystem.

The effects of heat on the zooplankton of Lake Sangchris for the first 2 years of this study (1973–1974) were determined primarily by monitoring species population trends and determining the effects of condenser passage on soft-bodied organisms (Brigham et al. 1975). While those data satisfied the requirements of the initial phase of the project, I focused specifically in the 3rd year on (1) seasonal periodicity, composition, abundance, and diversity of zooplankton species and (2) standing crop and calorific fish-food value comparisons of the zooplankton biomass in littoral as well as limnetic communities of this cooling reservoir. Analyses of the final year's data were enhanced by comparing the data to those obtained by similar sampling techniques in Lake Shelbyville, a nearby noncooling reservoir.

DESCRIPTION OF THE STUDY AREA

During the initial monitoring phase of this study, six sampling areas, representing the various limnetic regions, were chosen for the warmwater discharge and intake arms and the cold-water control arm (Fig. 1). Located near midchannel, these sampling stations are lentic habitats with depths ranging from 5 to 12 m. Station 5, representing the discharge region, was originally located centrally within the discharge canal, but in 1975 this station was moved to the junction of the canal and the reservoir basin to facilitate sampling. Stations 2, 4, and 7 are similar in morphometry although current velocities are proportionate to their distances from the discharge canal. Five additional stations in coves A, B, C, D, and X (Fig. 1) were added in May 1976 to compare the littoral communities of the cooling loop and the control arm. Water depths in these littoral areas never exceeded 2 m.

METHODS

During the monitoring phase (1973–1974) zooplankton samples were taken with a plankton pump. One 65-liter volume was pumped biweekly from the 1-m and 5-m depths at each station. Samples were strained through a no. 20 mesh Wisconsin net, reducing the original sample to 60 ml, and were then fixed and preserved with Neosynephrine and 5-percent formalin, respectively. Zooplankters were identified, counted, and recorded as numbers per liter of lake water.

For the more intensive studies conducted during 1975, three vertical hauls (replicates) were procured monthly from the same limnetic stations using a 30-cm diameter conical plankton net with 80μm nylon mesh. Beginning in May 1976, an additional three replicates also were taken monthly, using an 11-cm diameter Wisconsin net (80μm mesh), from each of five isolated coves. All concentrated samples were fixed and preserved in a 5-percent formalin and 50-percent alcohol solution tinted with rose bengal stain.

To obtain the most efficient working density, the concentrated samples were diluted to 25 to 200 ml, depending on the volume of water strained and the density of organisms in the original lake water. Three 1-ml subsamples of each replicate were placed in gridded Sedgewick-Rafter cells for identification and enumeration

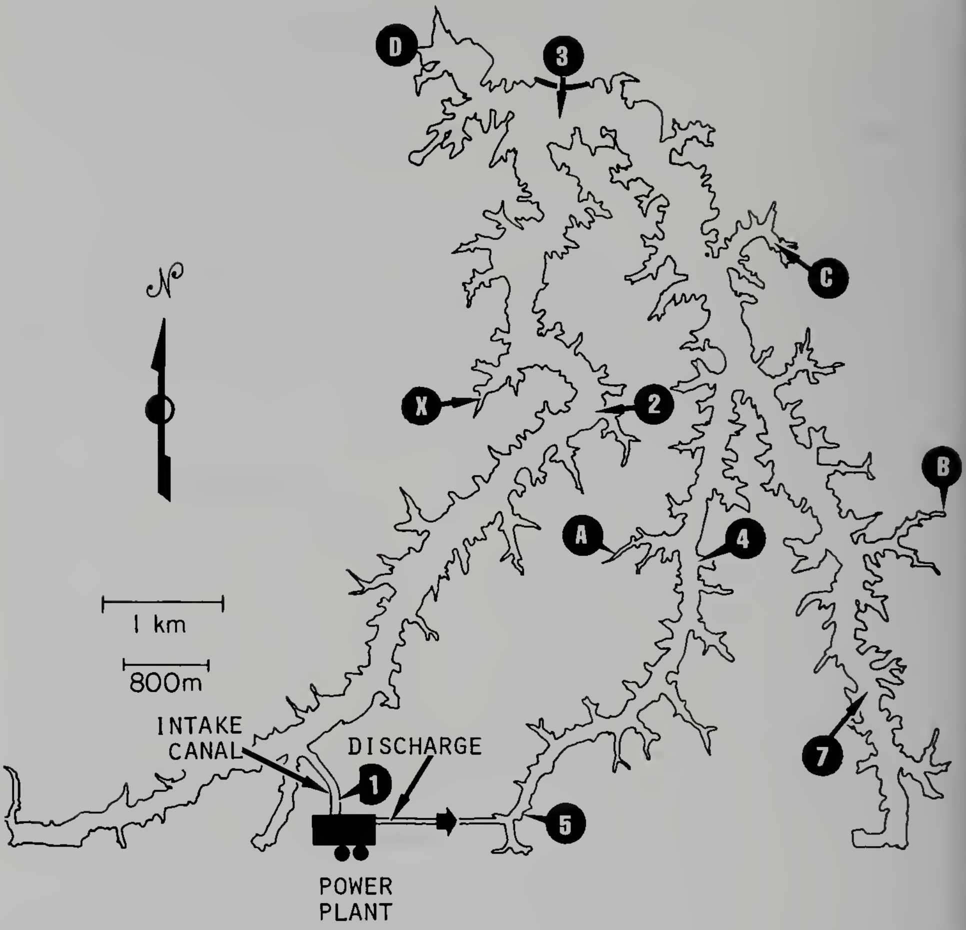

Fig. 1.—Zooplankton sampling stations in Lake Sangchris. Stations 1, 2, 3, 4, 5, and 7 represent limnetic regions of the lake basin, while A, B, C, D, and X represent littoral areas in the cooling loop and control arm.

of species. The remaining portion was poured into a petri dish, and taxa not observed in the subsamples were recorded and computed. Identifications were made using a stereo dissecting microscope with 1:4 zoom range (10x to 40x) and a trinocular compound microscope at 100x to 400x. Species identifications for the entire project were based on published keys by Ahlstrom (1940 and 1943), Pennak (1953), Brooks (1957 and 1959), Edmondson (1959), Wilson & Yeatman (1959), and Goulden (1968).

All samples collected during 1975 were filtered, dried, and ashed at 500°C for 1 hour to determine estimates of the zooplankton standing crop in dry and ash-free biomass units (mg) per cubic meter. Approximations of the calorific value of the total biomass were computed from equations by Winberg (1971).

An account of the total zooplankton species diversity was characterized by an index ($\bar{d}$) based on the methodologies of Wilhm & Dorris (1968) and Patten (1962).

RESULTS AND DISCUSSION

COMMUNITY DYNAMICS

Species Composition

Twenty-nine species of rotifera and 38 microcrustaceans were collected from October 1973 to October 1976 (Table 1). Other constituents of plankton included

Table 1.—Distribution of rotiferan and crustacean zooplankters collected from open-water stations 1, 2, 3, 4, 5, and 7 and littoral cove stations A, B, C, D, and X in Lake Sangchris. Species indicated by a superscript letter (a) are those not collected in Lake Shelbyville.

	Stations and Periods of Collection			
Taxa	Sept. 1973–Sept. 1974	Sept. 1974–Sept. 1975	Sept. 1975–Oct. 1976	May 1976–Oct. 1976
Rotifera				
Class Monogononta				
Family Brachionidae				
Brachionus angularis	123457	123457	123457	ABCDX
B. calyciflorus Pallas	123457	123457	123457	ABCDX
B. caudatus Barrois and Daday	123457	123457	123457	ABCDX
B. quadridentata Hermann	123457	23457	123457	ABCDX
B. urceolaris Muller	123457	123457	123457	A
B. nilsoni Ahlstrom	3		5	ABCD
B. bennini Leissling[a]				X
B. bidentata Anderson			5	B DX
Keratella cochlearis (Gosse)	123457	12 4	123457	A CD
K. quadrata (Muller)			345	C
Notholca spp. Gosse	123457	12 457	1 34 7	
Platyias patulus (O.F. Muller)			1	ABCDX
P. quadricornis[a]	57			A X
Euchlanis spp. Ehrenberg[a]	45	1 4		B DX
Epiphanes spp. Ehrenberg[a]	123457	123457	4	B X
Colurella spp. Bory de St. Vincent	34			
Family Lecanidae				
Lecane luna Nitzsch	1 457	1 345	123457	B DX
Monostyla spp. Ehrenberg	1			BC X
Family Notommatidae				
Cephalodella spp. Bory de St. Vincent	4	5	123457	ABC
Family Trichocercidae				
Trichocerca spp. Lamarck	123457	123457	123 5	ABCDX
Family Asplanchnidae				
Asplanchna priodonta Gosse	123457	12 457	123457	ABCDX
Family Synchaetidae				
Synchaeta sp. Ehrenberg	123457	123457	123457	ABCDX
Polyarthra vulgaris Carlin	123457	123457	123457	ABCDX
Family Testudinellidae				
Filinia longiseta (Ehrenberg)	1234 7	123457	123457	ABCD
Family Hexarthridae				
Hexarthra sp. Schmarda	123457	123457	123457	ABCD
Family Conochilidae				
Conochiloides spp. Hlava	123457	123457	5	CDX
Conochilus spp. Hlava		123457		
Family Proalidae				
Proales sp. Gosse		234		
Family Collothecidae				
Collotheca spp. Harring		123457		
Arthropoda				
Class Crustacea, Subclass Branchiopoda				
Order Cladocera				
Family Sididae				
Sida crystillina (O. F. Muller)[a]			4 7	
Diaphanosoma brachyurum (Lieven)	123457	123457		
D. leuchtenbergianum Fischer			123457	ABCDX
Family Daphnidae				
Daphnia parvula Fordyce	123457	123457	123457	ABCDX
D. ambigua Scourfield	12345			
Ceriodaphnia lacustris Birge	123457	123457		
C. reticulata (Jurine)		12		
C. quadrangula (O.F. Muller)			1 3457	B
Simocephalus vetulus Schodler[a]				X

Table 1.—Continued.

	Stations and Periods of Collection			
Taxa	Sept. 1973–Sept. 1974	Sept. 1974 Sept. 1975	Sept. 1975–Oct. 1976	May 1976–Oct. 1976
Scapholeberis kingi Sara[a]	4			B X
Moina micrura Kurz				D
Family Bosminidae				
Bosmina longirostris (O.F. Muller)	123457	123457	1234 7	ABCDX
Family Macrothricidae				
Ilyocryptus sordidus (Lieven)		12 4 7	4	
Wlassicsia kinistinensis Birge	3			
Family Chydoridae				
Kurzia latissima (Kurz)[a]				X
Leydigia quadrangularis (Leydig)	123457		12 5	
L. acanthoceroides (Fischer)	4	4 7		
L. leydigi		3 7		
Alona costata Sars	123457		57	
A. guttata Sars			3	A
A. rectangula Sars			1	X
A. quadrangularis (O.F. Muller)	12 7			
A. circumfermbrates		3 7		
Pleuroxus denticulatus Birge	12	2 4	1 457	B X
P. hamulatus Birge	34 7		1 4	DX
Chydorus sphaericus (O.F. Muller)	123457	123457	123457	X
Camptocercus rectirostris Schodler[a]	2			X
Family Leptodoridae				
Leptodora kindtii (Focke)			7	
Subclass Copepoda				
Order Calanoida				
Family Diaptomidae				
Diaptomus pallidus Herrick				B
D. siciloides Lilljeborg	123457	123457	123457	ABCDX
Order Cyclopoida				
Family Cyclopidae				
Cyclops vernalis Fischer	123457	123457	123457	
C. bicuspidatus thomasi (S.A. Forbes)	123457	123457	123457	
Eucyclops speratus (Lilljeborg)	1 7	1 7	1 7	
Mesocyclops edax (S.A. Forbes)	123457	123457	123457	CDX
Macrocyclops albidus (Jurine)			5	X
Paracyclops fimbriatus poppei (Rehberg)	4			
Tropocyclops prasinus (Fischer)	7			
Family Ergasilidae				
Ergasilus spp.	3		123457	BCD
Order Harpacticoida	123457	23 7	7	

Hydra, nematodes, oligochaetes, ostracods, trichopterans, and two dipteran families. Although most zooplankton forms (i.e., holoplankton) spend their entire life history beneath the surface film, the chironomids and *Chaoborus* are only part-time constituents of the limnoplankton, since the adult forms are aerial land-dwelling midges. With the exception of four rotifera taxa and five species of microcrustacea, all holoplankton collected in Lake Sangchris have been observed in nearby Lake Shelbyville.

While the composition of zooplankton species in a reservoir system can be quite variable from year to year, 13 species were unobserved in Lake Sangchris until 1975 when a more strenuous sampling regime was initiated. The new cladoceran records included species of *Kurzia*, *Simocephalus*, *Moina*, *Sida*, *Ceriodaphnia*, and *Alona*, which typically inhabit weedy, littoral regions.

Most zooplankton records from Lake Sangchris are typical of lentic systems in this region of the Midwest. Yet, the species composition was unusual due to the absence of several common forms. The largest cladoceran, *Leptodora kindtii*, is a common inhabitant of local reservoirs from April to October, yet this species was observed only once (December 1975) at Lake Sangchris. Although it is a summer form, it may never have been introduced successfully into this watershed, or possibly it could not tolerate discharge turbulence or temperatures exceeding 30°C. Another explanation suggests that the few individuals collected in December 1975 may have been transported to the reservoir by wildfowl migrating southward.

One of the most common North American cyclopoid copepods, *Macrocyclops albidus,* was never observed in Lake Sangchris until 1975, when it was collected in coves and other backwaters. *Paracyclops fimbriatus poppei* and *Tropocyclops prasinus* are also common and widespread lentic forms on the North American continent, but their presence in Lake Sangchris was limited to a very brief occurrence during the monitoring phase of this study (1973–1974).

An analysis of water chemistry data (Brigham 1981) suggests that few or no chemical limitations were imposed on the zooplankton in Lake Sangchris. Since most species of Cladocera and Copepoda can withstand oxygen concentrations of less than 1 ppm, the amount of dissolved oxygen in Lake Sangchris was of little significance except in the hypolimnion during short periods of thermal and oxygen stratification (Brigham 1981). The most easily recognized parameter affecting zooplankton survival is pH, or rather the complex of physicochemical variables, each of which by itself may be capable of affecting species composition. The large majority of rotifers are "transcursion" species that occur in both acid and alkaline waters (pH – 4.1–8.5), and most Cladocera occur in waters having a pH of 6.5–8.5. Since the pH of Lake Sangchris ranged from 6.7 to 9.5 during the study (Brigham 1978), there was little chance that it was a limiting factor to most zooplankton constituents.

Periodicity of Species

The periodicity of selected species (only those species collected in at least 2 of the 3 study years were considered) is shown in Table 2. Several taxa, including *Brachionus angularis, Polyarthra, Synchaeta, Bosmina longirostris,* and *Diaptomus siciloides,* were observed throughout the year, while *Chydorus sphaericus* and *Daphnia parvula* were common species on virtually all sample dates. Most other species were somewhat dicyclic, but others were monocyclic or very sporadic; the latter included the crustaceans *Alona, Pleuroxis, Camptocercus,* and *Eucyclops speratus,* which typically inhabit the more shallow, weedy areas. Since this information indicates only general trends in a particular aquatic system, little or no effect on zooplankton periodicity can be attributed to the operation of the generating plant. However, some traditionally dicyclic species (particularly the crustaceans) became perpetual in the heated system, indicating that possibly the interrelated biological and physicochemical factors in Lake Sangchris favored continual growth and reproduction for these forms.

Brigham & Moran (1974) suggested that "heat tolerant" species in Lake Sangchris should become abundant sooner than "less tolerant" forms. But the data showed that abundance peaks were inconsistent and that population densities increased from the relatively shallow discharge canal to the deeper regions adjacent to the dam. In view of these data, lake basin morphometry and not heat input was suggested by Brigham as the primary influence on zooplankton periodicity.

In 1976 I disregarded Brigham's peak-of-abundance theory and hypothesized that in a heated lake, temperature increases above ambient may induce longer or shorter growing periods for warmwater (summer) and cold-water (winter) species, respectively. This hypothesis was based on a suggestion by Gibbons (1976) that certain temperature elevations in a cooling system might provide an extension of seasonal species duration, a situation which may produce more offspring during normally nonreproductive periods (Gibbons 1976). In addition, the animals would grow larger, and this increased size, coupled with higher temperatures, could result in increased filtering and feeding rates (Waite 1976). To facilitate an analysis of the seasonal duration of zooplankton in Lake Sangchris, a comparison of species common to Lake

Table 2.—Periodicity of zooplankton species collected from Lake Sangchris in at least 2 years between September 1973 and October 1976. Letters indicate the months in which each species was observed

Taxon	Year																																					
	1973				1974												1975												1976									
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
Rotifera																																						
Asplanchna priodonta	S	O	N	D	J	F	M	A	M	J	J	A	S								M	J	J	A	S	O		D	J	F	M	A	M	J	J	A	S	O
Brachionus angularis	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
B. calyciflorus		O		D	J	F	M	A	M		J	A					J	F	M	A	M	J	J				N	D	J	F	M	A	M	J	J	A		
B. caudatus	S	O				F	M		M	J	J	A	S								M	J	J	A	S	O							M	J	J	A	S	O
B. nilsoni		O					M																											J				
B. quadratus	S	O	N	D	J	F	M	A	M		J																N						M		J	A	S	
B. urceolaris					J	F	M	A										F	M	A	M	J	J					D		F	M	A	M		J	A		
Filinia longiseta				D	J	F	M	A	M		J	A						F	M	A	M	J	J		S		N	D	J	F	M	A	M	J	J	A	S	O
Hexarthra sp.	S	O	N						M	J	J	A	S								M	J	J	A								A			J	A	S	
Keratella cochlearis				D	J	F	M	A	M	J								F		A		J	J	A											J	A	S	O
Platyias patulus	S	O	N						M		J	A											J	A											J	A	S	O
Polyarthra vulgaris	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
Rotaria neptunia															N	D	J			A	M	J		A			N				M	A	M					
Synchaeta sp.	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
Trichocerca sp.													S	O					M		M	J	J	A													S	O
Cladocera																																						
Alona costata					J	F	M																				N											
Bosmina longirostris		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
Camptocercus rectirostris				D																																		
Chydorus sphaericus		O	N	D	J	F	M	A	M	J	J	A	S	O	N		J		M	A	M	J	J	A	S	O	N		J	F	M	A	M	J	J		S	O
Daphnia parvula		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M		M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
Diaphanosoma brachyurum	S	O	N				M	A	M	J	J	A	S	O								J	J	A														
D. leuchtenbergianum																									S	O	N	D				A	M	J	J	A	S	O
Leydigia quadrangularis				D	J	F	M			J	J																N	D		F								O
Pleuroxus denticulatus				D	J	F													M	A	M				S			D						J				
P. hamulatus										J	J																									A	S	O
Scapholeberis kingi										J																								J			S	
Copepoda																																						
Cyclops vernalis	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
C. bicuspidatus thomasi				D	J	F	M	A	M	J					N	D	J	F	M	A	M						N	D	J	F	M	A	M					
Mesocyclops edax		O	N		J	F	M	A	M	J	J	A	S	O	N				M	A	M	J	J	A	S	O							M	J	J	A	S	O
Eucyclops speratus															N			F	M																		S	
Diaptomus siciloides	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O

Sangchris and Lake Shelbyville was made, based on data accumulated from July 1975 through March 1977 (Table 3).

ROTIFERA.—Representatives of the loricate family Brachionidae had the greatest variation of seasonal duration in the two reservoirs. A typical summer species, *Brachionus caudatus,* was observed from July to September in Lake Shelbyville, but in Lake Sangchris this species occurred 2 months earlier in May. Likewise, *B. calyciflorus,* a common species that usually reaches its peak abundance in July or August, was collected lakewide most of the year in Lake Shelbyville but was found in Lake Sangchris only during spring, midsummer, and late autumn. A typical coolwater form, *B. urceolaris,* was common from November to May in the unheated lake, but in Lake Sangchris it was restricted to late winter and early spring. One of the most common brachionids, *B. angularis,* reproduced throughout the year in Lake Sangchris, but its growing season in Lake Shelbyville was restricted to a 7-month period. Although *Keratella quadrata* populations usually peak in June and move to the cooler hypolimnion before declining in midsummer, this species was collected in Lake Shelbyville during May and June but was observed only in the April collections from Lake Sangchris. *Hexarthra* sp., a typical late summer form, was found only in August at Lake Shelbyville, but in Lake Sangchris this soft-bodied form was prevalent from July through September. Feeding on chrysomonads and protozoans, *Synchaeta* sp. populations were dicyclic in both reservoirs; their longest growing period in Lake Sangchris was early winter to early summer, whereas the interval at Lake Shelbyville was July to November. Occurring all year at Lake Sangchris, *Filinia longiseta* was collected only from May to September at Lake Shelbyville.

CLADOCERA.—Usually observed in winter and spring, *Bosmina longirostris* was a common inhabitant in the heated lake most of the year. Inhabiting the bottom ooze during most of its life history, *Ilyocryptus sordidus* was found in the Sangchris plankton only during July, yet in Lake Shelbyville it was collected in March, August, and September. While *Ceriodaphnia quadrangula* was collected from early summer to November in Lake Shelbyville, this species was dicyclic in Lake Sangchris.

COPEPODA.—Common to Lake

Table 3.—A comparison of seasonal occurrences of zooplankton species common to lakes Sangchris and Shelbyville. Monthly collections were made from July 1975 through March 1977.

Taxa	Lake Sangchris	Lake Shelbyville
Rotifera		
Brachionus anguloris	Jan.–Dec.	May–Dec.
B. calyciflorus	Mar.–May, July, Dec.	Jan.–Nov.
B. urceolaris	Feb.–April	Nov.–May
B. caudatus	May, July–Sept.	July–Sept.
B. bidentata	June–Sept. (coves only)	Sept.
Filinia longiseta	Jan.–Dec.	May–Sept.
Keratella quadrata	April	May–June
Hexarthra sp.	July–Sept.	August
Synchaeta sp.	Dec.–June, Aug.–Oct.	Mar.–Apr., July–Nov.
Asplanchna priodonta	Mar.–Oct.	Feb.–Apr., July–Dec.
Cladocera		
Bosmina longirostris	Feb.–Dec.	Dec.–June
Ceriodaphnia quadrangula	June–July, Oct.–Dec.	June–Nov.
Ilyocryptus sordidus	July	Mar., Aug.–Sept.
Copepoda		
Cyclops vernalis	May–June, Sept.–Nov.	Jan.–Dec.
Mesocyclops edax	May–Oct.	July–Oct.
Macrocyclops albidus	June, Aug.–Oct.	Jan., Mar., Sept.

Shelbyville all year, *Cyclops vernalis* was dicyclic in Lake Sangchris in late spring and autumn, while *Mesocyclops edax* appeared in the heated reservoir 2 months earlier than in Lake Shelbyville. The appearance of *Macrocyclops albidus* seemed random in both lakes, and thus no specific trends were associated with this species.

These preliminary observations led me to conclude that the reproductive period for some Lake Sangchris zooplankters (mostly rotifers) appeared to increase or decrease depending upon the temperature preference of the individual species. Increased growth periods could result in increased fecundity and production of zooplankters during normally nonreproductive periods, thus precipitating the development of a more substantial food base for newly hatched fry and young-of-the-year planktivorous fishes. Such data, combined with biomass estimates, would be of great practical importance to fishery scientists interested in creating conditions conducive to increased fish production in cooling reservoirs.

Number of Species

Many classical zooplankton studies have shown that the abundance of these organisms undergoes extensive seasonal variation. The typical curve of seasonal zooplankton abundance usually has a large spring pulse; a decreased population during the summer; and a second, less pronounced pulse in the fall, followed by a very small population in winter. Furthermore, the number of species may also follow a somewhat similar pattern unless the natural periodicity is modified or eliminated by various biological, chemical, or physical parameters.

The mean numbers of zooplankton species in Lake Shelbyville are compared to the mean numbers in the cooling loop and control arm of Lake Sangchris from September 1975 to May 1977 (Fig. 2). As is typical of nonheated reservoirs in this region, the mean number of Lake Shelbyville species decreased to 6 during the winter but increased to 16–19 species in the spring and early summer. Likewise, conditions in the cold-water control arm in Lake Sangchris resulted in a similar curve but with less variability and slightly fewer species. In contrast, the cooling loop had 9–11 species during autumn and winter and gradually increased to 15 species by midsummer. However, a *t*-test analysis revealed no evidence of significant differences (0.05 level) among the three monthly means for any particular sample date. Thus, while the number of species in the cooling loop did not exhibit the classical seasonal fluctuations observed in Lake Shelbyville, there were no indications of complete

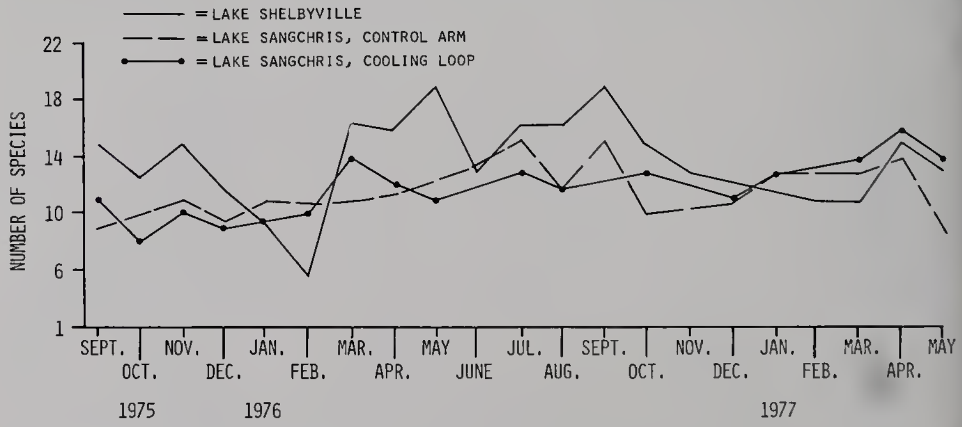

Fig. 2.—A comparison of the total number of zooplankton species in Lake Shelbyville and in the cooling loop and control arm of Lake Sangchris, September 1975 to October 1976.

species suppression, but rather I observed a damping effect that allowed little annual variability of species numbers.

While these observations may seem unimportant, the ecological significance may be noteworthy in terms of the immediate relationships of primary and secondary producers and ultimately of the entire trophic structure. Coutant (1977) showed that algal populations in Lake Sangchris have had fewer highly pronounced blooms and declines than the populations in other lakes. According to Wetzel (1975), the seasonal amplitude of the maximum and minimum of phytoplankters in temperate waters is usually very large (one thousandfold), but the amplitude in Lake Sangchris was only fiftyfold, a level more nearly approaching the fivefold to tenfold difference of tropical lakes.

Probably the most important consequences of this damping of the lower trophic levels are the atypical relationships of the plankton and the physicochemical limnology of the cooling lake basin from winter through spring. The winter phyto- and zooplankton constituents in most lakes and reservoirs are cold-water, low-light adapted species that can survive only within a narrow range of conditions. Spring circulation, which follows the loss of ice cover, results in the mixing of nutrients from the hypolimnion, and these particles, combined with increasing light levels, contribute to the typical synchronous blooms of phyto- and zooplankton populations in the spring.

In Lake Sangchris, however, heated discharge waters and the continuous circulation were probably directly related to the damping phenomenon. Continual mixing of water, especially in the cooling loop, prevents winter stratification; hence, few or no nutrients are available for the typical burst of spring phytoplankton growth. The formation of ice, which limits light penetration, was prominent in Lake Sangchris only in the vicinity of the intake arm, in the control arm, and in coves adjacent to the warmwater arm. Additionally, since the duration of ice cover in this lake is relatively short compared to that on unheated lakes, greater light penetration and warmer water temperatures are certain to affect species composition, succession, and standing crop from late autumn through spring, i. e., cold-water, low-light adapted species are limited to a shorter period while warmwater species are present later in autumn and earlier in spring (see previous section).

Although damping of the lower trophic levels in Lake Sangchris from autumn through spring defies the classical theory regarding the winter decline and spring blooms of plankton, this condition may be an enhancement by providing a stabilized food base for such secondary and tertiary consumers as invertebrate predators and planktivorous fishes.

Species Diversity

Analyses of zooplankton communities were aided by using the species diversity index ($\bar{d}$) (Wilhm & Dorris 1968) to express a relationship between (1) the richness of species in a community and (2) the distribution or evenness of individuals among those species. Although the index is used primarily to evaluate terrestrial and benthic biotopes, it can also characterize the degree of stress affecting zooplankton communities, as well as compare the relative conditions of populations in different habitats. Unlike low values of benthic diversity, however, low zooplankton values may not necessarily be indicative of a fatal stress; rather, such values could indiciate a period when species succession is occurring or when diversity and abundance are normally low, i.e., during the winter months. Therefore, data should be carefully analyzed before assessing the reasons for low values.

Index values of the limnetic zooplankton (Rotifera, Cladocera, and Copepoda) diversity in Lake Sangchris ranged from 0.18 to 3.00 from September 1975 to October 1976 (Table 4). For most

Table 4.—Variation of species diversity index values ($\bar{d}$) for limnetic zooplankton populations in Lake Sangchris, September 1975 to October 1976.

	Station						
Date	1	2	3	4	5	7	Mean
1975							
September	2.65	2.47	2.25	2.61	2.58	2.30	2.48
October	1.59	1.62	1.71	1.36	1.51	1.42	1.54
November	0.18	1.83	2.09	2.02	1.94	1.74	1.72
December	1.91	2.11	1.83	1.84	2.14	1.92	1.96
1976							
January	. . .	1.48	0.94	1.03	. . .	. . .	1.15
February	1.32	1.38	1.45	1.24	1.12	1.57	1.35
March	1.67	1.98	1.78	2.31	2.02	1.78	1.92
April	2.64	2.39	2.83	2.86	2.86	1.43	2.67
May	2.35	2.14	2.17	2.19	2.34	2.35	2.26
June	2.80	3.00	2.72	3.00	2.88	2.67	2.85
July	2.10	2.32	2.67	1.96	2.14	1.84	2.17
August	2.03	2.17	2.23	2.29	2.12	2.02	2.14
September	2.74	2.59	2.72	2.77	2.86	2.44	2.69
October	2.67	2.46	1.99	2.10	2.15	2.40	2.30

winter samples (November to March) these values were less than 2.00, the lowest occurring in January. The highest $\bar{d}$ value (3.00) was observed in June at stations 2 and 4, and moreover, the highest mean diversity for all stations occurred in the same month. No significant differences (0.05 level) were found between values for the intake (Station 1) and discharge (Station 5) canals; the $\bar{d}$ values were virtually the same at both stations. Overall, species diversity values were highly variable, with differences and similarities attributed primarily to similar seasonal responses and erratic power plant discharge conditions.

Since limnetic zooplankton populations continually drift with the current around the cooling loop, I hypothesized that isolated coves containing stable littoral communities would exhibit more varied responses to the presence of heated water. Data comparing species diversity in coves adjacent to the cooling loop and control arm are shown in Table 5. The overall means were lowest during July and August, when $\bar{d}$ values were consistently higher at limnetic stations. While the mean observed diversity at Station X was generally as high as or higher than those at other coves during summer, the diversity at that station decreased quickly in September and October, a period coincident with the decline of macrophyte and phytoplankton standing crops. Generally, for the summer and autumn months, diversity in coves showed a dissimilar response to heated water compared to those of the lake stations. Additional data collections must be statistically analyzed before the null hypothesis can be accepted.

Table 5.—Variation of the mean species diversity index values (d) of zooplankton populations in coves adjacent to the cooling loop (stations A, C, D, X) and control arm (Station B) at Lake Sangchris.

	Station					
Date	A	C	D	X	B	Mean
1976						
May	1.84	2.62	2.11	2.28	1.94	2.56
June	2.09	2.63	2.38	2.57	2.76	2.29
July	1.13	1.32	1.74	2.42	1.93	1.71
August	0.70	1.36	0.54	2.15	1.81	1.31
September	2.91	1.75	3.02	0.97	1.25	1.98
October	2.00	2.08	2.21	0.93	1.86	1.82

EFFECTS OF CONDENSER PASSAGE

There are several conflicting reports in Kittitsina (1973) regarding the condition of zooplankters after passing through power plant condensers. A number of investigators from the United States, Asia, and eastern Europe have reported that the organisms become traumatized when passing through condenser units and lose up to 50 percent in biomass and numbers. In contrast, other studies in the U.S.A., and particularly studies in Great Britain, show that the zooplankton remain viable after passing through the tubes. Likewise, the latter situation appeared to be the case in Lake Sangchris, because during the 2 years of monitoring (1973–1974) there was little difference between the intake and discharge canals in numbers of species and organisms collected. However, that investigation did not determine whether the animals in the discharge samples were dead or alive at the time of collection or the length of time the animals were viable after passing through the condensers.

STANDING CROP

Standing crop is a general index reflecting the sum total of all biotic and abiotic interrelationships. In aquatic systems, it can be expressed as (1) the dry and ash-free biomass per unit volume or surface area and/or (2) estimations of calorific values (kcal g^{-1} of dry weight) per unit volume or surface area.

This investigation has shown that the standing crop of pelagic zooplankton in a heated reservoir undergoes many seasonal variations (Table 6). The standing crop in Lake Sangchris was highest during early spring, decreasing through late spring and summer. This trend was opposite that recorded for the unheated Lake Shelbyville system, where the biomass was highest during late spring and summer. In Poland, Sherstyuk (1971) also observed that in unheated lakes the late spring and winter plankton had the highest and lowest values, respectively.

Probably several interrelated factors acting on a heated system result in decreased biomass during the summer. One theory suggests that entrainment may significantly reduce the zooplankton biomass, especially during periods of peak electrical power production. Kittitsina (1973) in Lithuania has shown evidence of a 50-percent decrease in the abundance and biomass of the zooplankton fauna during summer. However, in Lake Sangchris the number of organisms may not have been reduced significantly after passing through the condensers. Davies et al. (1976) suggest

Table 6.—Mean zooplankton biomass (mg m^{-3}) of Lake Sangchris sampling stations, with a comparison to the mean in Lake Shelbyville, October 1975 to October 1976.

	Lake Sangchris								
	Collecting Station						Cooling Loop	All Stations	Lake Shelbyville
Date	1	2	3	4	5	7	Mean	Mean	Mean
1975									
October	135	96	48	128	80	129	97	103	100
November	139	142	131	77	304	191	159	164	52
December	107	86	128	159	117	133	119	122	85
1976									
February	46	49	53	56	31	109	47	57	76
March	41	58	34	44	47	35	45	43	58
April	47	39	43	62	73	47	53	52	18
May	. . .	149	75	105	. . .	147	110	119	91
June	71	47	50	73	89	62	66	63	120
July	42	43	49	40	65	24	48	44	69
August	53	73	57	55	38	59	55	56	134
September	50	64	58	60	106	80	68	70	94
October	46	24	22	43	98	39	47	45	. . .

that either zooplankters remain viable after condenser passage, or the discharge receiving waters support a plankton recovery rate capable of compensating

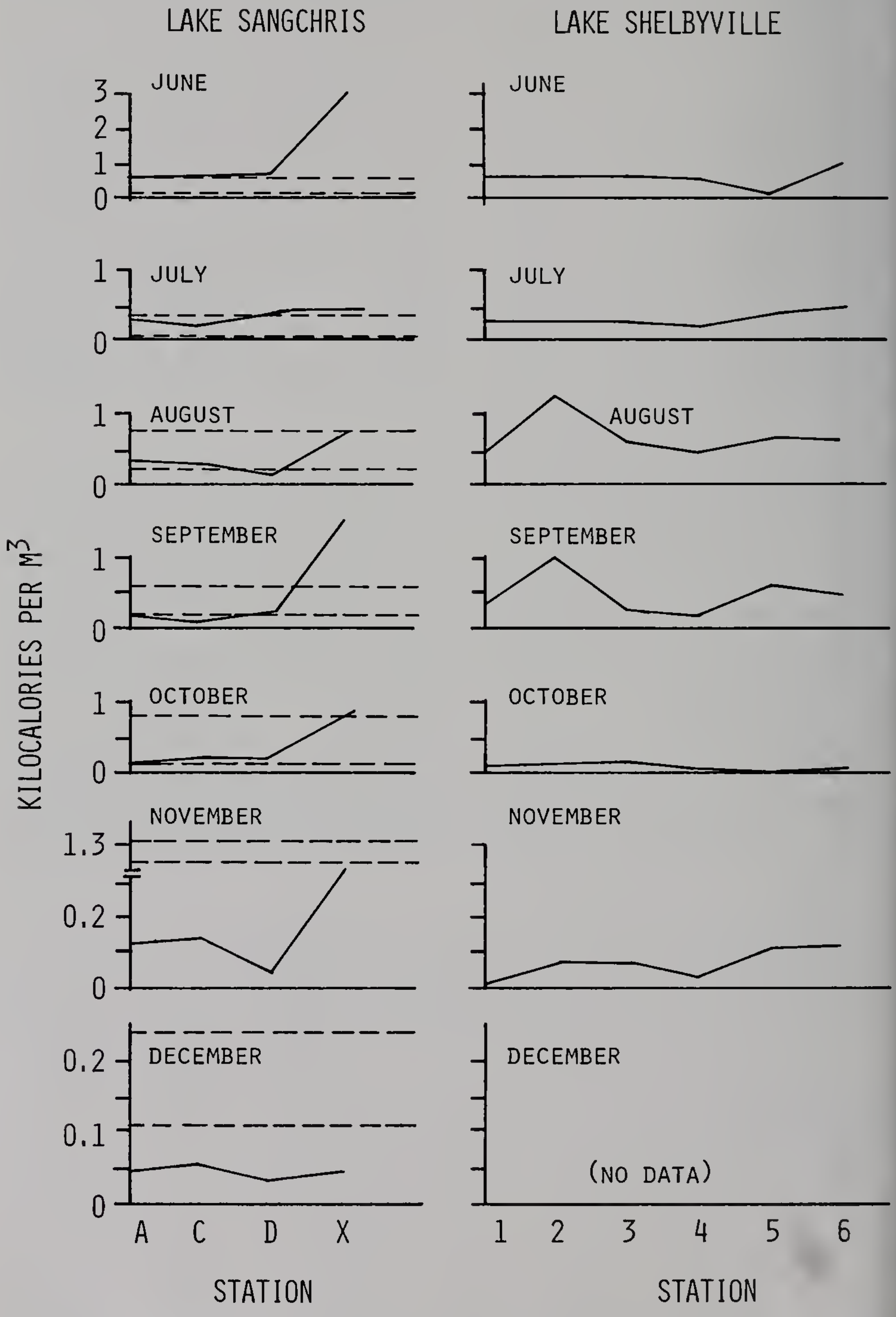

Fig. 3.—A comparative summary of the production of littoral and pelagic zooplankton collected from Lake Sangchris and pelagic zooplankton of Lake Shelbyville. The solid lines represent the number of kilocalories available per m^3 at cove stations A, C, D, and X in Lake Sangchris and open-water stations 1, 2, 3, 4, 5, and 6 in Lake Shelbyville. The dashed lines indicate the range of calorific values computed from all open-water stations in Lake Sangchris.

for entrainment mortality. My calculations from the ashed biomass data revealed that the small reduction of biomass due to entrainment probably was offset by the addition of organisms via the slag pond overflow at the discharge canal (Fig. 1).

The second theory cites water temperatures as the most influential factor affecting heated aquatic systems. Although the monitoring studies of the first 2 years examined the reaction of the drifting plankton to heated effluents, little was done in regard to planktobenthic organisms inhabiting the many side coves. To determine if the standing crop of zooplankton in these regions reflects the effects of heated waters to the same extent as do their pelagic counterparts, I hypothesized that the zooplankton standing crop in the coves was significantly decreased during the warmer months due to a combination of shallow water and the circulation of heated water into the coves.

In making estimates of mean lakewide production of zooplankton (measured in available energy units per unit volume) in Lake Shelbyville, pelagic production was compared with cove production in Lake Sangchris from June through December 1976 (Fig. 3). In June and July, production in all Lake Sangchris cove stations was well within or above the upper range of open-lake values (0.4–0.6 kcal m^{-3}), but in late autumn and winter, cove production decreased to levels below those in all nearby lake stations. Production in Lake Shelbyville, however, was highest during the summer (sometimes higher than in Lake Sangchris), but dropped to lower levels during the autumn and winter.

When the temperature rose during the summer in Lake Sangchris, zooplankton production in the main channel was significantly lower than it was in the coves. Harleman et al. (1976) showed that heated water circulating into side coves suffers a heat loss at the air-water interface, resulting in somewhat cooler water temperatures than those in the main channel. This cooling effect probably enhanced zooplankton survival in the Lake Sangchris coves by reducing the mortality rates of warmwater species subjected to sublethal or lethal water temperatures. Therefore, the null hypothesis was rejected, because during the warmer months, increased water temperatures in pelagic regions resulted in less biomass there compared with the standing crops in coves and other littoral regions.

In addition, this study revealed that some zooplankton assemblages may be enhanced by the atypically warmwater temperatures encountered during late autumn and winter. A comparison of autumn and early winter production of the open-water regions of Lake Sangchris and Lake Shelbyville indicated generally higher values in the former from September through October. Moreover, Lake Sangchris production was significantly higher (0.05 level) in November, which provides a possible additional explanation for the increased abundance of the largely planktivorous yellow bass in the discharge canal relative to that in the intake canal in cold months (J.A. Tranquilli, personal communication). Kititsina (1973) noted that in various Soviet lakes heating stimulated zooplankton development in autumn and winter, and the peaks of abundance and biomass during these seasons were most evident in the discharge zone. Consequently, the addition of heat provided a potential enhancement for the system during winter, but in summer, thermal loading resulted in zooplankton density and biomass reductions in the pelagic regions, with the coves serving as sanctuaries during the hottest months and providing a continuing food base for young-of-the-year planktivorous fishes.

SUMMARY

The chemical parameters associated with electrical power production did not impose any detectable limitations on the Lake Sangchris zooplankton during this study.

While most zooplankton records from Lake Sangchris are typical of those of midwestern lake systems, there were several notable absences, including the largest cladoceran, *Leptodora kindtii*, a common inhabitant of other lakes in Illinois.

Several traditionally dicyclic species became perpetual in the heated system; this phenomenon was a possible indication that the complex of biological and physicochemical parameters in Lake Sangchris favored continual growth and reproduction for these organisms.

The reproductive periods of some Lake Sangchris zooplankters (especially rotifers) appeared to increase or decrease, depending on the temperature preference of the individual taxon; the increased periods probably enhanced the population by increasing total production during normally nonreproductive periods. Species having increased growth periods during the spring in Lake Sangchris may contribute to a more substantial food base for the newly hatched planktivorous fishes.

A comparison of the zooplankton species collected in Lake Sangchris and those found in Lake Shelbyville revealed that the numbers of species in the cooling loop of the former did not exhibit the traditional seasonal fluctuations of the species in the latter, but experienced a damping effect that resulted in little annual variability of species numbers.

Species diversity index values of zooplankton in Lake Sangchris were highly variable, with differences and similarities attributed to seasonality and erratic power plant discharge conditions. There was no evidence of significant differences (0.05 level) of the diversity of zooplankton populations in the intake and discharge canals.

The standing crop of zooplankters in Lake Sangchris was highest during winter and early spring, decreasing through late spring and summer.

The calorific values of Lake Sangchris littoral zooplankton crops were well within or above the range of open-lake values (0.4–0.6 kcal m^{-3}), but in late autumn and winter, littoral production decreased to levels below those in all nearby open-lake stations. A comparison of open-water production at Lake Sangchris and Lake Shelbyville indicated generally higher values in the former, with production in Lake Sangchris significantly higher in November.

Generally, the addition of heat and the resulting physicochemical conditions in Lake Sangchris provided a potential enhancement for the system during autumn, winter, and spring; however, in summer, thermal loading resulted in zooplankton density and biomass reductions in the open-water regions, while coves apparently served as sanctuaries to reinoculate these regions when conditions for growth and reproduction were improved.

REFERENCES CITED

AHLSTROM, E. H. 1940. A revision of the rotatarian genera *Brachionus* and *Platyias* with descriptions of one new species and two new varieties. American Museum of Natural History Bulletin 77:143–184.

——— 1943. A revision of the rotatarian genus *Keratella* with descriptions of three new species and five new varieties. American Museum of Natural History Bulletin 80:411–457.

BRIGHAM, A.R., and R. L. MORAN. 1974. Plankton investigations at Lake Sangchris 5 September 1973 through 4 September 1974. Pages 2.1–2.97 *in* Annual report for fiscal year 1974. Lake Sangchris project. Illinois Natural History Survey, Urbana.

———. 1981. Water quality in a cooling water reservoir. Pages 290–319 *in* R. W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

———, and S. R. GNILKA. 1975. Plankton investigations at Lake Sangchris 4 September 1974 through 17 August 1975. Pages 2.1–2.68 *in* Annual report for fiscal year 1975. Lake Sangchris project. Illinois Natural History Survey, Urbana.

BROOKS, J. L. 1957. Systematics of North American *Daphnia*. Connecticut Academy of Arts and Sciences Memoirs 13:1–180.

———. 1959. Cladocera. Pages 587–656 *in* W.T. Edmondson, ed., Ward and Whipple's fresh-water biology. 2nd ed. John Wiley and Sons, Inc., New York.

COUTANT, L. W. 1979. Algal dynamics of Lake Sangchris and Lake Shelbyville. Pages 3-1–3-55 *in* Evaluation of a cooling lake fishery. Vol. 4. prepared by Illinois Natural History Survey for

Electric Power Research Institute, Palo Alto, CA.

DAVIES, R.M., C. H. HANSON, and L. D. JENSEN. 1976. Entrainment of estuarine zooplankton in a mid-Atlantic power plant: delayed effects. Pages 349–357 *in* G. W. Esch and R. W. McFarlane, eds., Thermal ecology, ERDA Syposium Series (CONF-750425), Augusta, GA.

EDMONDSON, W. T. 1959. Rotifera. Pages 420–494 *in* W. T. Edmondson, ed., Ward and Whipple's fresh-water biology. 2nd ed. John Wiley and Sons, Inc., New York.

GIBBONS, J. W. 1976. Thermal alteration and the enhancement of species populations. Pages 27–31 *in* G. W. Esch and R. W. McFarlane, eds., Thermal ecology, ERDA Syposium Series (CONF-750425), Augusta, GA.

GOULDEN, C. E. 1968. The systematics and evolution of the Moinidae. American Philosophical Society Transactions 58(6):1–101.

HARLEMAN, D., G. JIRKA, and K. STOLZENBACH with P. RYAN and E. ADAMS. 1976. Heat disposal in the water environment. Massachusetts Institute of Technology Press.

KEDL, R. J., and C. C. COUTANT. 1976. Survival of juvenile fishes receiving thermal and mechanical stresses in simulated power plant condenser. Pages 394–400 *in* G. W. Esch and R. W. McFarlane, eds., Thermal ecology, ERDA Syposium Series (CONF-750425), Augusta, GA.

KITTITSINA, L. A. 1973. Effect of hot effluent from thermal and nuclear power plants on invertebrates in cooling ponds. Hydrobiological Journal 9 (5):67–75.

PATTEN, B. C. 1962. Species diversity in net phytoplankton of Raritan Bay. Journal of Marine Research 20:57–75.

PENNAK, R. W. 1953. Fresh-water invertebrates of the United States. Ronald Press Co., Inc., New York.

SHERSTYUK, V. V. 1971. Calorific value of food organisms in the Kremenchug Reservoir. Hydrobiological Journal 7 (6):85–88.

TRANQUILLI, J. A., R. KOCHER, and J. M. MCNURNEY. 1981. Population dynamics of the Lake Sangchris fishery. Pages 413–499 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

WAITE, S. W. 1976. Filter-feeding dynamics of two Kansas cladocerans. Emporia State Research Studies 25(2):1–28. Emporia Kansas State University, Emporia, KS.

WETZEL, R. G. 1975. Limnology. W. B. Saunders Co., Philadelphia.

WILHM, J. L. and T. C. DORRIS. 1968. Biological parameters for water quality criteria. Bioscience 18:477–481.

WILSON, M. S. 1959. Free-living Copepoda: Calanoida. Pages 788–794 *in* W. T. Edmondson, ed., Ward and Whipple's fresh-water biology. 2nd ed. John Wiley and Sons, Inc., New York.

———, and H. C. YEATMAN. 1959. Free-living Copepoda: Harpacticoida. Pages 815–861 *in* W. T. Edmondson, ed., Ward and Whipple's fresh-water biology. 2nd ed. John Wiley and Sons, Inc., New York.

WINBERG, G. G. 1971. Methods for the estimation of production of aquatic animals. Academic Press, New York.

YEATMAN, H. C. 1959. Free-living Copepoda: Cyclopoida. Pages 795–815 *in* W. T. Edmondson, ed., Ward and Whipple's fresh-water biology. 2nd ed. John Wiley and Sons, Inc., New York.

The Benthic Macroinvertebrates from the Cooling Lake of a Coal-Fired Electric Generating Station

Donald W. Webb

ABSTRACT

The benthic macroinvertebrate community of Lake Sangchris was examined to determine the effect of heated effluent from a coal-fired electric power plant on its distribution and abundance. Of the 23 taxa of macroinvertebrates collected, chaoborids and chironomids made up 98 percent of the total. The species composition in Lake Sangchris was similar to that of nearby Otter Lake although the latter had more oligochaetes. A significantly higher abundance of benthic macroinvertebrates occurred in the deep water near the dam than elsewhere in the lake because of the large numbers of *Chaoborus punctipennis* found at that station. Significantly lower levels of abundance were found in the discharge channel than at other stations because silicate slag covered the bottom. The abundance of benthic macroinvertebrates in Lake Sangchris was comparable with or significantly higher than those in Otter Lake and in the profundal zones of Lake Shelbyville, Carlyle Lake, Peoria Lake, and Lake Wawasee. The abundance of benthic macroinvertebrates in the heated area of Lake Sangchris indicated that they readily tolerated the increased water temperatures, and the seasonal biomass closely followed the pattern for the seasonal abundance. The dominant benthic macroinvertebrates in Lake Sangchris aggregated in the deeper portions of the lake where a silt substrate was present, and the greatest diversity occurred between 4 and 6 m, the transition zone from hardpan clay and sand to silt. Artificial substrate samplers indicated that increased water temperatures in the discharge channel were not a limiting factor and that macroinvertebrates would colonize that area if a suitable substrate were present.

INTRODUCTION

The benthic macroinvertebrate community of Lake Sangchris was examined from September 1973 to September 1976 to determine the effect of the heated effluent from a coal-fired electric power plant on the species diversity and temporal and spatial distribution of macroinvertebrates relative to the various thermal regimes in the lake.

Lake Sangchris is on the boundary of Sangamon and Christian counties in central Illinois. It is an artificial impoundment developed by damming three branches of Clear Creek, a tributary of the South Fork of the Sangamon River. The lake consists of three long, narrow arms (Fig. 1) generally oriented in a north-south direction. The lake covers an area of 876 ha (2,165 acres) with an average depth of 4.6 m (15.0 feet) and a maximum depth of 13.7 m (44.9 feet) at the normal elevation of 178.3 m (585 feet) above mean sea level.

Lake Sangchris lies on the Jacksonville till of the Illinoian Stage of glacial deposits (Johnson 1964). Core samples (Limnetics, Inc. 1972) showed the surface sediments to be dark gray clay and silty clay with fine-grained sand and organic fibers. The lake bottom from the shoreline to a depth of 4 m was generally hardpan clay with isolated areas of sand and fine gravel. Below 4 m the lake

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bottom consisted of fine silt with allochthonous organic detritus. The bottom sediment in the discharge channel from the power plant was covered with a layer of silicate slag.

For purposes of comparison with a lake not receiving heated effluent, the benthic community of Otter Lake was examined from April through November 1975 and from April through September 1976. Otter Lake is a water supply reservoir 9.7 km (6 miles) west of Girard, Macoupin County, Illinois, and lies on the same sediment topography as Lake Sangchris.

Benthic samples also were collected during 1974 and 1975 in the East Branch (6.1 km south of Bulpitt) and the West Branch (1.6 km north of Zenobia) of Clear Creek above the impounded waters of Lake Sangchris to gain insight into the probable composition of the stream fauna prior to the stream's impoundment.

MATERIALS AND METHODS

The average biweekly bottom temperature and oxygen concentration for the heated, or discharge arm, (stations 5, 4, and 3) and unheated or intake- and control-arm, areas (stations 2, 1, and 7) of Lake Sangchris from 1973 through 1976 have been extracted from data collected by Brigham (1977).

Monthly benthic collections in Lake Sangchris began on 19 September 1973

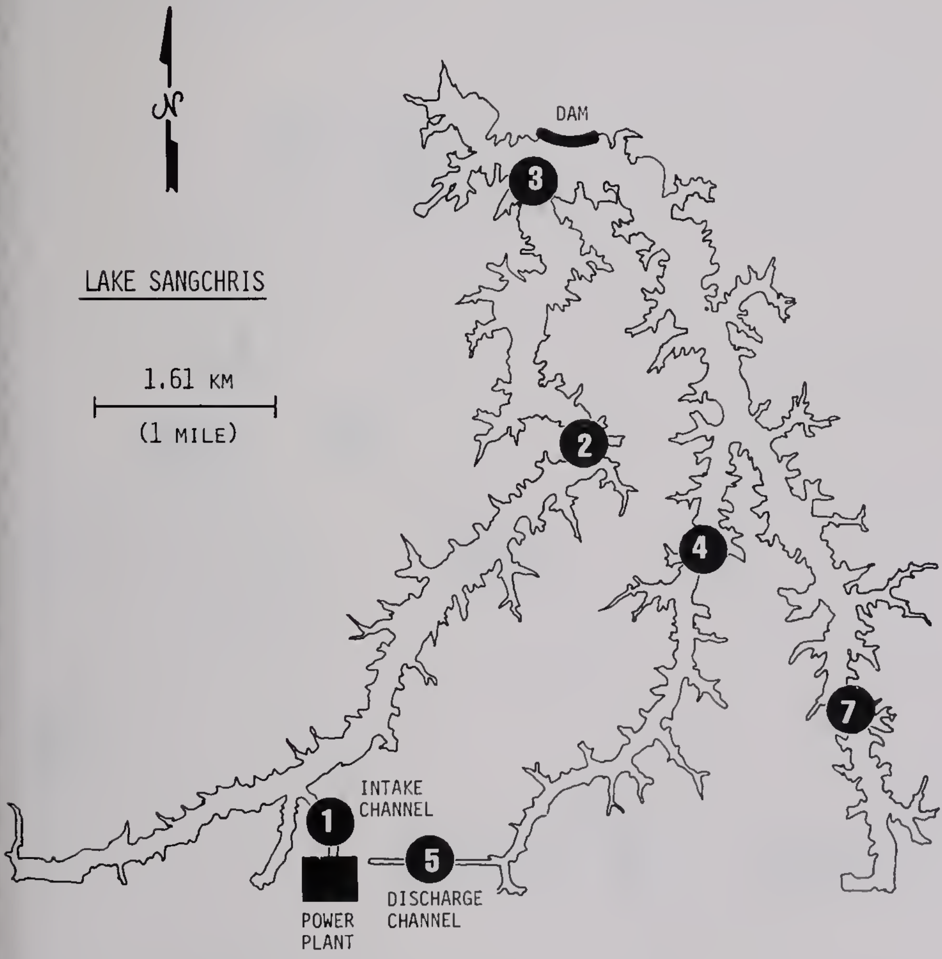

Fig. 1.—Lake Sangchris sampling stations for benthic macroinvertebrates.

and continued through 3 September 1976. Collections were made at six midchannel (profundal) sites (Fig. 1). Three 15.2- x 15.2-cm (6- x 6-inch) Ekman grab samples were taken at each station and at a depth of 2 m at both shoreline at stations 2, 3, 4, and 7. The selection of three samples at each site was based on species averaging for one standard deviation from a mean of 30 samples that had been collected for statistical analysis. Samples were washed through a brass screen (no. 30 mesh), preserved in 70-percent ethyl alcohol, and sorted in white enamel pans. At each station, species diversity (d) was determined by the equation of Margalef (1958), which expresses the relationship between the number of species (s) and the natural logarithm of the total number of individuals (N):

$$d = \frac{s-1}{\ln N}$$

To determine the spatial distribution of benthic macroinvertebrates, 12 transects were selected (Fig. 2). At each transect three Ekman grab samples were collected at the shoreline and then at every 2 m in depth across the transect to the opposite shore. A total of 288 samples was taken at 96 sites during collecting periods in May, July, and September of 1974 and May and July of 1975. Comparisons were made among different transect locations, depths, substrates, months, and water temperatures.

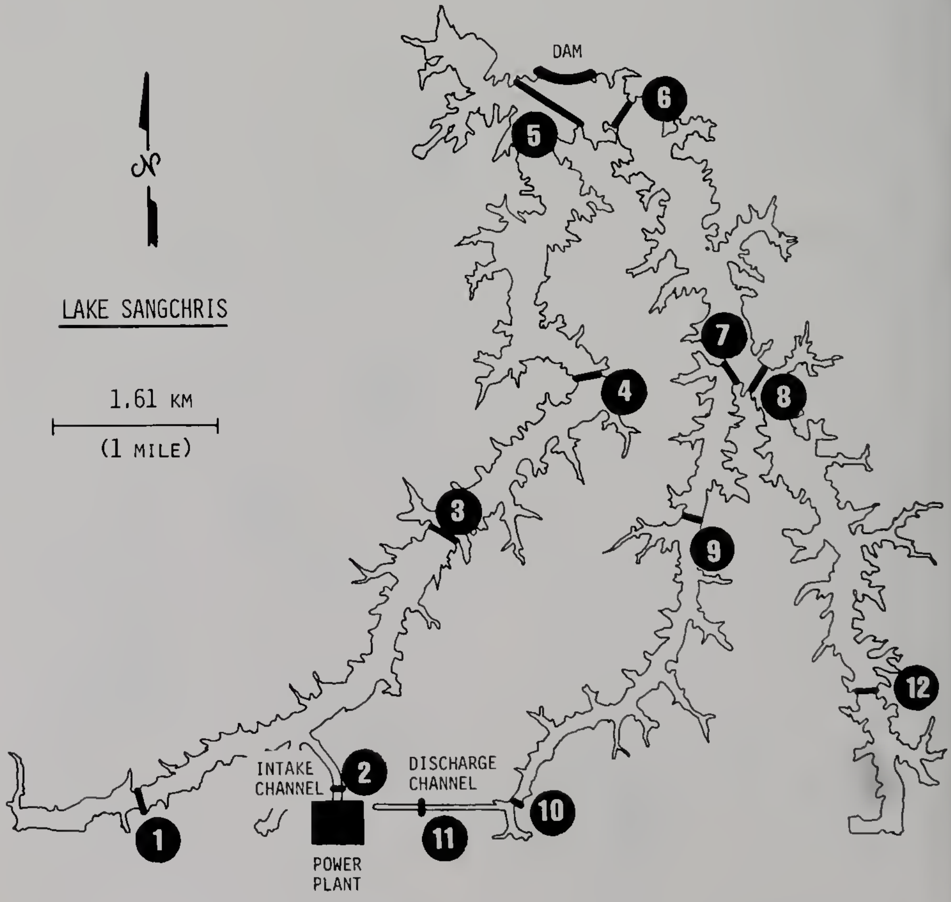

Fig. 2.—Lake Sangchris sampling transects for spatial distribution of benthic macroinvertebrates.

In viewing the distribution pattern of benthic macroinvertebrates within Lake Sangchris, the sampling efficiency of the Ekman grab on hardpan clay and sand must be taken into consideration. For samples taken along the shoreline the jaws of the grab were closed by hand to ensure that the surface area enclosed by the grab was scraped clean. In taking samples from depths of 2–4 m, only those samples in which the jaws of the grab were completely closed were retained for sorting and counting.

The effect of heated effluent and bottom substrate on benthic macroinvertebrates in the discharge channel (Station 5) was compared to that in the intake channel (Station 1) by taking three artificial substrate samples at each station, beginning in April 1975, and collecting the colonizing organisms in June, August, and October. The artificial substrate samplers were constructed from half of a minnow trap with an aluminum pan sealing each end. Each sampler contained four 7.6- x 7.6- x 7.6-cm (3- x 3- x 3-inch) cement blocks, with a surface area of 1,386 cm^{-2}, placed on edge. Only specimens from the bottom pan and six sides of the four cement blocks, having a total area of 1,796.7 cm^{-2}, were collected.

In Otter Lake, benthic collections were taken monthly from 16 April through 18 November 1975 and from 19 April through 3 September 1976. Three Ekman grab samples were collected at each of six sites (Fig. 3) in the northern half of Otter Lake. The depth at these sites ranged from 1 to 8 m, with stations 1 to 5 in the littoral-sublittoral zone and Station 6 in the profundal zone.

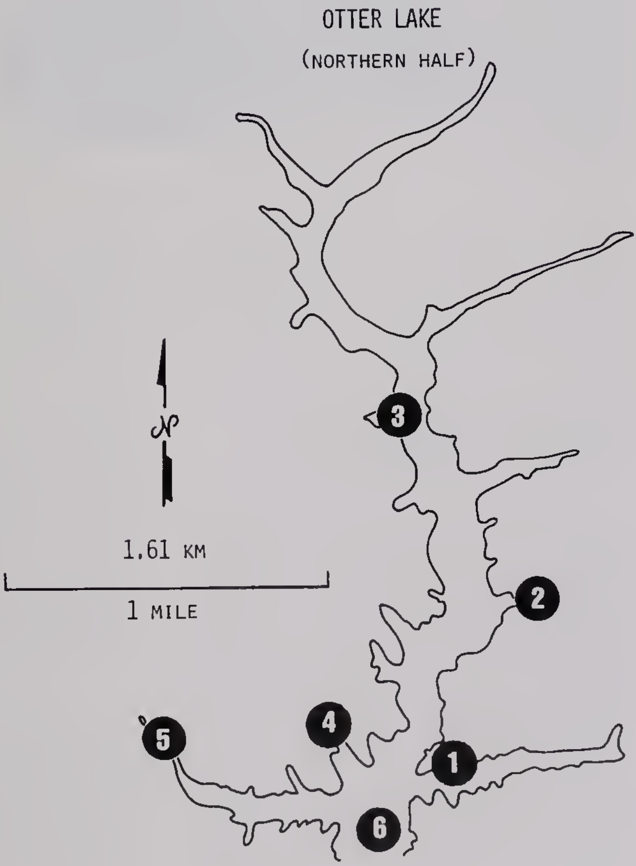

Fig 3.—Otter Lake sampling stations for benthic macroinvertebrates.

Artificial substrate sampler used in benthic studies at Lake Sangchris.

Data were analyzed by one-way analysis of variance and the Kramer (1956) extension of Duncan's multiple range test. Comparisons were made at the 0.05 level of significance.

RESULTS AND DISCUSSION

WATER TEMPERATURE AND OXYGEN CONTENT

Because both water temperature and oxygen concentration can limit the growth, distribution, and abundance of benthic macroinvertebrates, the seasonal variation of those parameters in Lake Sangchris are presented (Fig. 4 and 5) for reference to the distribution and abundance of benthic organisms.

Bottom temperatures in Lake Sangchris were highest in the discharge channel (Station 5), ranging from 25° to 40° C during the summer and 10°–15° C during the winter. The next highest temperatures were at Station 4 and Station 3, considered a transition zone between the heated and unheated areas and included in the heated area because it was affected by the thermal effluent. Differences in the average bottom temperatures between the heated and unheated areas generally ranged from 4° to 8° C through the spring, summer, and autumn and between 8° and 12° C during the winter months. Bottom temperatures in Otter Lake followed the general pattern observed for Lake Sangchris.

Oxygen concentrations generally ranged higher in the unheated area of Lake Sangchris from 1973 through 1976 than in the heated area (Fig. 5), but the discharge channel consistently had the highest levels of oxygen (except for the winter of 1973–1974). The higher oxygen concentrations in the discharge channel were due to enhanced atmospheric reaeration resulting from

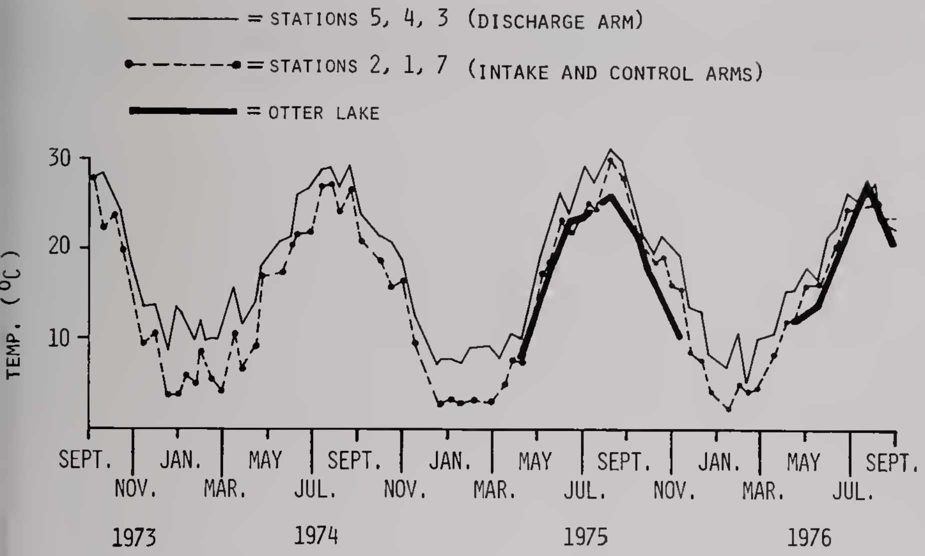

Fig. 4.—Average bottom temperatures in the discharge and the intake and control arms of Lake Sangchris from 1973 through 1976 and in Otter Lake during 1975 and 1976.

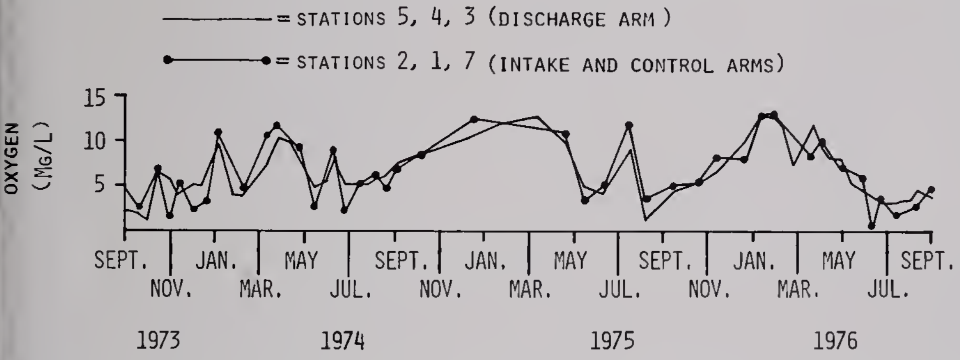

Fig. 5.—Average oxygen concentrations in the discharge and the intake and control arms of Lake Sangchris from 1973 through 1976.

the high turbulence as the heated effluent was expelled from the power plant. Oxygen concentrations in Otter Lake for 1975 (April through November) and 1976 (April through September) ranged from 3.4 to 9.6 mg/l at a depth of 8 m, which was comparable to those at Station 2 in the unheated area of Lake Sangchris.

TAXA COLLECTED

Twenty-three taxa of oligochaetes, decapods, mollusks, and insects were collected in Lake Sangchris (Table 1). The phantom midge (*Chaoborus punctipennis*) represented 59 percent of all organisms collected, and the nonbiting midges (Chironomidae) 39 percent. Within the Chironomidae, six species (*Chironomus attenuatus, Cryptochironomus fulvus, Coelotanypus concinnus, Glyptotendipes lobiferus, Procladius bellus, Xenochironomus festivus)* of the 15 collected represented 94 percent of the chironomids collected. Other benthic macroinvertebrates, such as mayflies, caddisflies, and oligochaetes, represented only 2 percent of the organisms collected.

Benthic macroinvertebrates (Table 1) in the headwaters of the East and West branches of Clear Creek above the impounded waters of Lake Sangchris exhibited greater diversity than did those in the impounded habitat. Forty-one taxa were collected, including the major taxa occurring in Lake Sanghcris. The greater

Table 1.—Species of benthic organisms collected in dredge samples from Lake Sangchris, Lake Sangchris tributaries, and Otter Lake.

Species	Lake Sangchris Stations						Clear Creek		Otter Lake Stations					
	1	2	3	4	5	7	East Branch	West Branch	1	2	3	4	5	6
Annelida														
Oligochaeta														
Limnodrilus hoffmeisteri	X	X	X	X		X	X	X	X	X	X	X	X	X
Branchiura sowerbyi			X	X		X	X							
Hirudinea														
Helobdella sp.					X									
Insecta														
Ephemeroptera														
Hexagenia limbata	X	X	X	X			X	X		X			X	
Caenis sp.		X	X	X		X	X		X	X		X	X	
Baetis sp.							X	X						
Heptagenia sp.								X						
Trichoptera														
Cyrnellus marginalis		X	X	X		X	X							
Hydropsyche sp.							X							
Cheumatopsyche sp.							X	X						
Odonata														
Argia sp.							X							
Somatochlora sp.							X							
Ischnuria sp.							X							
Hemiptera														
Mesovelia mulsanti							X	X						
Corixidae								X						
Coleoptera														
Dubiraphia quadrinotata							X			X			X	
Macronychys glabratus							X							
Stenelmis sp.							X	X						
Diptera														
Chaoborus punctipennis	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Chironomus attenuatus	X	X	X	X		X	X	X	X	X	X	X	X	X
Cryptochironomus fulvus	X	X	X	X		X	X	X	X	X	X	X	X	X
Procladius bellus	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Coelotanypus concinnus	X	X	X	X		X		X	X	X	X	X	X	X
Palpomyia complex	X	X	X	X		X	X	X	X	X	X	X	X	X

diversity was due primarily to the greater diversification of habitat.

Eighteen taxa of oligochaetes and insects (Table 1) were collected from Otter Lake, all of which were collected in Lake Sangchris. The oligochaete,

Table 1.—Continued.

Species	Lake Sangchris Stations						Clear Creek		Otter Lake Stations					
	1	2	3	4	5	7	East Branch	West Branch	1	2	3	4	5	6
Glyptotendipes lobiferus	X	X	X	X			X	X	X	X	X	X	X	X
Xenochironomus festivus		X	X	X	X	X	X	X	X	X		X	X	
Cricotopus bicinctus		X	X	X		X	X	X		X	X	X		X
Dicrotendipes modestus	X	X	X	X	X	X		X		X				
Dicrotendipes neomodestus							X	X						
Tanypus stellatus		X		X		X								
Polypedilum sp.		X	X	X		X	X	X	X	X	X	X	X	
Ablabesmyia sp.	X			X				X			X		X	
Harnischia sp.	X	X			X			X			X	X	X	
Paracladopelma sp.								X						
Paralauterborniella nigrohalteralis							X	X						
Thienemannimyia complex							X	X						
Tanytarsus sp.		X		X			X	X	X	X	X	X	X	
Micropsectra sp.						X		X						
Phaenopsectra jucundus							X	X						
Tabanus sp.							X	X						
Psychoda sp.							X	X						
Tipula sp.							X	X						
Hexatoma sp.							X	X						
Mollusca														
Pelecypoda														
Corbicula fluminea	X	X	X	X	X	X								

Limnodrilus hoffmeisteri (18 percent), the phantom midge, *Chaoborus punctipennis* (40 percent), and the nonbiting midges (Chironomidae) (39 percent) made up 97 percent of the total organisms collected from Otter Lake. Oligochaetes were distinctly more abundant in Otter Lake than in Lake Sangchris.

Initially, Limnetics, Inc., (1972) reported a paucity of benthos in Lake Sangchris, but in a supplemental study (Limnetics, Inc. 1973) collected 24 taxa. Paloumpis & Starrett (1960) studied three floodplain lakes of the Illinois River near Havana. The species composition consisted of Diptera larvae (*Pelopia = Tanypus, Procladius, Coelotanypus, Chaoborus)*, oligochaetes, mayflies (*Hexagenia limbata*), sphaeriid clams, and leeches. The benthic communities varied markedly from lake to lake although oligochaetes constituted over 60 percent of the fauna in each of the lakes. Studies on Illinois River lakes (Richardson 1921*a*, 1921*b*, 1924, 1925, and 1928) indicated that oligochaetes and clams were the dominant macroinvertebrates although a variety of leeches, chironomids, snails, amphipods, isopods, caddisflies, mayflies, odonates, and sialids were present. Most of these organisms were distributed in the wide portions of the lakes, away from the main river channel. A study of Clearwater Lake, Missouri, (O'Connell & Campbell 1953) showed that a wide variety of taxa inhabits newly formed reservoirs. Oligochaetes, Culicidae (probably Chaoboridae), and Chironomidae constituted 90 percent of the fauna, and at no time were fewer than 13 taxa collected in the littoral zone during any sampling period.

Annual reports to the Army Corps of Engineers for Lake Shelbyville (Brigham 1973, 1974, 1975, and 1976) and Carlyle Lake (Dufford, Swadener, & Waite 1976 and 1977) indicated that the diversity of benthic organisms was greatest at lotic stations. The lentic stations in these central Illinois reservoirs were dominated by chaoborids, oligochaetes, and chironomids, which accounted for more than 80 percent of the benthic macroinvertebrates.

The wide variety of macroinvertebrates in northern Indiana lakes was similar to that collected in Illinois River lakes. In Wabee Lake (Wohlschlag 1950) benthic macroinvertebrates were restricted to a narrow littoral zone because a marl substrate covered much of the lake bottom. In Lake Wawasee (Scott, Hile, & Spieth 1928) 22 taxa were collected, with the diversity of macroinvertebrates extending well into the profundal zone (9–15 m).

The diversity of macroinvertebrates in Lake Sangchris appears normal when compared with those of other central Illinois lakes (Otter Lake, Lake Shelbyville, Carlyle Lake) although it lacks the variety of clams, isopods, amphipods, and leeches prevalent in Illinois River and northern Indiana lakes. The littoral zone of Lake Sangchris, outside of the coves, consists primarily of hardpan clay and sand with scattered areas of macrophytes, a habitat which may account for the absence of certain macroinvertebrates there.

SEASONAL ABUNDANCE

The seasonal abundances of benthic macroinvertebrates at midchannel (profundal) sites in Lake Sangchris from 1973 through 1976 are shown in Fig. 6. In the discharge channel (Station 5) benthic macroinvertebrates ranged in abundance from 0 to 244 organisms m^{-2}. Although the highest bottom temperatures and oxygen concentrations were in the discharge channel, the silicate slag covering the bottom provided an unsuitable habitat for the animals. Artificial substrate samples at that station (Table 4) indicated that benthic macroinvertebrates would colonize a suitable substrate in areas of high water temperature. With the exception of those taken from the discharge channel, benthic macroinvertebrates collected from the cooling loop of the lake (stations 4, 3, 2, and 1) 57 to 5,028 organisms m^{-2}, equal to or greater than the levels of

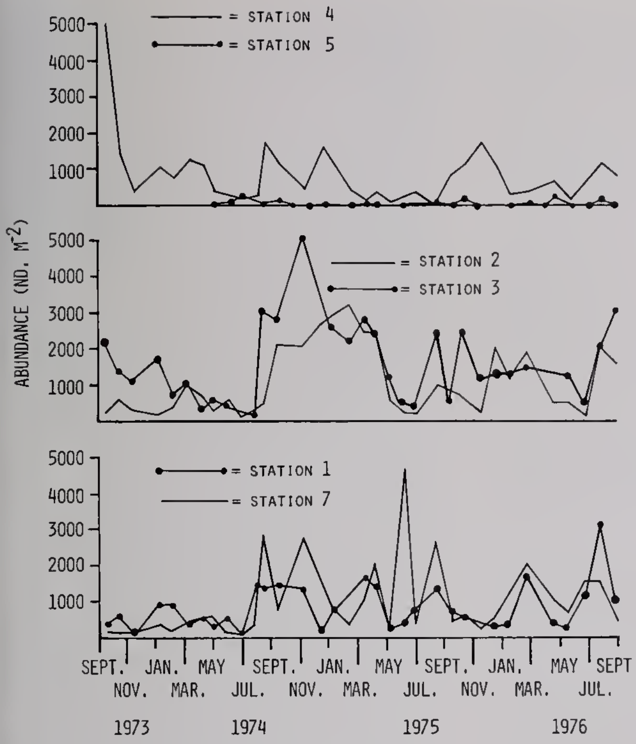

Fig. 6.—Seasonal abundances of benthic microinvertebrates in Lake Sangchris from 1973 through 1976.

abundance (86–4,735 organisms m^{-2}) found in the control arm (Station 7). The seasonal abundance of benthic macroinvertebrates in Lake Sangchris was in phase with those of Illinois lakes that receive no heated effluent.

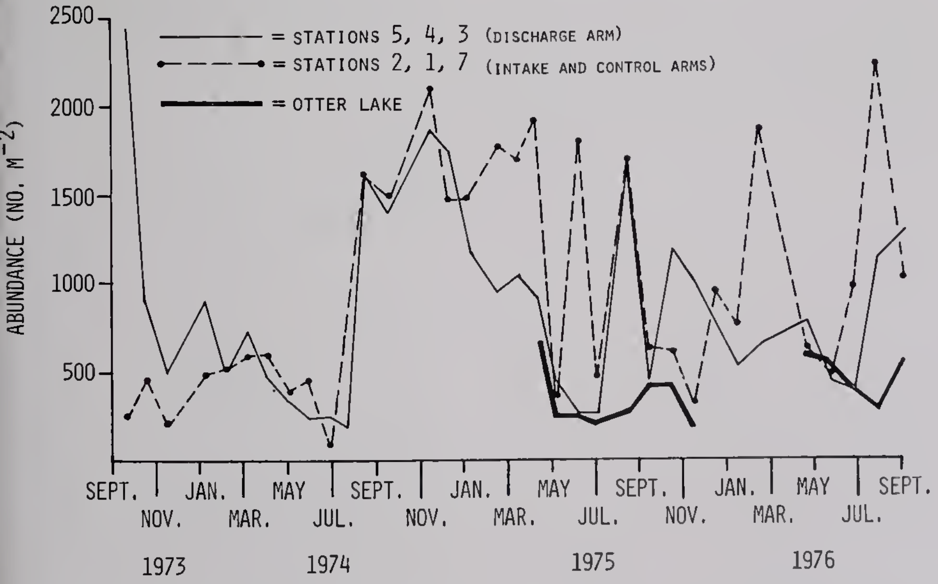

Fig. 7.—Average seasonal abundances of benthic macroinvertebrates in the discharge arm (heated) and intake and control arms (unheated) of Lake Sangchris from 1973 through 1976 and in Otter Lake during 1975 and 1976.

The average abundance of benthic macroinvertebrates (Fig. 7) was higher in the discharge (heated) arm (stations 5, 4, and 3) of Lake Sangchris from September 1973 through March 1974 and then closely paralleled the abundance in the intake and control arms (stations 2, 1, and 7) through the rest of the year. Through 1975 and 1976, the average abundance fluctuated considerably, particularly in the intake and control arms, with the average abundance generally higher there than in the discharge arm. The average abundance for the entire lake during this study ranged from 250 to 2,000 organisms m^{-2} and was, with one exception, always above the levels of abundance observed for Otter Lake.

Analyses of variance of the mean numbers of benthic macroinvertebrates at each profundal station in Lake Sangchris demonstrated that they were significantly more abundant (0.05 level) at Station 3 than at any other station (Table 2). Stations 2, 7, 4, and 1 (in rank order of decreasing means) formed a subset having an intermediate level of abundance. The mean abundance of macroinvertebrates was significantly (0.05 level) lower at Station 5 in the discharge channel than at any other station.

In Otter Lake during both 1975 and 1976, Station 6 in the profundal zone was significantly higher in the abundance of macroinvertebrates (0.05 level) than were stations 1 through 5 in the littoral-sublittoral zone (Table 2).

From April through November 1975, the abundances of macroinvertebrates at stations 3, 4, and 7 in Lake Sangchris were comparable to that at Station 6 in Otter Lake (Table 2). During April through September 1976, the abundances of macroinvertebrates at stations 3, 1, 7, and 2 in Lake Sangchris were comparable to that at Station 6 in Otter Lake (Table 2). During both periods the numbers in the discharge channel (Station 5) of Lake Sangchris were comparable to those of the littoral-sublittoral stations of Otter Lake.

A comparison of the profundal stations of Lake Sangchris, Lake Shelbyville (Brigham 1973, 1974, 1975,

Table 2.—Comparison of the analyses of variance of the means of abundance of benthic macroinvertebrates at each profundal station in Lake Sangchris (Sa); in Otter Lake (Ot); and in the profundal zones of Lake Shelbyville (Sh), Carlyle Lake (Ca), and Lake Wawasee (Wa), Indiana (0.05 level of confidence). Each underlined value is comparable to values with the same underline and is significantly higher than the other values to its right.

Lake Sangchris Profundal Stations

Station	3	2	7	4	1	5
Mean	1,688	1,117	985	920	818	40

Otter Lake 1975 (April to November)

Station	6	2	4	5	3	1
Mean	61	23	15	12	12	10

Otter Lake 1976 (April to September)

Station	6	1	5	3	4	2
Mean	84	27	21	21	13	13

Lake Sangchris (Sa) Otter Lake (Ot) 1975 (April to November)

Station	3(Sa)	4(Sa)	7(Sa)	6(Ot)	2(Sa)	1(Sa)	2(Ot)	4(Ot)	5(Ot)	3(Ot)	1(Ot)	5(Sa)
Mean	101	66	62	61	55	51	23	15	12	12	10	.3

Lake Sangchris (Sa) Otter Lake (Ot) 1976 (April to September)

Station	3(Sa)	6(Ot)	1(Sa)	7(Sa)	2(Sa)	4(Sa)	1(Ot)	5(Ot)	3(Ot)	4(Ot)	2(Ot)	5(Sa)
Mean	118	84	83	74	68	47	27	21	21	13	13	2

Lake Sangchris (Sa) Lake Shelbyville (Sh) Carlyle Lake (Ca) Lake Wawasee (Wa)

Station	3(Sa)	(Sh)	2(Sa)	(Ca)	7(Sa)	4(Sa)	(Wa)	1(Sa)	5(Sa)
Mean	1,688	1,209	1,117	1,114	985	920	890	818	40

and 1976), Carlyle Lake (Dufford, Swadener, & Waite 1976 and 1977), and Lake Wawasee, Indiana (Scott, Hile, & Spieth 1928) (Table 2) showed that the abundance of macroinvertebrates at Station 3 in Lake Sangchris and in the profundal zone of Lake Shelbyville were comparable and significantly higher (0.05 level) than those at stations 2, 7, 4, 1, and 5 of Lake Sangchris and of Carlyle Lake and Lake Wawasee. Macroinvertebrate abundances in Lake Shelbyville, Carlyle Lake, and Lake Wawasee were comparable to those of stations 2, 7, 4, and 1 of Lake Sangchris. The discharge channel (Station 5) of Lake Sangchris had a significantly lower abundance (0.05 level) than the other stations in Lake Sangchris and Lake Shelbyville, Carlyle Lake, and Lake Wawasee.

The range of abundance of benthic macroinvertebrates in Lake Sangchris is also comparable to those in Upper, Middle, and Lower Peoria Lake (Richardson 1928) in the Illinois River. During 1924 the abundance of macroinvertebrates in Peoria Lake varied from 192 to 5,634 organisms m^{-2} (mean 2,252), and in 1925 from 844 to 1,684 organisms m^{-2} (mean 1,530). In contrast, Paloumpis & Starrett (1960) found benthic macroinvertebrates in Lake Matanzas, middle Quiver Lake, and Lake Chautauqua to vary from 1,959 to 16,792 (mean 5,326), 2,680 to 43,981 (mean 11,922), and 3,767 to 17,976 (mean 9,533) organisms m^{-2}, respectively. Those lakes are broad expansions of floodplain lakes of the Illinois River and received considerable enrichment from waterfowl.

From these data it is evident that the benthic macroinvertebrates of Lake Sangchris form three distinct subsets in terms of abundance, the deepest profundal zone (Station 3) being significantly higher in macroinvertebrate abundance; the cooling loop and control arm being intermediate and, within this subset, having comparable populations; and the discharge channel having a significantly lower abundance of macroinvertebrates than the other stations. With the exception of the discharge channel, where the presence of slag covering the bottom apparently limits the colonization by benthic macroinvertebrates, the abundance of such organisms in the cooling loop of Lake Sangchris is comparable to or significantly higher than the abundance at Station 7 in the control arm and the abundance in Lake Shelbyville, Carlyle Lake, Lake Wawasee, and Peoria Lake. Apparently no reduction in the abundance of benthic macroinvertebrates has resulted from the increase in water temperature.

ABUNDANCE OF DOMINANT SPECIES

Analyses of variance of the means of abundance of the dominant macroinvertebrates of Lake Sangchris showed that *Chaoborus punctipennis* was significantly more abundant (0.05 level) in the deepest area of the lake (Station 3) than at any other station. Its lowest abundance occurred in the control arm (Station 7) and the discharge channel (Station 5) (Table 3).

Table 3.—Comparison of the analyses of variance of the means of abundance of the dominant benthic macroinvertebrates from the profundal zone of Lake Sangchris (0.05 level of confidence). Each underlined value is comparable to values with the same underline and is significantly higher than the other values to its right.

	Chaoborus punctipennis					
Station	3	4	2	1	7	5
Mean	96	64	35	35	25	1
	Procladius bellus					
Station	7	3	1	2	4	5
Mean	13	6	4	4	4	0.03
	Coelotanypus concinnus					
Station	7	2	1	3	4	5
Mean	4	2	2	1	1	0.15
	Chironomus attenuatus					
Station	2	3	1	7	4	5
Mean	34	19	11	10	1	0.03
	Cryptochironomus fulvus					
Station	1	7	2	3	4	5
Mean	3	3	2	2	1	0.31

This is the typical distribution for *C. punctipennis* in large lakes, where they tend to be restricted to the deeper zones (Eggleton 1931, Juday 1921, Stahl 1966). The mature larvae live in the mud during the day and become nektonic and limnetic during the night (Berg 1937, Eggleton 1931, Juday 1921), feeding on copepods, oligochaetes, chironomid larvae, rotifers, mosquito larvae, and other chaoborid larvae (Berg 1937, Deonier 1943, Main 1953, Stahl 1966). Chaoborid larvae are especially abundant in the deeper portions of lakes where the hypolimnion becomes depleted of oxygen (Thienemann 1922, Findenegg 1955). Although showing a preference for the deeper, colder zone of a lake, chaoborid larvae are extremely eurythermal, capable of migrating from 4° C to 20° C and back to 4° C within a day (Welch 1952).

Procladius bellus and *Coelotanypus concinnus* were significantly more abundant (0.05 level) in the control arm (Station 7) (Table 3) than at other stations in the lake. Both species are considered predators or scavengers and eurythermal (Beck 1977). Roback (1969) reported both species feeding heavily on diatoms, as well as on oligochaetes, cladocerans, and other chironomid larvae. The level of phytoplankton photosynthesis in the control arm (Station 7) was higher than it was at other stations (R.L. Moran, Illinois Natural History Survey, personal communication) although the abundance of benthic macroinvertebrates there was comparable to that of the cooling loop in general except at Station 3 and significantly below the abundance of macroinvertebrates in the intake arm. There was no evidence that fish predation on benthic macroinvertebrates was concentrated in the control arm as compared with such predation at other stations in the lake. These data suggest that *Procladius bellus* and *Coelotanypus concinnus* may have been seeking the area of greatest growth or abundance of phytoplankton.

Chironomus attenuatus was significantly more abundant (0.05 level) (Table 3) at Station 2 in the intake arm than at any other station, and its lowest abundance was at stations 4 and 5 in the discharge arm. This species is embenthic (Beck 1977) and considered primarily a scavenger, feeding on nonliving plant and animal material. It is also eurythermal to mesothermal (Beck 1977) although Iovino & Miner (1970) found it to be oligothermal in Beaver Reservoir, Arkansas. In Beaver Reservoir, Iovino & Miner (1970) found that *C. attenuatus* concentrated in the deepest areas of the lake. In Lake Sangchris, the aggregation of *C. attenuatus* at Station 2 rather than in the deepest area of the lake (Station 3) could be the result of competition for space with *Chaoborus punctipennis* or of heavy predation from *Chaoborus punctipennis* feeding on the earlier and smaller instars of *Chironomus attenuatus*. Both possibilities are conceivable, as *Chaoborus punctipennis* was nearly three times more abundant at Station 3 than *Chironomus attenuatus*. The abundance of *Cryptochironomus fulvus* was not significantly different among the sampling sites. Thus, each of the dominant species of macroinvertebrates in Lake Sangchris tends to exhibit a distinctiveness in its abundance with respect to its interrelationships which other species and with the physical conditions of the lake.

SEASONAL VARIATIONS IN BIOMASS

The seasonal variations in the average biomass (wet weight) of benthic macroinvertebrates for the heated and unheated arms of Lake Sangchris from 1973 through 1976 and in Otter Lake for 1975 (April through November) and 1976 (April through September) are shown in Fig. 8. The variations in biomass generally followed the pattern for the seasonal level of abundance (Fig. 7). The biomass in the discharge (heated) arm ranged from 0.11 to 2.30 g m^{-2} and was quite similar to that of the intake and control arms (0.04 – 1.47 g m^{-2})(Fig.8), indicating that increased water temperatures did not limit the growth of

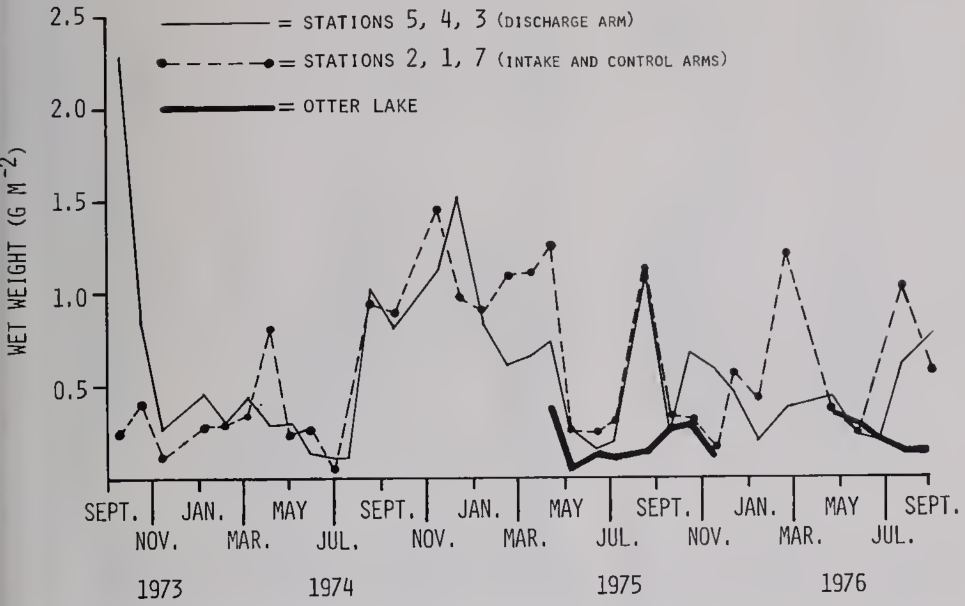

Fig. 8.—Average seasonal distribution of the standing crop of benthic macroinvertebrates in the discharge arm (heated) and the intake and control arms (unheated) of Lake Sangchris from 1973 through 1976 and in Otter Lake during 1975 and 1976.

benthic macroinvertebrates in the heated arm of the lake. The small numbers of benthic macroinvertebrates in the discharge channel reduced the average values for biomass in the heated portion of the lake. With two exceptions, the biomass values in the heated and unheated parts of Lake Sangchris were higher than the levels for Otter Lake, which ranged from 0.06 to 0.38 g^{-2} during the summer of 1975 and 0.15 to 0.37 g m^{-2} during the summer of 1976. In Carlyle Lake (Dufford, Swadener, & Waite 1977) the lentic biomass ranged from 0.15 to 5.64 g m^{-2}, and for the floodplain lakes of the Illinois River (Paloumpis & Starrett 1960) the average biomass in Lake Matanzas, middle Quiver Lake, and Lake Chautauqua was 9.69, 47.79, and 16.15 g m^{-2}, respectively. The high average biomass of benthic macroinvertebrates in the floodplain lakes compared to that of Lake Sangchris is due to the larger biomass of fingernail clams collected. The biomass in Lake Sangchris falls within the range of those found in other central Illinois lakes (Otter Lake, Carlyle Lake).

BATHYMETRIC DISTRIBUTION

The bathymetric distribution of benthic macroinvertebrates in Lake Sangchris during 1974 and 1975 indicated that their greatest abundance (Fig. 9) occurred at depths of 4 m or more where the bottom sediments were composed primarily of silt. The bottom sediments from the shoreline to a depth of 4 m contained large areas of hardpan clay and sand, in addition to the layer of slag which covered the bottom of the discharge channel, all of which are unsuitable as habitats for most benthic organisms. *Xenochironomus festivus*, *Glyptotendipes lobiferus*, and *Cricotopus bicinctus*, which is epiphytic (Beck 1977), were collected only in the littoral and sublittoral zones from 0 to 4 m. Both *Procladius bellus* and *Coelotanypus concinnus*, which are eurythermal and predaceous or scavengers (Beck 1977), were distributed throughout all depths of the lake. *Chaoborus punctipennis* and *Chironomus attenuatus*, which is embenthic (Beck 1977), were generally collected only in the profundal zone.

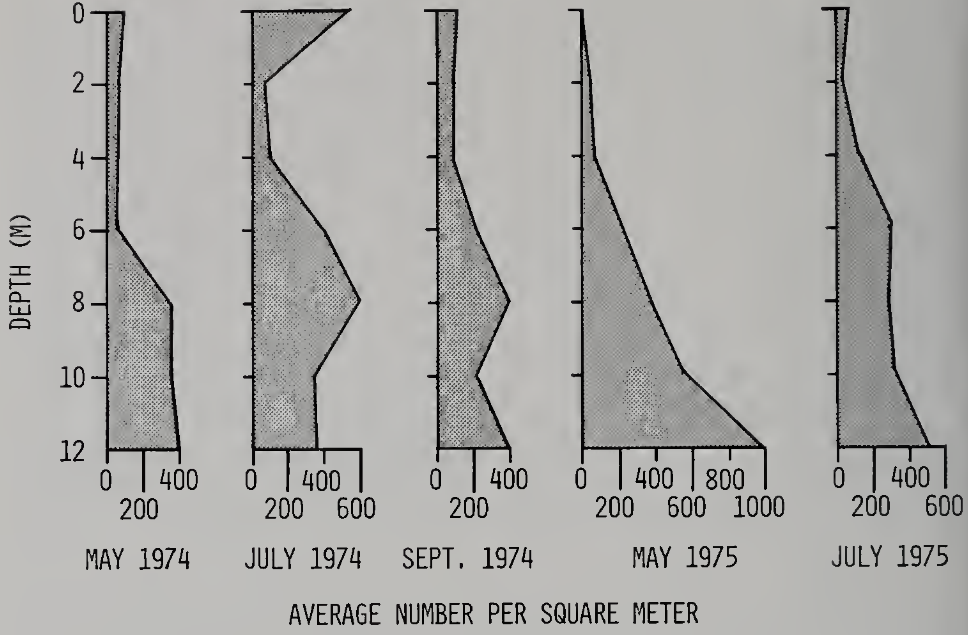

Fig. 9.—Bathymetric distribution of benthic macroinvertebrates in Lake Sangchris during 1974 and 1975.

SPATIAL DISTRIBUTION

The spatial distribution of benthic macroinvertebrates in Lake Sangchris during 1974 is shown in Fig. 10. The flow of heated effluent moves from transect 11 in the discharge channel (Fig. 2) to transect 1 in the intake arm, with transect 12 in the control arm of the lake unaffected by the thermal discharge. In May, July, and September, the general abundance of benthic macroinvertebrates increased in numbers from transect 11 in the discharge channel to transect 3 in the intake arm and then decreased moderately toward the intake area. Across each transect the abundance of macroinvertebrates increased with depth, the greatest abundance occurring generally in the deepest portions of each transect. On some occasions high concentrations of benthic macroinvertebrates (reaching 2,500-3,000 organisms m^{-2}) were collected immediately along the shoreline (Fig. 10) although generally the abundance of macroinvertebrates in the littoral zone averaged below 200 organism m^{-2} (Fig. 9). When large numbers of chironomid larvae (*Cricotopus bicinctus*) were collected along the shoreline, they were associated with a layer of algae covering the hardpan clay. The low abundance of macroinvertebrates collected during May can be attributed to the emergence of aquatic insects at that period of the year. Larvae hatching from deposited eggs would account for the increase in abundance during July and September.

Depth distributions of benthic macroinvertebrates have not been reported for other Illinois lakes although in Lake Wawasee, Indiana (Scott, Hile, & Spieth 1928) benthic macroinvertebrates were collected abundantly to the deepest portions of the lake, reaching over 1,000 organisms m^{-2} at depths of 3, 11, 13, 15, and 17 m. The bottom sediments in Lake Wawasee consisted of fine silt at depths of 3–23 m, indicating that silt provides a suitable substrate for the growth and development of benthic macroinvertebrates.

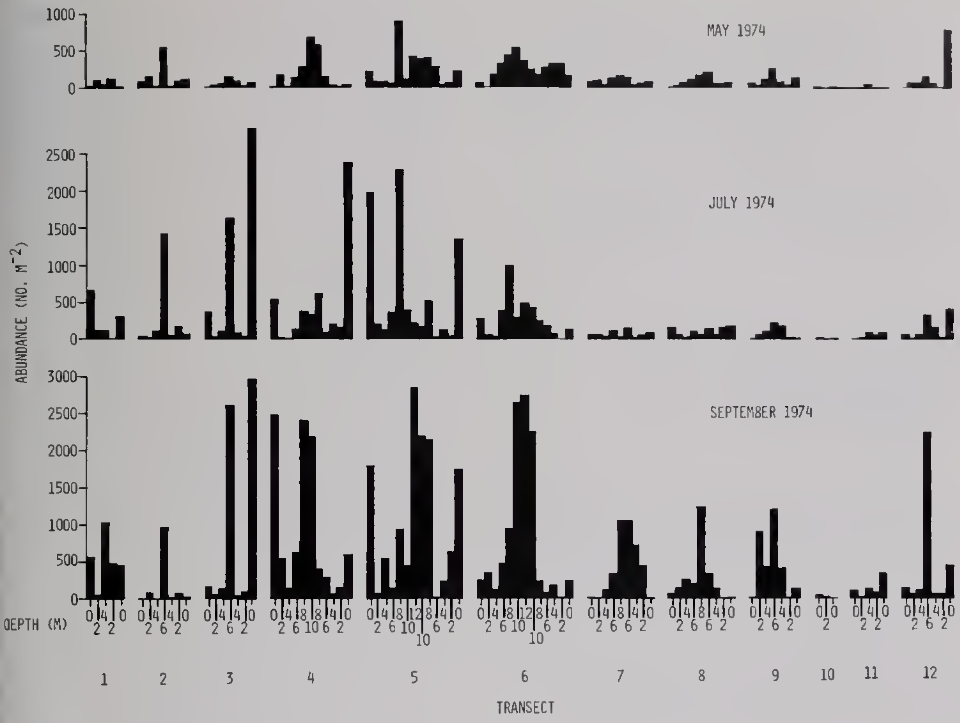

Fig. 10.—Spatial distribution of benthic macroinvertebrates in Lake Sangchris during May, July, and September 1974.

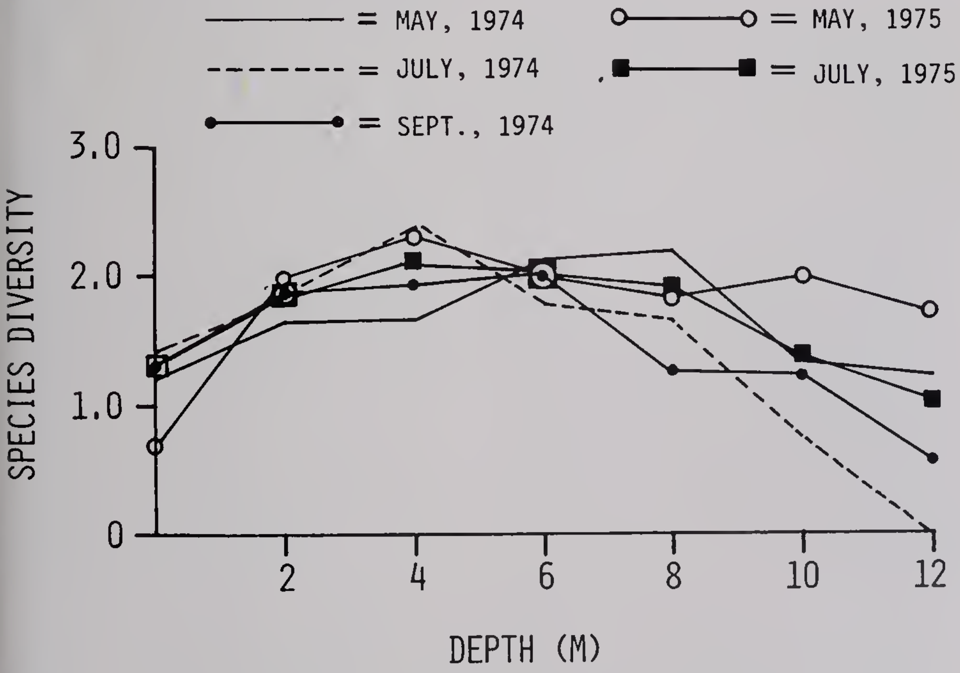

Fig. 11.—Average species diversity at various depths of benthic macroinvertebrates in Lake Sangchris during 1974 and 1975.

SPECIES DIVERSITY BY DEPTH

All values for species diversity across the 12 transects were averaged for each depth for collections taken in May, July, and September 1974 and May and July 1975. Fig. 11 shows the greatest diversity occuring at 4–6 m, the transition zone from hardpan clay and sand to silt.

EFFECTS OF WATER TEMPERATURE AND BOTTOM TYPE

To determine if increased water temperatures or the presence of silicate slag caused the severe paucity of benthos in the discharge channel (Station 5), three artificial substrate samplers were placed in both the discharge channel (Station 5) and the intake channel (Station 1) during 1975. The abundance and diversity of organisms collected from the samplers during June, August, and October are shown in Table 4. Macroinvertebrates were most abundant in the intake channel (Station 1) during August and October. The lower numbers observed in June could be attributed to the emergence of adult insects from the lake during this period. A high degree of species diversity was observed during each period. At the discharge channel (Station 5) the abundance of organisms collected was relatively low, ranging from 180 to 407 organisms m^{-2}, compared with 244–800 organisms m^{-2} for Station 1. During June and August the species

Table 4.—Benthic organisms collected from artificial substrate samplers in the intake channel and discharge channel of Lake Sangchris during 1975. The numbers shown were taken from three substrate samplers unless otherwise noted.

Species	Intake Channel (Station 1)			Discharge Channel (Station 5)		
	June	August	October	June	August	October
Oligochaeta						
Limnodrilus hoffmeisteri	4	1	. . .	. . .	. . .	2
Ephemeroptera						
Hexagenia limbata	3	5	11	. . .	. . .	. . .
Caenis sp.	. . .	3	. . .	. . .	. . .	. . .
Trichoptera						
Cyrnellus marginalis	. . .	85	62	. . .	. . .	10
Odonata						
Argia sp.	15	5	4	. . .	2	2
Diptera						
Chaoborus punctipennis	4	. . .	. . .	. . .	. . .	. . .
Proclodius bellus	11	2	. . .	. . .	. . .	. . .
Coelotanypus concinnus	4	8	191	. . .	2	. . .
Chironomus attenuatus	2	. . .	5	. . .	. . .	. . .
Glyptotendipes lobiferus	42	178	. . .	111	93	48
Polypedilum sp.	1	. . .	. . .	. . .	. . .	2
Cricotopus bicinctus	3	. . .	. . .	. . .	. . .	8
Dicrotendipes modestus	. . .	7	. . .	. . .	. . .	. . .
Ablabesmyia sp.	14	5	. . .	. . .	. . .	. . .
Cryptochironomus fulvus	. . .	3	. . .	. . .	. . .	1
Xenochironomus festivus	. . .	1	64	. . .	. . .	. . .
Decapoda						
Orconectes virilis	7	3	. . .	. . .	. . .	. . .
Mollusca						
Corbicula fluminea	21	124	26	6	. . .	. . .
Total	*131*	*430*	*363*	*117*	*97*	*73*
Number of taxa	*13*	*14*	*7*	*2*	*3*	*7*
Number per square meter	*244*	*800*	*675*[a]	*218*	*180*	*407*[b]

[a] Numbers based on specimens collected from two substrate samplers

[b] Numbers based on specimens collected from one substrate sampler.

diversity was low but showed an increase during October. When the abundance of macroinvertebrates at Station 5 was compared with the numbers collected during standard Ekman grab sampling (Fig. 6), it was evident that the increased water temperature in the discharge channel was not the principal factor limiting the presence of benthic macroinvertebrates, but rather the presence of an unstable silicate slag covering the bottom sediments. Organisms colonized in this channel when a suitable substrate was provided.

Massengill (1976) found that benthic macroinvertebrates in the discharge channel from a nuclear power plant on the Connecticut River ranged from 0 to 900 organisms m^{-2}, and generally fewer than 200 organisms m^{-2} were collected during most of the year. With water temperatures of 37° C, *Limnodrilus hoffmeisteri* was the only species of macroinvertebrate present during July, reaching 900 organisms m^{-2}. Four days later at temperatures of about 40° C, the abundance of *L. hoffmeisteri* dropped to 30 organisms m^{-2}. The maximum temperature this organism could tolerate appeared to be slightly above 37° C.

The bottom sediment in the discharge channel was predominately silt, and the average velocity in the channel varied from 0.3 to 0.6 m/sec, diminishing to 6 cm/sec at the mouth. During February, April, and June, when average temperatures were 11°, 14°, and 22° C, respectively, the abundance of benthic macroinvertebrates was less than 200 organisms m^{-2}. The highest abundance of macroinvertebrates occurred at temperatures of 37° C during July.

Massengill presented no reasons for the paucity of macroinvertebrates in the discharge channel except at temperatures over 37° C during the summer. During the remainder of the year, bottom temperatures were not excessive and considerable silt habitat was present. At no time was the channel velocity high enough to remove the silt from the channel. From this study it is evident that only prolonged periods of high water temperatures would restrict the diversity of benthic macroinvertebrates.

SUMMARY

1.—Twenty-three taxa of benthic macroinvertebrates were collected in Lake Sangchris, with chaoborids (59 percent) and chironomids (39 percent) representing 98 percent of the total numbers. The diversity of benthic macroinvertebrates in Lake Sangchris is consistent with those of other central Illinois lakes (Otter Lake, Lake Shelbyville, Carlyle Lake) although it lacks the variety of clams, isopods, amphipods, and leeches prevalent in Illinois River and northern Indiana lakes.

2.—Eighteen taxa of benthic macroinvertebrates were collected in Otter Lake, with chaoborids (40 percent), chironomids (39 percent), and oligochaetes (18 percent) representing 97 percent of the total numbers, the major species being the same as those in Lake Sangchris.

3.—The abundance of benthic macroinvertebrates in Lake Sangchris shows three distinct subsets: it was significantly higher in the deepest areas; intermediate in the cooling loop and control arm, where there were comparable populations; and significantly lower in the discharge channel than elsewhere in the lake.

4.—The abundance of *Chaoborus punctipennis* (59 percent of the total numbers of macroinvertebrates) was greatest in the deepest areas of the lake. The significantly low abundance of macroinvertebrates in the discharge channel was due to the silicate slag covering the bottom and providing an unsuitable substrate for colonization.

5.—With the exception of the discharge channel, the abundance of benthic macroinvertebrates in the cooling loop of Lake Sangchris was comparable with or significantly higher than those in the control arm (Station 7) and in the Lake Shelbyville, Carlyle Lake, Lake

Wawasee, and Peoria Lake, and showed no detrimental effects from the increase in water temperature.

6.—*Chaoborus punctipennis* was significantly more abundant in the deepest water, *Procladius bellus* and *Coelotanypus concinnus* were significantly more abundant in the control arm, and *Chironomus attenuatus* was significantly more abundant in the intake arm than at the other stations in Lake Sangchris. *Cryptochironomus fulvus* was ubiquitous in its distribution. Each dominant species exhibits a distinctiveness in its abundance with respect to its interrelationship with other species and the physical conditions of the lake.

7.—The seasonal variation in biomass (wet weight) of benthic macroinvertebrates in the discharge (heated) arm of Lake Sangchris was quite similar to that of the intake and control arms. Average biomass values were generally higher than those of Otter Lake and comparable to those determined for Carlyle Lake, indicating that increased water temperatures in the heated arm did not limit the growth of benthic macroinvertebrates in Lake Sangchris.

8.—The greatest abundance of benthic macroinvertebrates in Lake Sangchris occurred at depths of 4 m or more where the bottom sediment was silt. The presence of hardpan clay to a depth of 2–4 m and the absence of layers of organic detritus within the littoral-sublittoral zone, outside the peripheral coves, appear to limit the habitat and food availability for benthic macroinvertebrates in this zone.

9.—The greatest species diversity of benthic macroinvertebrates in Lake Sangchris occurred between 4 and 6 m, the transition zone from hardpan clay and sand to silt.

10.—The abundance and diversity of benthic macroinvertebrates collected from substrate samplers in the discharge channel indicated that increased water temperature was not a limiting factor but that the bottom provided an unsuitable substrate for benthic colonization.

REFERENCES CITED

Beck, W. M., Jr. 1977. Environmental requirements and pollution tolerance of common freshwater Chironomidae. Environmental Monitoring Series. EPA—600/4—77—024. Environmental Monitoring and Support Laboratory, USEPA, Cincinnati. 261 p.

Berg, K. 1937. Contributions to the biology of *Corethra* Meigen (*Chaoborus* Lichtenstein). Danske Videnskabernes Selskab, Biologiske Meddelelser 13. Levin & Munksgaard, Copenhagen. 101 p.

Brigham, A. R. 1973. Water quality investigation in the Lake Shelbyville, Illinois basin. Annual report submitted to the U. S. Army Corps of Engineers, St. Louis District. 44 p.

———. 1974. Water quality investigations in the Lake Shelbyville, Illinois basin. Annual report submitted to the U. S. Army Corps of Engineers, St. Louis District. 42 p. and appendices.

———. 1975. Water quality investigations in the Lake Shelbyville, Illinois basin. Annual report submitted to the U. S. Army Corps of Engineers, St. Louis District. 23 p. and appendices.

———. 1976. Water quality investigation in the Lake Shelbyville, Illinois basin. Annual report submitted to the U. S. Army Corps of Engineers, St. Louis District. 41 p.

———. 1977. Water quality investigations at Lake Sangchris. Pages 1.1–1.5.18 in annual report for fiscal year 1976, Lake Sangchris project. Illinois Natural History Survey, Urbana.

Deonier, C. C. 1943. Biology of the immature stages of the Clear Lake gnat. Entomological Society of America Annals 36:383–388.

Dufford, D. W., S. O. Swadener, and S. W. Waite. 1976. Annual summary of biological investigations at Carlyle Lake 1974-1975. Annual report submitted to the U. S. Army Corps of Engineers, St. Louis District. 51 p.

———, ———, and ———. 1977. Annual summary of biological investigations at Carlyle Lake 1975–1976. Annual report submitted to the U. S. Army Corps of Engineers, St. Louis District. 51 p.

Eggleton, F. E. 1931. A limnological study of the profundal bottom fauna of certain fresh-water lakes. Ecological Monographs 1:231–331.

Findenegg, I. 1955. Die profundale Fauna der Kärntner Seen und ihr Verhaltnis zu deren Trophiezustand. Pages 121–140 *in* Vittorio Tonolli, ed., Symposium on biological, physical, and chemical characteristics of the profundal zone of lakes. Istituto Italiano di Idrobiologia, Memorie, supplemente 8.

Iovino, A. J., and F. D. Miner. 1970. Seasonal abundance and emergence of Chironomidae of Beaver Reservoir, Arkansas (Insecta: Diptera).

Kansas Entomological Society Journal 43: 197–216.

JOHNSON, W. H. 1964. Stratigraphy and petrography of Illinoian and Kansas drift in central Illinois. Illinois State Geological Survey Circular 378. 38 p.

JUDAY, C. 1921. Observations on the larvae of *Corethra punctipennis* Say. Biological Bulletin 40:271–286.

KRAMER, C. Y. 1956. Extension of multiple range tests to group means with unequal numbers of replications. Biometrics 12:307–310.

LIMNETICS, INC. 1972. A limnological survey of Lake Sangchris, Illinois. Limnetics, Inc., Milwaukee. 274 p.

——— 1973. A second limnological survey of Lake Sangchris, Illinois. Limnetics, Inc., Milwaukee. 42 p.

MAIN, R. A. 1953. A limnological study of *Chaoborus* (Diptera) in Hall Lake, Washington. M.S. thesis. University of Washington, Seattle. 106 p.

MARGALEF, R. 1958. Temporal succession and spatial heterogeneity in phytoplankton. Pages 323–349 *in* A. A. Buzzati-Traverso. ed. Perspectives in marine biology. University of California Press, Berkeley.

MASSENGILL, R. R. 1976. Benthic fauna: 1965–1967 versus 1968–1972. Pages 39–53 *in* D. Merriman and L. M. Thorp, eds. The Connecticut River ecological study. American Fisheries Society Monograph 1.

O'CONNELL, T. R., JR., and R. S. CAMPBELL. 1953. The benthos of Black River and Clearwater Lake, Missouri. The Black River Studies. University of Missouri Studies 26(2):25–41.

PALOUMPIS, A. A., and W. C. STARRETT. 1960. An ecological study of benthic organisms in three Illinois River flood plain lakes. American Midland Naturalist 64:406–435.

RICHARDSON, R. E. 1921*a*. The small bottom and shore fauna of the middle and lower Illinois River and its connecting lakes, Chillicothe to Grafton: its valuation; its sources of food supply; and its relation to the fishery. Illinois Natural History Survey Bulletin 13:363–522.

———. 1921*b*. Changes in the bottom and shore fauna of the middle Illinois River and its connecting lakes since 1913–1915 as a result of the increase, southward, of sewage pollution. Illinois Natural History Survey Bulletin 14:33–75.

———. 1924. Changes in the small bottom fauna of Peoria Lake, 1920 to 1922. Illinois Natural History Survey Bulletin 15:327–388.

———. 1925. The Illinois River bottom fauna in 1923. Illinois Natural History Survey Bulletin 15:389–422.

———. 1928. The bottom fauna of the middle Illinois River, 1913–1925. Illinois Natural History Survey Bulletin 17:387–475.

ROBACK, S. S. 1969. Notes on the food of Tanypodinae larvae. Entomological News 80:13–19.

SCOTT, W., R. O. HILE, and H. T. SPIETH. 1928. Investigations of Indiana Lakes. I. A quantitative study of the bottom fauna. Lake Wawasee (Turkey Lake). Indiana Department of Conservation Publication 77. 25 p.

STAHL, J. B. 1966. The ecology of *Chaoborus* in Myers Lake, Indiana. Limnology and Oceanography 11:177–183.

THIENEMANN, A. 1922. Die beiden Chironomusarten der Tiefenfauna der norddeutschen Seen. Archiv für Hydrobiologie 13:609–646.

WELCH, P. S. 1952. Limnology. McGraw-Hill Book Company, Inc., New York. 538 p.

WOHLSCHLAG, D. E. 1950. Vegetation and invertebrate life in a marl lake, Investigations of Indiana Lakes and Streams 3:321–372.

Reproduction, Growth, Distribution, and Abundance of *Corbicula* in an Illinois Cooling Lake

Herbert Dreier and John A. Tranquilli

ABSTRACT

The spawning season, growth rate, and population density of *Corbicula* were examined in the intake, discharge, and control arms of Lake Sangchris, a cooling lake for a 1,232-MW coal-fired electrical generating station. Clams in areas adjacent to the power plant were observed to obtain data that might aid in controlling this organism, which had the potential of becoming a serious fouling agent at the station. Major spawning seasons were observed in all three arms of the lake during the spring and the fall.

The average annual growth of clams caged in the discharge arm was significantly greater ($P < 0.05$) than the growth of clams in the intake and control arms, and was attributed to the extended growth period made possible by the heated water. The annual growth of marked individuals was inversely proportional to original length, small clams growing faster than large clams. Estimates of annual growth based on the growth of caged clams indicated that lengths of 21, 31, 36, and 40 mm were reached by clams caged in the discharge arm after 1, 2, 3, and 4 years of life, respectively.

The *Corbicula* population density varied inversely with depth; higher concentrations were found in substrates composed of 2–10 cm of loose sand, silt, or clay over hard clay than were found in areas where a thick layer of loose silt was present. In littoral areas, the mean clam density was higher in all sections of the cooling loop (25–67 clams/m^2) except the discharge canal than it was in the control arm (8 clams/m^2), suggesting that the population in the cooling loop benefited from power plant operations.

A clam die-off apparently occurred in the vicinity of the discharge canal as a result of highly elevated water temperatures (up to 40°C) during the summer of 1975, but by February 1976 the canal had been repopulated. A low survival rate for young-of-the-year individuals (≤ 5 mm in length) was indicated in Lake Sangchris, because larger clams comprised only 12 percent of the total clam population. Predation by fishes in the lake was presumed to be a major cause of mortality for smaller clams.

INTRODUCTION

The introduced Asiatic clam, *Corbicula fluminea (= C. manilensis)* has extended its range across the United States since its discovery in 1938 in the Columbia River near Knappatan, Washington. Major concerns regarding the introduction of *Corbicula* into various streams and reservoirs across the country are that it may serve as a fouling organism in electrical generating stations and other industrial plants that use large amounts of untreated water and that its prolific nature may allow it to outcompete and thereby reduce our native molluscan fauna (Sickel 1973; Gardner et al. 1976).

In 1973, *Corbicula* was first noticed in Lake Sangchris, a cooling reservoir in central Illinois. A short time later it was found inside the Kincaid Generating Station, but it had not yet created mechanical fouling problems as serious as those reported in plants of the TVA

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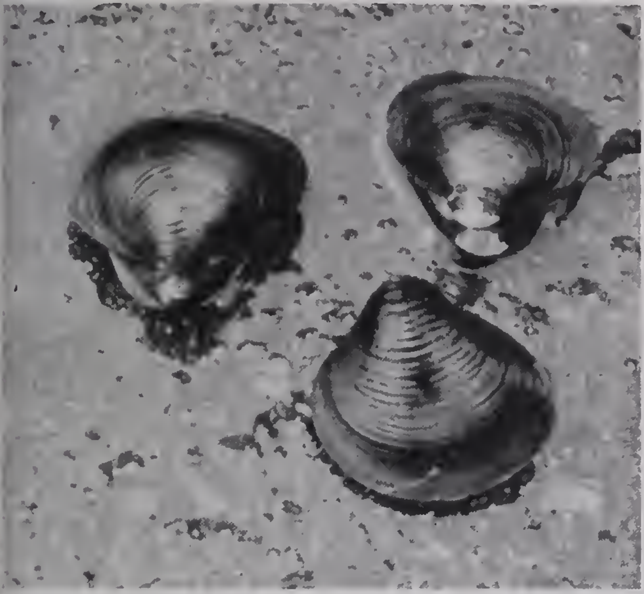

Corbicula fluminea from Lake Sangchris.

system (Goss & Cain 1975). The overall objective of this study, begun in April 1975, was to investigate various aspects of the life history of a natural population of *Corbicula* and to provide biological information that might aid in its control if it should become a serious problem at Kincaid Generating Station. Although numerous studies of this clam have been conducted since it was discovered in this country, most have occurred in areas of the United States with more moderate temperatures than those in central Illinois.

Specific objectives of this study were (1) to compare the spawning season, growth rate, and population density of *Corbicula* in the discharge, intake, and control arms of Lake Sangchris and (2) to observe the clam populations in the immediate vicinity of the power plant at the intake and discharge canals, the slag pond, and the intake structure (cribhouse).

MATERIALS AND METHODS

DESCRIPTION OF THE STUDY AREA

Lake Sangchris in central Illinois has an area of 876 ha and is composed of three arms, intake, discharge, and control (Fig. 1), each approximately 8 km in length. The water, used for cooling a 1,232-MW coal-fired electrical generating plant, is drawn from the intake arm, heated a maximum of 9°C, and emptied into the discharge arm, creating a 16-km "cooling loop." The third arm is not included in the cooling loop and was used as a control area. The slag pond adjacent to the power plant is a diked 32-ha area, where unheated water is used to slurry the residue of burned coal (slag). Excess water from the slag pond, which serves as a settling basin, is returned to the lake by a large pipe that empties into the discharge canal. Larimore & Tranquilli (1981) present a more detailed description of the entire study area in the introductory chapter of this monograph.

SPAWNING

The spawning seasons of *Corbicula* in the three arms of Lake Sangchris were determined by counting the number of larvae (trochophores or veligers) and eggs in the marsupial gills of adult clams. The actual rate at which larvae or eggs were released by adult clams was not determined. However, studies by Villadolid & Del Rosario (1930),

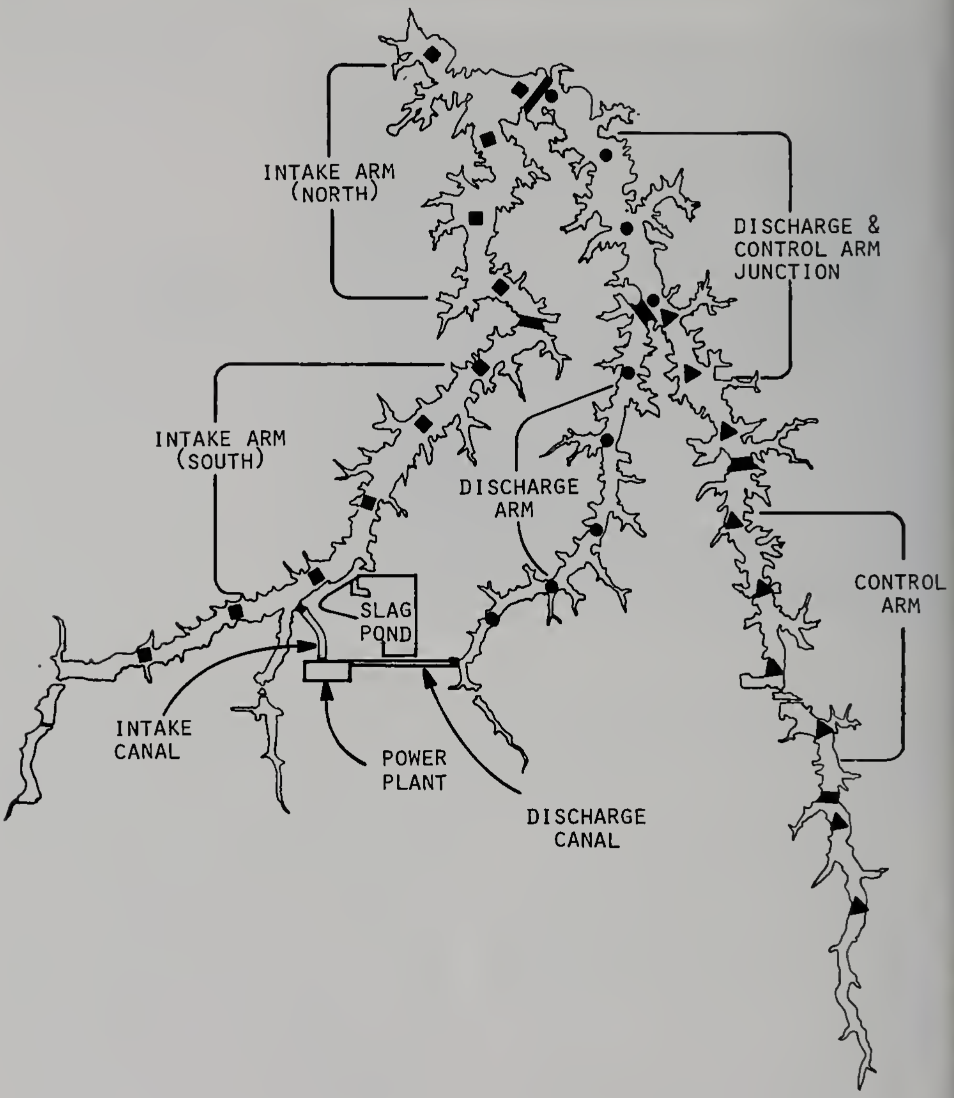

Fig. 1.—Map showing three main areas of Lake Sangchris: intake arm (squares), discharge arm (circles), and control arm (triangles). Eight sampling areas (seven lake areas and the slag pond), where the distribution and abundance of *Corbicula* were determined during the summer of 1975, are also labeled

Heinsohn (1958), and Aldridge & McMahon (1976) indicated that *Corbicula* release a small percentage of their larvae or eggs daily over a few weeks rather than releasing most of them at once.

The name *Corbicula fluminea* (= *C. manilensis*) was used because Britton & Morton (1979) concluded that the single introduced species of *Corbicula* in North America is *C. fluminea* (Muller 1774) and because Smith et al. (1979) found little genetic variability among *Corbicula* populations from California, Texas, Arkansas, Tennessee, and South Carolina.

Corbicula ranging in length from 16 to 41 mm were examined for eggs and larvae. Villadolid & Del Rosario (1930), Heinsohn (1958), and Sinclair & Isom

(1963) determined that clams of those sizes were sexually mature. From 8 May to 22 October 1975 five clams were collected approximately biweekly from a specific area in each of the three arms of Lake Sangchris. Additional clams were collected from the discharge arm on 23 April and from all three arms on 14 November and 31 December 1975. All *Corbicula* were taken from shoreline areas in water less than 1.5 m deep and were preserved in formalin until they could be examined.

To determine the number of eggs and larvae, the gills were removed and divided into small pieces under a dissecting microscope. When it appeared that 300 or fewer eggs and larvae were present, they were counted as the gills were disassembled. When more eggs and larvae were present, the gills were divided into small sections and the eggs and larvae were washed into a container with a known volume of water. Five subsamples were taken, and the eggs and larvae in each subsample were counted. The total numbers of eggs and larvae in each clam were estimated with the equation:

$$N = \frac{SSN \times SV}{SSV}$$

where N = the estimated number of larvae in each adult, SSN = the number of larvae in the subsample, SV = the sample volume, and SSV = the subsample volume. The final estimate was an average of the five subsample totals.

Veliger and trochophore larval stages and eggs were differentiated according to descriptions by Sinclair & Isom (1963).

GROWTH

The growth of *Corbicula* in Lake Sangchris was determined by several methods. The first method involved determining the annual growth of larvae produced in cages during 1975. One cage containing 15 adult clams was placed in each arm of the lake during May 1975. Growth cages (1.0 x 0.5 x 0.25 m) consisted of a wooden frame covered by 2.54-cm^2 wire mesh to provide free water circulation. A natural substrate was always provided by placing a few centimeters of lake bottom material within each cage. Clams produced during 1975 were collected from the growth cages during May 1976 and counted. Growth of young-of-the-year clams was determined by measuring their anterior to posterior length to the nearest millimeter with a dial caliper. To determine the effect of water temperatures on *Corbicula* growth, temperatures in each arm of the lake were recorded at approximately biweekly intervals.

Annual growth of adult *Corbicula* in all parts of Lake Sangchris was determined by studying individuals longer than 10 mm that were marked during the spring of 1975. Each individual was identified by scratching a series of marks on either or both valves with a saw blade, and each was placed in a growth cage in the original sampling area. Three cages were placed in the discharge arm, three in the control arm, and four in the intake arm; each cage received 25–40 clams. One year later the clams were recovered from the cages, and the growth of individuals was determined to the nearest 0.1 mm. Clams produced in these cages during 1975 were also counted and measured to increase the sample size for determination of the annual growth of larvae.

The growth of adult *Corbicula* during the summer was determined by returning the clams marked during 1975 to their respective cages in the three arms of the lake in May 1976 and measuring them again in September 1976. The summer growth of 1975 year class *Corbicula* was studied by returning to the growth cages young-of-the-year clams with a known length frequency distribution along with their marked parents.

The growth of *Corbicula* in the discharge arm was observed monthly from 17 May until 16 November 1976. Clams longer than 7 mm were measured to the nearest millimeter and put into one of four cages. To determine the growth of clams in each 1-mm size group, they were separated by 4-mm intervals. The size distribution placed in cage 1 was 7, 11, 15, 19 mm, etc. Similar size distributions were created in cages 2, 3, and 4 with the smallest individuals measuring 8, 9, and 10 mm, respectively. These cages (50 x 50 x 10 cm) were constructed of 0.6-cm² wire mesh and were placed in the discharge arm near the mouth of the discharge canal at the site where the clams had been collected. The clams in each cage were measured monthly to determine their average growth. Additional small clams were collected from the same area of the lake several times during the summer to replace those that had grown to larger sizes.

Corbicula growth rates observed in various parts of the lake were compared by a one-way analysis of variance using the statistical analysis system (SAS) regression procedure on an IBM 360/75 computer. Growth rates of clams of different sizes were adjusted for by using the reciprocal length (one ÷ initial length) as a covariable before comparing the growth of clams in different areas of the lake. Other statistical tests used were standard procedures outlined in Steel & Torrie (1960).

POPULATION DENSITY

The *Corbicula* populations in seven areas of Lake Sanchris and in the slag pond (Fig. 1) were studied from 11 June to 12 August 1975. The study areas in the lake were the discharge canal, discharge arm, control arm, control and discharge arm junction, intake arm-north, intake arm-south, and intake canal. Three 22.9-cm² Ponar dredge hauls were taken at each meter depth, working along transects from the shoreline to the middle of the lake. A sieve with a mesh size of 2 mm was used to separate clams from the substrate. The number, size, location, and depth of clams and the bottom type at each sampling site were noted. Approximately the same number of samples was taken from the eight study areas every week so that reproduction would not influence results obtained in one study area more than those obtained in another. The populations of two size groups of *Corbicula,* those longer than 5 mm and those 5 mm or shorter, were determined for each area. Clams shorter than 5 mm were considered to have been produced during 1975.

In areas which are more strongly influenced by power plant operations (discharge and intake canals) the population was sampled again during February 1976 for comparison with data from the previous summer.

To determine the population density and size distribution of clams inside the generating station, Ponar dredge hauls were taken near each of six rotating screens inside the water intake structure (cribhouse) during May 1976. The intake structure was sampled again during September 1976 to monitor changes in the clam population.

RESULTS AND DISCUSSION

SPAWNING

Marsupial gills of *Corbicula* did not contain larvae and eggs at the same time. Several clams did simultaneously contain trochophore and veliger larvae, but one stage always greatly outnumbered the other. The average size of all clams examined for eggs and larvae from the discharge, intake, and control arms was 25.0, 29.4, and 27.7 mm, respectively.

Small numbers of larvae and/or eggs were found in *Corbicula* collected from the discharge arm on 23 April 1975 at a water temperature of 21.5°C and in the intake and control arms on 8 May 1975 (Table 1), when water temperatures were 21° and 22°C, respectively. There was a simultaneous increase in the average number of larvae in clams from all three arms between 8 and 21 May as mean water temperatures $(N=3)$ increased (Fig. 2) to 24.3°, 22.6°, and 23.8°C in the discharge, intake, and control arms, respectively. In California, Heinsohn (1958) correlated larval development from March through June with optimal water temperatures of around 20°C. Isom (1971) reported that spawning occurred

Table 1.—Average numbers of larvae (veliger or trochophore) and eggs in marsupial gills of *Corbicula* from the three arms of Lake Sangchris during 1975. Five clams from each area were examined on each date.

	Discharge Arm		Intake Arm		Control Arm	
Date	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs
April 23	27	0	...	...	...	...
May 8	20	418	400	0	3	6
May 21	3,304	0	2,982	0	7,303	0
June 5	0	2	3,388	0	1,001	10
June 17	1,016	2	5,666	0	214	0
July 16	2	19	8,954	0	0	649
July 30	0	4	1,665	1,426	14	0
Aug 14	0	0	83	0	977	0
Aug 26	0	0	20	0	0	2
Sept 14	0	0	23	0	233	0
Sept 23	4	0	220	2,281	0	0
Oct 8	1,129	0	3,399	1	0	0
Oct 22	6,196	0	55	4	4,684	0
Nov 14	97	0	1,379	0	81	0
Dec 31	0	0	2	0	24	1

at water temperatures above 18.3°C. The number of larvae in clams from the discharge and control arms on 21 May represented the maximum number found in those two arms during the spring or summer, whereas reproduction continued in the intake arm until an average of 8,954 larvae per clam was found on 16 July. Thus, a major spawn began in mid-May in all three arms of Lake Sangchris, lasting through mid-June in the discharge and control arms and through the end of July in the intake arm.

Low levels of larval production occurred throughout the summer in the intake and control arms, but not in the discharge arm. Apparently, elevated water temperatures in the discharge arm during July and August (39° to 40°C) suppressed larval production there, whereas lower maximum temperatures (34°C) in the intake and control arms allowed larval production to continue.

An increase in the production of larvae by clams in all three arms of the lake during the fall of 1975 indicated a second major spawn (Fig. 2) that started in the discharge and intake arms between 23 September and 8 October, when mean weekly water temperatures (N = 3) were 25.4° and 19.9°C, respectively. Larval production increased in the control arm between 8 October and 22 October, when

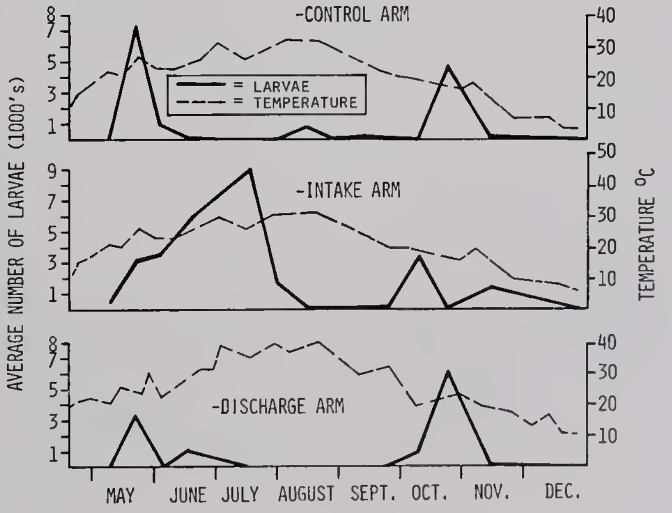

Fig. 2.—The average number of larvae (veliger and trochophore) in marsupial gills of *Corbicula* from the three arms of Lake Sangchris during 1975 in relation to water temperatures.

the mean weekly water temperature (N = 3) was 20.8°C. This second spawning season extended from early October through mid-November in the discharge and intake arms, and occurred during mid-October in the control arm. In California Heinsohn (1958) found a major *Corbicula* reproduction peak occurring from late April through June, a near absence of reproduction during midsummer, and a second minor reproductive peak in late August and early September. In the Delta-Mendota Canal, California, Eng (1979) also found two peaks in spawning activity, resulting in the appearance of two size classes annually. Aldridge & McMahon (1976) found that a natural population of *Corbicula manilensis* in a Texas cooling lake produced two generations per year, one in the spring and one in the fall.

The reproductive potential of *Corbicula* in Lake Sangchris was shown by maximum larval counts of 21,030, 16,996, and 16,505 in individual clams from the discharge, intake, and control arms, respectively.

GROWTH

In general, the greatest growth occurred in cages in the discharge arm and the least growth in cages in the control arm. Average annual growth of 1975 year class *Corbicula* produced in cages in the discharge, intake, and control arms during 1975 was 20.9, 18.1, and 16.4 mm, respectively (Fig. 3). According to results of Duncan's new multiple-range test (Steel & Torrie 1960), growth of young-of-the-year clams from the discharge arm was significantly greater ($P < 0.05$) than it was in the control arm, but not significantly greater than growth in the intake arm. In the same analyses, the mean growth of clams in the intake and control arms was not different. In similar studies conducted at the Kingston Steam Plant, Tennessee, Mattice (1979) found that the growth of *Corbicula* caged in the discharge was significantly greater than that of *Corbicula* caged in the intake for comparable periods.

In our study the greater annual growth of young-of-the-year clams in the discharge arm was attributed to the extended growth period made possible by the heated water from the generating station. In the discharge arm, higher water temperatures contributed to an earlier completion of spawning in the spring and allowed growth to continue later into the fall than was possible in the intake or control arms. O'Kane (1976) determined that young-of-the-year *Corbicula* from unheated Texas reservoirs grew in 1 year to a mean length of 14–15 mm and to a maximum length

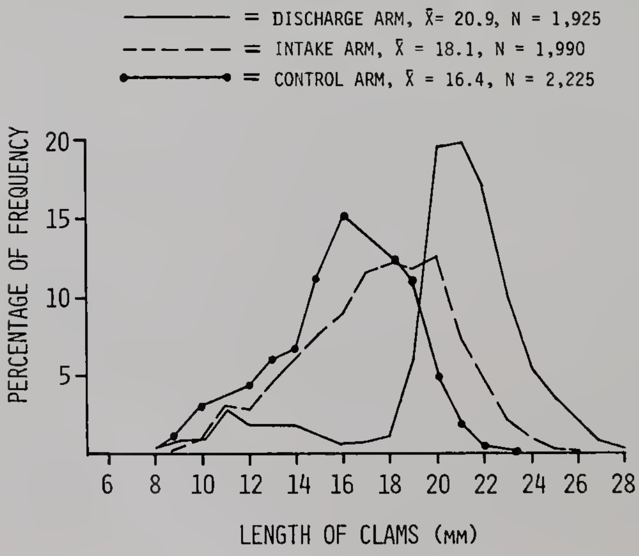

Fig. 3.—Average annual size of young-of-the-year *Corbicula* in cages in the discharge, intake and control arms of Lake Sangchris during 1975.

of 25 mm. Aldridge & McMahon (1976) found that *Corbicula* had a somewhat faster growth rate in a Texas cooling lake, where a more southerly latitude allowed an even longer growing season. In the Texas cooling lake, larvae produced during a mid-April to late July spawning period grew to a mean length of 28.7 mm by mid-December of that year, and larvae produced during a late August to late November spawning period grew to a mean length of 31.0 mm by mid-August of the following year.

Extremely high water temperatures (up to 40°C) occurred in areas of the discharge arm during the summer of 1975, and all clams in one cage near the discharge canal died. The death of those clams was believed to be directly related to the high water temperatures, because Mattice & Dye (1976) determined that *Corbicula* acclimated at 30°C experienced 100-percent mortality when exposed to 43°C for 30 minutes and 50-percent mortality at the upper incipient lethal temperature of 34°C. Additional sampling in the discharge canal indicated a summer die-off, because by late summer only a few live clams, along with numerous empty shells, could be found in a region where there had been a large concentration of live clams during the previous spring. Clams in two other cages in the discharge arm during the summer of 1975 survived throughout the year. They may have been partially buffered from the high water temperatures, however, because one cage was in a cove and the other was approximately 1.25 km downstream from the entrance of the discharge canal into the lake.

The annual growth of individually marked adult clams was inversely proportional to their original length, with smaller clams growing faster than larger individuals. Smaller clams (10–13 mm) grew as much as 18.7 mm per year, while larger clams (34–39 mm) grew only 1.8–4.8 mm per year (Fig. 4). O'Kane

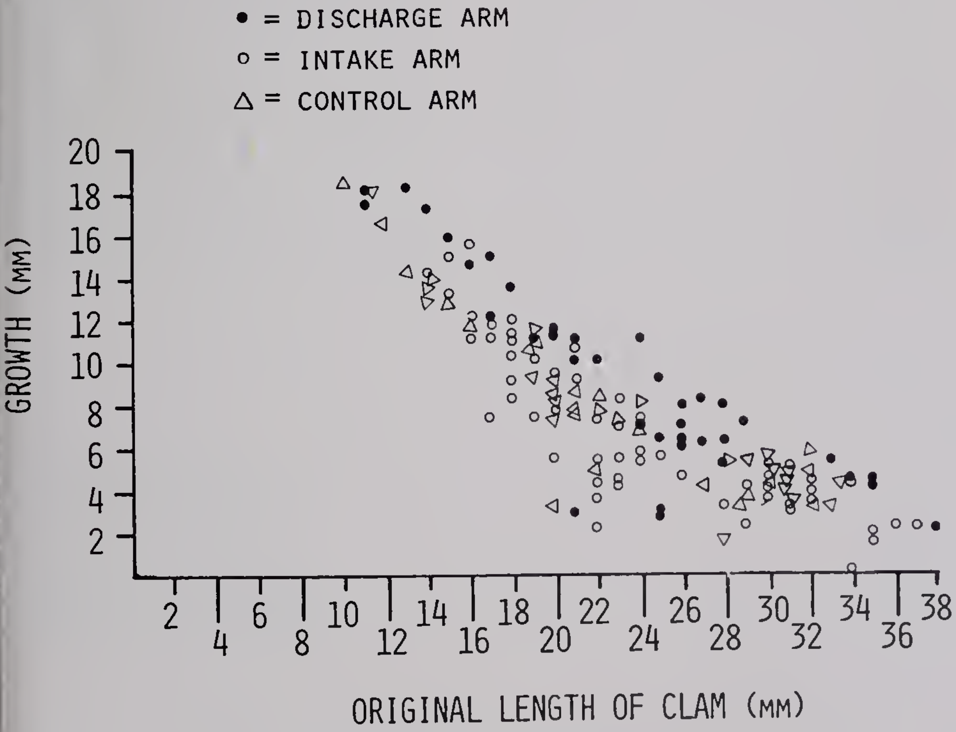

Fig. 4.—Annual growth of individually marked *Corbicula* of different sizes in the three arms of Lake Sangchris from May 1975 to May 1976.

(1976) and Britton et al. (1979) also found that smaller *Corbicula* increased in length at a faster rate than did larger ones. The initial lengths of clams caged in each arm were adjusted to a common mean by the least-squares method so that their average growth could be determined. After having been adjusted for initial length, the growth of marked clams in the discharge arm was found to be much greater ($P < 0.01$) than the growth of those in the intake and control arms, while the growth of clams in the latter two arms was not different. Clams from the discharge arm grew an average of 10.2 mm, while those from each of the other two arms grew only 7.8 mm per year.

A 1976 year class of clams was found inside cages raised in late September 1976 to determine summer growth of both individually marked adults and 1975 year class clams. The 1976 young-of-the-year clams produced in one cage in the discharge arm had grown to a mean length of 13.3 mm, while those produced in two cages in the intake arm had grown to mean lengths of 12.9 and 13.6 mm during the summer (Table 2). O'Kane (1976) reported that young-of-the-year *Corbicula* in unheated Texas reservoirs grew an average of 11–12 mm and a maximum of 20 mm in 4 months.

Clams of the 1975 year class, having a bimodal length frequency distribution (representing spring and fall reproduction), were placed in one discharge arm cage during the summer of 1976. Clams spawned in the discharge arm during the spring of 1975 grew from a mean length of 22.3 mm to 30.2 mm during the summer of 1976, while clams spawned there during the fall of 1975 grew from a mean length of 12.4 to 24.7 mm during the same time period (Fig. 5). In two intake arm cages, 1975 year class clams that were spawned during the spring (represented by a unimodal length frequency distribution) grew from mean

Table 2.—Mean summer growth in millimeters of young-of-the-year *Corbicula* produced in the discharge and intake arms of Lake Sangchris during 1976. Growth was determined by length frequency distribution analysis (percentage frequency).

Length in Millimeters	Discharge Arm	Intake Arm	
	Cage 1	Cage 1	Cage 2
7	. . .	. . .	. . .
8	0.2	1.1	. . .
9	0.5	2.2	. . .
10	4.0	6.5	0.8
11	11.8	14.2	4.0
12	23.8	25.4	20.9
13	30.8	27.3	37.8
14	17.0	18.9	26.9
15	8.3	4.4	8.8
16	2.2	. . .	0.4
17	1.2	. . .	. . .
18	. . .	. . .	. . .
19	. . .	. . .	. . .
Mean growth	*13.3*	*12.9*	*13.6*
Standard Deviation	1.4	1.4	1.0
Total N	399	275	249

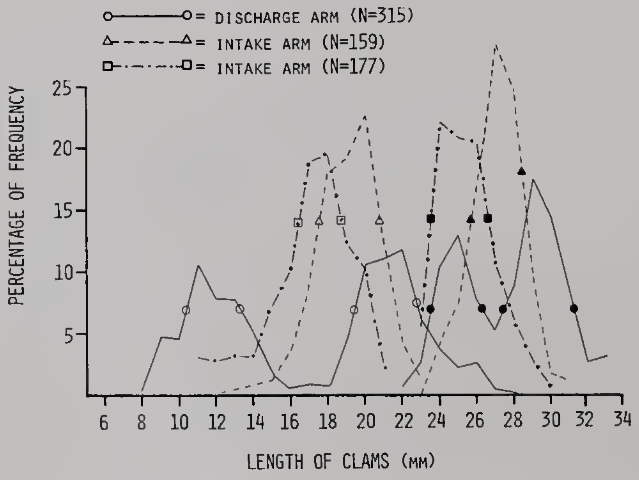

Fig. 5.—Sizes of 1975 year class *Corbicula* caged in the discharge and intake arms of Lake Sangchris during the summer of 1976. The spring (open symbols) and fall (solid symbols) length frequency distributions are indicated

Table 3.—Average growth in millimeters of individually marked *Corbicula* caged in the discharge, intake, and control arms of Lake Sangchris from May to September 1976. The number of clams present in each 1-mm length group is shown in parentheses.

May 1976 Clam Length in Millimeters	Discharge Arm Length Increase	Intake Arm Length Increase	Control Arm Length Increase
25	...	5.0(2)	...
27	...	3.2(4)	5.2(3)
28	...	2.8(5)	4.3(4)
29	4.2(1)	4.9(11)	4.2(7)
30	...	4.3(7)	4.1(8)
31	3.4(3)	3.0(6)	2.0(1)
32	3.8(1)	4.1(5)	3.6(1)
33	1.2(2)	1.9(4)	2.3(3)
34	...	1.8(6)	2.3(4)
35	...	2.3(2)	3.0(8)
36	...	2.4(6)	1.9(5)
37	...	0.2(2)	...
38	...	2.0(4)	2.6(2)
39	1.6(2)	...	...
40	1.6(2)	...	...
42	1.0(1)	...	...

lengths of 17.9 and 19.6 mm to 25.7 and 27.6 mm, respectively, during the summer of 1976.

The growth of individually marked adult clams during the summer of 1976 was again inversely proportional to the original length of the clams, with smaller clams growing faster than larger individuals (Table 3). Since the smallest original length of those clams was relatively large (25 mm), their overall growth in length was relatively small. Statistical analyses of these data were not appropriate because of major differences in sample sizes between the three arms.

When the growth periods for caged clams of all size groups and year classes were equalized during the summer of 1976, only slight differences in growth rates were found between clams in the heated and unheated areas. During 1976, however, summer water temperatures in the discharge arm were abnormally low in comparison to those of the 2 previous years, and in August water temperatures became about the same over the entire lake as a result of a power plant shutdown (Larimore & Tranquilli 1981). Thus, while higher water temperatures alone did not seem to enhance clam growth during 1976, different results may occur in more normal years when a greater temperature differential is found between heated and unheated areas.

Monthly examination of clam growth in the discharge arm during 1976 (Table 4) showed that fastest growth occurred during the first month. Adjustment of the initial length of clams in each cage to a common mean at the beginning of each month by the least-squares method revealed that monthly clam growth decreased gradually from 17 May to 16 November. The mean monthly growth in millimeters for classes of all sizes was: May–June, 2.7; June–July, 1.9; July–August, 1.7; August–September, 1.4; September–October, 1.3; and October–November, 0.2. The data in Table 4 further show that small clams grew faster than large clams until the last month (October–November), when clams of all sizes increased in length at approximately the same rate. Slower growth by clams of all sizes during the last month was related to naturally decreasing autumn water temperatures.

The growth of caged clams during 1975 and 1976 indicated that clams from the discharge arm of Lake Sangchris reached a length of 21 mm at approximately 1 year of age, while clams in the intake and control arms only grew to 18 mm (Table 5). Estimates of annual growth based on the growth of caged clams also showed that *Corbicula* in the discharge arm were larger than clams in the other two arms after their 2nd, 3rd,

Table 4.—Average monthly (17 May-16 November 1976) growth of *Corbicula* caged in the discharge arm of Lake Sangchris. The number of clams present in each 1-mm length group at the start of each period is shown in parentheses.

Length in Millimeters	Length Increase in Millimeters					
at Start of Period	17May–21 June	22 June–16 July	17 July–13 Aug	14 Aug–17 Sept	18 Sept–20 Oct	21 Oct–16 Nov
7	6.3(3)	. . .	. . .	. . .	. . .	. . .
8	5.5(21)	. . .	. . .	3.1(7)	3.1(1)	. . .
9	5.8(14)	. . .	3.4(16)	. . .	2.7(16)	. . .
10	5.7(7)	. . .	3.5(1)	3.0(2)	2.0(7)	0.5(1)
11	5.0(2)	. . .	3.3(2)	3.0(1)	2.1(17)	0.2(16)
12	4.5(2)	. . .	. . .	2.4(19)	1.9(21)	0.3(24)
13	. . .	3.1(6)	. . .	2.1(3)	1.7(7)	. . .
14	4.0(2)	3.0(21)	. . .	2.5(1)	1.7(11)	0.2(21)
15	4.0(3)	3.1(22)	2.5(1)	. . .	1.8(15)	0.2(8)
16	3.5(11)	2.5(2)	. . .	. . .	1.6(6)	0.3(12)
17	3.7(9)	. . .	2.4(22)	. . .	1.5(2)	0.4(14)
18	3.1(5)	. . .	2.1(17)	. . .	1.5(1)	. . .
19	3.0(1)	2.0(3)	2.5(2)	. . .	1.5(1)	0.3(2)
20	3.0(1)	2.4(11)	. . .	1.4(15)	1.3(11)	0.0(1)
21	2.9(8)	2.4(13)	2.2(3)	. . .	1.3(24)	0.3(11)
22	2.5(6)	2.5(1)	1.9(11)	. . .	1.3(12)	0.2(24)
23	2.2(8)	1.6(5)	. . .	1.2(3)	1.3(6)	0.1(12)
24	2.2(9)	1.4(14)	1.5(1)	. . .	1.4(4)	0.2(6)
25	1.8(4)	1.5(8)	. . .	. . .	1.1(14)	0.1(4)
26	2.0(4)	1.2(7)	0.8(7)	. . .	1.2(17)	0.4(13)
27	1.0(2)	1.1(4)	0.8(9)	0.7(7)	1.1(10)	0.1(17)
28	. . .	1.1(4)	. . .	. . .	0.9(8)	0.3(10)
29	0.5(3)	1.0(1)	0.9(4)	0.5(2)	0.8(15)	0.2(20)
30	1.5(1)	2.0(2)	0.5(2)	0.5(2)	0.7(9)	. . .
31	1.1(10)	. . .	. . .	. . .	0.8(2)	0.2(9)
32	1.0(13)	0.5(23)	0.5(1)	0.5(2)	0.7(3)	0.2(5)
33	0.6(7)	0.5(8)	0.3(20)	0.3(2)	0.4(11)	0.1(11)
34	0.6(14)	0.5(14)	. . .	0.2(7)	. . .	0.1(24)
35	0.7(5)	. . .	0.4(14)	. . .	0.6(10)	. . .
36	0.5(8)	0.4(12)	. . .	0.2(5)	0.3(14)	0.2(14)
37	. . .	. . .	0.1(8)	. . .	. . .	. . .
38	. . .	. . .	. . .	. . .	0.5(1)	. . .

and 4th years of life. The growth pattern observed in Lake Sangchris thus agrees with that determined from studies conducted by Britton et al. (1979) in which growth increased rapidly at first, but the rate of increase diminished as size increased.

POPULATION DENSITY

Quantitative samples collected from seven areas of Lake Sangchris and the slag pond during the summer of 1975 indicated that *Corbicula* usually were more abundant in areas with a substrate composed of 2–10 cm of loose sand, silt, or clay over hard clay, than in areas with a thick layer of loose silt (Table 6). Excluding the steep-sided intake and discharge canals, the population density varied inversely with depth at lake stations where a gradual increase in depth occurred in the littoral zone. However, the largest concentrations of clams (138 and 121/m² at 11 and 12 m, respectively) were found in the intake canal near the cribhouse, where a 0.3-m/second current caused by the power plant created an artificial habitat.

In two central Arizona reservoirs Rinne (1974) found that *Corbicula* concentrations were highest on rock-

Table 5.—Estimated lengths in millimeters of *Corbicula* at 1-4 years of age in the discharge, intake, and control arms of Lake Sangchris.

	Age in Years			
Area	1	2	3	4
Discharge arm	21	31	36	40
Intake and Control arms	18	28	32	36

rubble slopes and that density increased directly with depth of water. He associated higher densities with more complex habitats, which also increased directly with increasing depth. In the Altamaha River of Georgia, Gardner et

Table 6.—Distribution and abundance of *Corbicula* in Lake Sangchris and the slag pond during the summer of 1975. For each station and depth, the mean density (number per m^2) of young-of-the-year clams (<5 mm in total length) is listed first (in italics), followed by the mean density of clams of all sizes, the number of samples (in parentheses), and the substrate type. Gravel (Gr), slag (Sl), Clay (Cl), silt (Si), and sand (Sa) substrates are listed in order of frequency of occurrence.

Depth In Meters	Discharge Canal	Discharge Arm	Discharge & Control Arm Junction	Intake Arm North	Intake Arm South	Intake Canal	Control Arm	Slag Pond
1	*6* 6 (6) Cl,Gr	*50* 64 (41) Cl,Si	*55* 62 (18) Cl	*53* 57 (27) Cl	*44* 46 (36) Cl	*45* 45 (3) Sa,Cl,Gr	*8* 10 (34) Cl,Sa,Si	*28* 108 (27) Sl,Si
2	*0* 0 (6) Gr	*31* 39 (31) Cl,Si	*34* 46 (18) Cl,Sa,Si	*22* 24 (26) Cl,Sa	*13* 15 (33) Cl,Si	*77* 92 (5) Sa,Cl,Gr	*7* 7 (34) Sa,Si	*17* 47 (9) Sl,Si
3	*6* 6 (3) Sl	*26* 40 (17) Si,Cl	*23* 23 (18) Si,Sa	*34* 36 (12) Cl,Sa	*6* 8 (24) Si,Sa,Cl	*54* 57 (6) Sa,Cl,Gr	*8* 8 (28) Si,Sa	*0* 124 (3) Sl,Si
4	...	*24* 27 (12) Si	*13* 15 (18) Si	*21* 27 (12) Cl,Sa,Si	*21* 25 (21) Si,Sa	*58* 67 (6) Sl,Sa,Gr	*5* 5 (25) Si	*6* 25 (3) Si
5	.	*3* 3 (6) Si	*14* 15 (18) Si	*22* 25 (12) Cl,Si,Sa	*5* 6 (15) Si,Sa	*102* 108 (6) Sl,Sa,Gr	*3* 3 (15) Si	*0* 0 (3) Si
6		*3* 3 (6) Si	*5* 6 (18) Si	*15* 15 (9) Si,Sa	*5* 5 (12) Si	*51* 57 (6) Sl,Sa,Gr	*2* 2 (9) Si	
7	.	*0* 0 (3) Si	*2* 2 (18) Si	*0* 0 (9) Si	*2* 2 (12) Si	*19* 19 (3) Sl,Sa,Gr	*0* 0 (6) Si	
8	..		*1* 1 (18) Si	*0* 0 (9) Si	*0* 0 (6) Si	[a]		
9			*0* 0 (18) Si	*0* 0 (9) Si	*0* 0 (6) Si	[a]		
10		..	*0* 0 (18) Si	*2* 2 (9) Si	.	[a]		
11			*0* 0 (9) Si	*0* 0 (3) Si		*128* 138 (6) Si,Sl,Sa		
12	...	...	*0* 0 (9) Si	...	...	*102* 121 (3) Si,Sl,Sa		

[a] No sampling was possible because of a vertical concrete wall

al. (1976) found *Corbicula* were more abundant on substrates of sand in combination with mud or detritus than they were on substrates which were predominantly mud or detritus. In Dale Hollow Reservoir, Tennessee, Abbott (1979) found highly significant differences between 8-m and 12-m depths for shell sizes and densities, with larger individuals occurring at 8 m and greater densities occurring at 12 m. Temperature differences between the 8- and 12-m depths were hypothesized as the major factor affecting shell size, whereas substrate type appeared to modify density. The highest densities of *Corbicula* in several Texas reservoirs were associated with sand-gravel substrates and boulder rubble, while the lowest densities were noted in fine sand, in sharp granite gravel, and in substrates containing a high percentage of clay and silt (O'Kane 1976). Eng (1979) reported densities in sediment bars of the concrete-lined Delta-Mendota Canal, California, of 10,000–20,000 clams/m².

During the summer of 1975, the mean density of clams in the littoral zone (1-3 m depth) was higher in all areas of the cooling loop (except the discharge canal) than it was in the control arm (Fig. 6). The highest average clam population in the littoral zone was found within the intake canal (64.7/m²). In other areas of the cooling loop average concentrations decreased gradually from 50 clams/m² in the discharge arm to 25 clams/m² in the intake arm south. The average density in the control arm littoral zone was at least three times lower at 8 clams/m², which suggested that the population in the cooling loop benefited from power plant operations that supplied heat and/or current. The lowest clam density in the littoral zone was in the discharge canal (4 clams/m²). That low population was attributed to the clam die-off during the summer of 1975 as a result of 40°C water temperatures. In contrast, Webb (1981) reported that populations of soft-bodied benthic organisms (mostly Chironomidae) were not affected by high water temperatures in the discharge canal, but instead were adversely affected by the presence of a shifting slag substrate.

Young-of-the-year individuals constituted 88 percent of all clams in Lake Sangchris during the 1975 population study (Table 6). The slag pond, adjacent to the lake, contained the highest population of large clams (12–15 mm in length) and was the only sampling area where clams > 5 mm in length were more numerous than smaller individuals (Fig. 6). The low number of adults in Lake Sangchris in relation to the number of juveniles indicated a low survival rate for young-of-the-year clams. In contrast, a high survival rate of young-of-the-year clams was common in growth cages, where the larvae were protected from predation. For example, 0.5 x 0.5 x 0.5 m cages, each containing 15 adult clams,

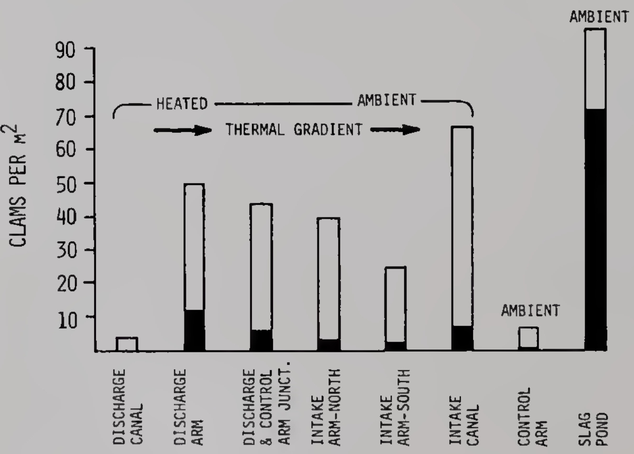

Fig. 6.—Average densities of *Corbicula* >5 mm long (solid bars) and ≤5 mm long (open bars) in the littoral zone of seven sampling areas of Lake Sangchris and the slag pond during the summer of 1975.

were placed in the discharge, intake, and control arms during the spring of 1975, and 1 year later they contained 5,720, 13,060, and 4,544 clams/m², respectively. In the lake, fish predation was believed to be a major source of mortality for small clams. Fish food-habit analyses revealed that *Corbicula* were regularly consumed by bluegill (*Lepomis machrochirus)*, freshwater drum *(Aplodinotus grunniens)*, and channel catfish (*Ictalurus punctatus*) in Lake Sangchris (Sule et al. 1981). Rinne (1974) similarily suggested that fish predation was a factor in affecting the density of *Corbicula* in two Arizona reservoirs. The greater abundance of large clams in the slag pond was attributed to a reduced rate of fish predation there. Tranquilli et al. (1977) surveyed the slag pond fish population and found only black bullheads (*Ictalurus melas*) during 1974 and only black bullheads, gizzard shad (*Dorosoma cepedianum*), and one yellow bass (*Morone mississippiensis*) during 1975. Since gizzard shad and yellow bass feed on plankton, black bullheads were the only potential clam predators present. However, the slag pond does serve as a waterfowl refuge during the autumn, and predation of larger clams by waterfowl may have been fairly high. Sanderson & Anderson (1981) reported that the slag pond attracts approximately one-half of the more than 100,000 waterfowl that congregate at Lake Sangchris every year and that 36 percent of the waterfowl shot by hunters at the lake contained *Corbicula* shells in their gizzards.

Quantitative samples taken in the discharge canal area of Lake Sangchris during February 1976 demonstrated that *Corbicula* were much more abundant than they had been during the previous summer. Average concentrations of 441 and 418 clams/m² were found at depths of 2 and 3 m, respectively, whereas only 8 and 6 clams/m² were found at these depths during the summer of 1975. In February, 48 percent of the clams were less than 3 mm in length, and all were less than 8 mm in length, indicating that they had been produced during the fall of 1975. That relatively high February clam concentration further suggested that the discharge canal area was repopulated during the fall by larvae produced in the intake canal, the power plant, and the slag pond. Some of the small clams were attached by byssal threads to particles of slag in the substrate. Apparently, large concentrations of small clams settle in the discharge canal every year and are later reduced by fish predation and/or high summer water temperatures.

When the intake canal was reexamined during February 1976, a much smaller clam population was present than was there during the previous summer. In 36 samples taken during February, there was an average of only 3.1 clams/m², whereas there was an average of 81.3 clams/m² in 44 samples during the previous summer. Very few empty shells were found during February; however, a 0.3-m/second current created by the circulating water pumps may have drawn live and/or dead clams past the trash racks at the entrance of the cribhouse. Examination of water quality parameters recorded in the intake canal between the summer of 1975 and February 1976 by Brigham (1981) suggested no cause for the observed reduction in clam population density.

The intake structure of the power plant was sampled in May 1976 (N = 6), and an average concentration of 6,788 clams/m² was found on the cribhouse floor. Approximately 70 percent of these clams ranged in length from 14 to 19 mm, indicating that most were produced during 1975. The umbones and ventral margins of clams from the cribhouse were scratched and worn, apparently the result of their having been moved about by water currents. The population inside the cribhouse may have been established by larvae or juveniles passing through the 6.2-mm² wire mesh barrier or by adults being carried over the vertically rotating screen to the cribhouse floor. Spawning in the cribhouse probably occurs during most of the warmer months, as it does in the intake arm. From the cribhouse, larval clams can be introduced directly into the generating station, where they may attach themselves to pipes by byssal threads.

The cribhouse floor was sampled again during September 1976, and an average of only 1,158 clams/m² was found in two dredge hauls. The 83-percent reduction in numbers through the summer may have occurred naturally, may have been an effect of small sample size, or may have been related to a complete shutdown of all the circulating water pumps for 6 days of each week during a 7-week period in midsummer. In any case, rapid fluctuation in population density should be expected when dealing with organisms such as *Corbicula,* which have high fecundities, produce two generations per year, and are highly vulnerable to predation by fishes.

SUMMARY

1.—During 1975, *Corbicula* in Lake Sangchris had major spawning seasons in the spring and in the fall.

2.—The average annual growth of young-of-the-year clams in the discharge arm during 1975 (20.9 mm) was significantly greater ($P < 0.05$) than the average growth of clams in the intake (18.1 mm) or control arms (16.4 mm).

3.—Annual growth of marked individuals was inversely proportional to their original length, with smaller clams growing faster than large clams. The growth of marked clams in the discharge arm was much greater ($P < 0.01$) than was the growth of individuals in the intake or control arms.

4.—The greater annual growth of clams in the discharge arm during 1975 was attributed to the extended growth period made possible by the heated water from the generating station.

5.—A partial clam die-off in the discharge arm near the discharge canal during the summer of 1975 probably was caused by elevated water temperatures (up to 40°C).

6.—Monthly examination of growth in the discharge arm during 1976 showed the fastest growth by clams of all sizes during the first month of study (May–June, decreasing progressively until October–November.

7.—Estimates of annual growth, based on the growth of caged clams during 1975 and 1976, indicated that clams in the discharge arm reached lengths of 21, 31, 36, and 40 mm after their 1st, 2nd, 3rd, and 4th years of life, respectively, and were always larger than clams of the same age from the intake and control arms.

8.—In Lake Sangchris the *Corbicula* population density varied inversely with depth; higher concentrations usually were found in areas associated with a substrate of 2–10 cm of loose sand, silt, or clay over hard clay than in areas with a thick layer of loose silt.

9.—During the summer of 1975 the mean clam density in the littoral zone was higher in all sections of the cooling loop (except the discharge canal where a die-off occurred) than it was in the control arm, suggesting that the population in the cooling loop benefited from power plant operations that supplied heat and/or current.

10.—During the 1975 Lake Sangchris *Corbicula* population study, few adults were found in relation to the number of juveniles, indicating low survival by young-of-the-year clams. Fish predation was believed to be a major source of mortality for small clams. A lower rate of fish predation upon young-of-the-year clams in the slag pond probably accounted for the higher proportion of adults found there.

11.—Quantitative samples collected from the discharge canal in February 1976 revealed that after the clam die-off during the summer of 1975 the canal was repopulated during the fall by larvae produced in the intake canal, the cribhouse, and the slag pond.

REFERENCES CITED

ABBOTT, T. M. 1979. Asiatic clam *(Corbicula fluminea)* vertical distributions in Dale Hollow Reservoir, Tennessee. Pages 111–118 *in* J. C. Britton, ed., First International *Corbicula* Symposium Proceedings. Texas Christian University, Fort Worth.

ALDRIDGE, D. W., and R. F. MCMAHON. 1976. Population growth and reproduction in the life-cycle of *Corbicula manilensis* Philippi. Abstract of paper presented at the 39th annual meeting, American Society of Limology and Oceanography. (Cited with permission of authors.)

BRIGHAM, A. R. 1981. Water quality in a cooling water reservoir. Pages 290–319 *in* R.W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

BRITTON, J. C., D. R. COLDIRON, L. P. EVANS, JR. C. GOLIGHTLY, K. D. O'KANE, and J. R. TENEYCK. 1979. Reevaluation of the growth pattern in *Corbicula fluminea* (Muller). Pages 177–192 *in* J.C. Britton, ed., First International *Corbicula* Symposium Proceedings. Texas Christian University, Fort Worth.

______, and B. MORTON. 1979. *Corbicula* in North America: the evidence reviewed and evaluated. Pages. 249–287 *in* J. C. Britton, ed. First International *Corbicula* Symposium Proceedings. Texas Christian University, Fort Worth.

ENG, L. L. 1979. Population dynamics of the Asiatic clam, *Corbicula fluminea* (Muller), in the concrete-lined Delta-Mendota canal of central California. Pages 39–68 *in* J. C. Britton, ed., First International *Corbicula* Symposium Proceedings. Texas Christian University, Fort Worth.

GARDNER, J. A., JR., W. R. WOODALL, JR., A. A. STAATS, JR., and J. F. NAPOLI. 1976. The invasion of the Asiatic clam *Corbicula manilensis* Philippi in the Altamaha River, Georgia. Nautilus 90(3):117–125.

GOSS, L. B., and C. CAIN, JR. 1975. Power plant condenser and service water system fouling by *Corbicula,* the Asiatic clam. Paper presented at the biofouling workshop, Johns Hopkins University, Baltimore, MD.

HEINSOHN, G. E. 1958. Life history and ecology of the freshwater clam, *Corbicula fluminea.* M. A. Thesis. University of California, Berkeley. 64 p.

ISOM, B. G. 1971. Evaluation and control of macroinvertebrate nuisance organisms in fresh-water industrial supply systems. Paper presented at the 19th annual meeting, Midwest Benthological Society, University of Notre Dame, IN.

LARIMORE, R. W., and J. A. TRANQUILLI. 1981. The Lake Sangchris project. Pages 279–289 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

MATTICE, J. S. 1979. Interactions of *Corbicula* sp. with power plants. Pages 119–138 *in* J. C. Britton, ed., First International *Corbicula* Symposium Proceedings. Texas Christian University, Fort Worth.

______, and L. L. DYE. 1976. Thermal tolerance of the adult Asiatic clam. Pages 130–135 *in* G. W. Esch and R. W. McFarlane, eds., Thermal ecology II. Energy Research and Development Administration Symposium Series (CONF-750425), Augusta, GA.

O'KANE, K. D. 1976. A population study of the exotic bivalve *Corbicula manilensis* (Phillipi, 1841) in selected Texas reservoirs. M. S. Thesis. Texas Christian University.

RINNE, J. N. 1974. The introduced Asiatic clam, *Corbicula,* in central Arizona reservoirs. Nautilus 88(2):56–61.

SANDERSON, G., and W. L. ANDERSON. 1981. Waterfowl studies at Lake Sangchris. Pages 656–690 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

SICKEL, J. B. 1973. A new record of *Corbicula manilensis* (Philippi) in the southern Atlantic slope region of Georgia. Nautilus 87(1):11–12.

SINCLAIR, R. M., and B. G. ISOM. 1963. Further studies on the introduced Asiatic clam *(Corbicula)* in Tennessee. Tennessee Stream Pollution Control Board and Tennessee Department of Public Health, Nashville. 78 p.

SMITH, M. H., J. BRITTON, P. BURKE, R. K. CHESSER, M. W. SMITH, and HAGEN. 1979. Genetic variability in *Corbicula,* an invading species. Pages 243–248. *in* J. C. Britton, ed., First International *Corbicula* symposium Proceedings. Texas Christian University, Fort Worth.

SULE, M. J., J. M. MCNURNEY, and D. R. HALFFIELD, JR. 1981. Food habits of some common fishes from heated and unheated areas of Lake Sangchris. Pages 500–519 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

STEEL, R. G. D., and J. H. TORRIE. 1960. Principles and procedures of statistics. McGraw-Hill Book Company, Inc. New York. 481 p.

TRANQUILLI, J. A., J. M. MCNURNEY, M. SULE, R. KOCHER, and R. W. LARIMORE. 1977. fish population and natural history studies. Pages 4.1–4.107 *in* Annual report for fiscal year 1976, Lake Sangchris project. Illinois Natural History Survey, Urbana.

VILLADOLID, D. V., and F. G. DEL ROSARIA. 1930. Some studies on the biology of Tulla *(Corbicula manillensis* Philippi), a common food clam of Laguna de Bay and its tributaries. Philippine Agriculturist 19:355–382.

WEBB, D. W. 1981. The benthic macroinvertebrates from the cooling lake of a coal-fired electric generating station. Pages 358–377 *in* R. W. Larimore and J. A. Tranquilli, eds., the Lake Sangchris study: case History of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

Aquatic Macrophytes in Lake Sangchris

Robert L. Moran

ABSTRACT

The aquatic vascular plants in an 876-ha cooling-water reservoir were studied from 1973 to 1976 to document the vegetational development of this reservoir and to determine what effects, if any, the thermal effluent may have had upon the vegetation. The vegetation was mapped for 4 consecutive years, the biomass of several stands of *Nelumbo lutea* and *Potamogeton nodosus* was determined, and an inorganic tissue analysis of *P. nodosus* was performed.

Shoreline erosion and turbidity had the greatest influence upon the occurrence and development of vegetation. The species immigration-extinction rate at Lake Sangchris was about 1.9-2.3 species per year. It is estimated that the maximum number of species will be about 28, and this number should be reached in 1985 when the lake is 21 years old. Some estimates from the literature suggest 50 as the maximum number of species in reservoirs, and this number could be reached by the year 2014.

Elevated water temperatures within the discharge arm were found to accelerate the development of *N. lutea* and *P. nodosus*. The distribution of *N. lutea* was confined to an area within the cooling loop with an annual thermal regime about 0.75°C warmer than the ambient water temperature, but not exceeding 37.6°C for more than 2.5 percent (9 days) of the year. The spring onset of *N. lutea* growth was earliest and stand biomass was greatest in the discharge arm of the lake. *P. nodosus* had a lakewide distribution, but achieved its greatest stand biomass in the intake arm.

Inorganic tissue analyses of *P. nodosus* showed that the highest concentrations of aluminum, boron, copper, magnesium, manganese, phosphorus, and zinc were in plants from the discharge arm.

INTRODUCTION

Lake Sangchris is an 876-ha reservoir formed in 1963–1966 by damming Clear Creek to supply cooling water for Commonwealth Edison's 1,232-megawatt coal-fired Kincaid Generating Station. The lake is composed of three arms with a general north-south orientation. The electric generating station lies between the western and middle arms and is connected to them by canals. The middle arm receives the thermal effluent and has been designated the discharge, or warmwater, arm; the western arm supplies the cooling water intake and is referred to as the intake, or cool-water, arm. Together these two arms form the cooling loop. The third, eastern, arm is not directly involved in the cooling loop flow and has been named the control arm (Fig. 1).

The purpose of this study was to document the development of vegetation in the reservoir and to determine what effects the operation of the Kincaid Generating Station and its thermal discharge had upon two aquatic vascular plants, *Nelumbo lutea* (Willd.) Pers. (American lotus) and *Potamogeton nodosus* Poiret (American pondweed).

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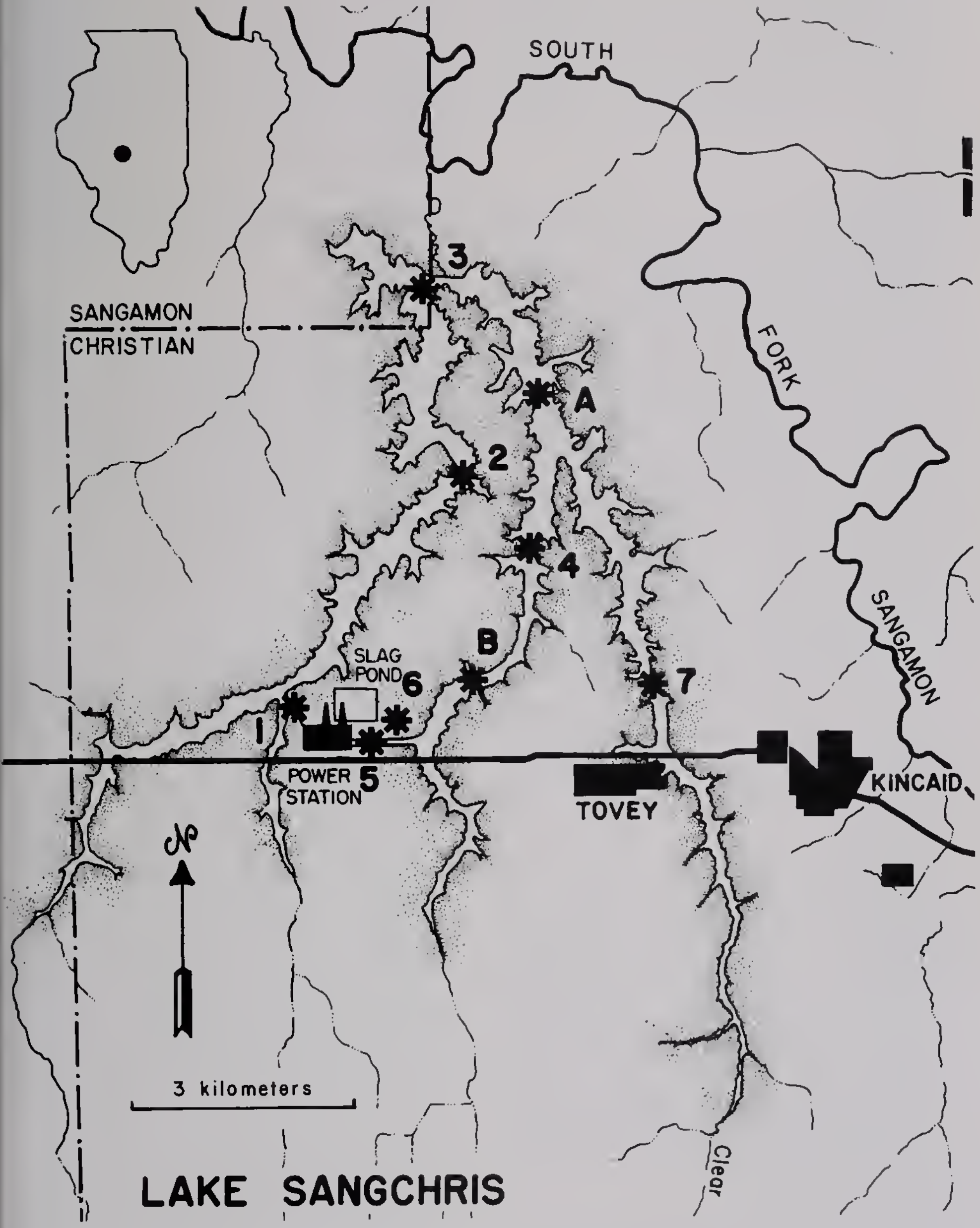

Fig. 1.—Lake Sangchris and its sampling stations.

METHODS

SOILS

The soils comprising the basin and immediate shoreline area were determined from Fehrenbacher et al. (1950).

VEGETATION

The vegetational surveys were accomplished by visual inspection of the shoreline and shallows from a boat during July and/or August each year. The occurrence and approximate distribution of each species were recorded on a map with a scale of 1:4,000. These surveys were conducted by Dreier (1974), Frakes & Moran (1975), and Moran (1977*a*).

BIOMASS

Potamogeton nodosus samples, including roots, were harvested in three 0.255-m^2 plots from each of four plant beds on 5 August 1974 and from eight plant beds on 24 July 1975. *Nelumbo lutea* samples, including rhizomes, were harvested in the same manner from six beds on 6 August 1975. Plants were rinsed thoroughly when picked, placed in plastic bags, and stored in a large styrofoam ice chest. On the following day, each sample was centrifuged in a commercial centrifugal extractor to remove the adherent water (Edwards & Owens 1960), and the fresh weights were determined to the nearest 0.1 g. Samples were dried for 24 hours at 105°C in a large forced-air plant dryer and cooled in plastic bags. Dry weights were determined to the nearest 0.1 g.

LEAF MEASUREMENTS

Measurements of *N. lutea* leaf diameters were made along line transects extended perpendicularly from the shoreline. Fifty to 100 leaves touching the vertical plane along the transect were measured in each plant bed. In early spring, when most leaves had not yet broken the surface, the emergent leaves were counted and categorized as spikes (leaves still tightly rolled), opening leaves, or fully opened leaves.

The significance of these data (0.05 level) was tested by a one-way analysis of variance and the modified new Duncan multiple-range test (Kramer 1956).

INORGANIC ANALYSES

Subsamples of *P. nodosus* leaves, stems, and roots were ground in a Sorval Omni-Mixer and stored in glass bottles. Analyses for aluminum, boron, calcium, copper, iron, magnesium, manganese, phosphorus, potassium, silicon, sodium, and zinc were performed by Dr. T. Peck, Professor of Soil Chemistry, University of Illinois, in a Jarrell-Ash Mark-IV Ebert direct-reading stigmatic spectrograph 3.4 m with a dispersal rate of 5 angstroms/mm.

RESULTS AND DISCUSSION

SOILS

The stream beds forming Lake Sangchris have Radford silt loam bottoms. On either side is a Hickory gravelly loam, except south of the intake canal and in a few scattered bays, where Velma loam flanks the Radford silt. Flanking these soils and forming the shoreline of the lake are Tovey and Bolivia silt loams, with Assumption silt loam dominating south of the intake canal and in scattered pockets around the lake.

The soils available for aquatic plant colonization in Lake Sangchris are Hickory gravelly loam and Bolivia and Tovey silt loams throughout most of the lake, with Velma loam and Assumption silt loam south of the intake canal. The soils of the shoreline can have a great effect upon the aquatic plants offshore. Not only is the fertility and ease of root or rhizome penetration important, but if the soils are easily eroded by wave action, the resulting deposition of the eroded material offshore may limit the suitability of that area for many plants. In Lake Sangchris, shoreline erosion seemed to be of great importance in the restriction of shoreline and submerged vegetation.

Soil type variations seemed to have little effect upon the distribution of aquatic vascular plants. The area south of the intake canal, which had soils different from those of the rest of the lake, had a flora similar in type and density to the southernmost portion of the control arm. The low densities of plants in both areas were probably related to other factors, such as temperature and their upwind isolation from the main portion of the lake and the cooling loop circulation pattern, restricting seed transportation and deposition.

VEGETATIONAL SURVEYS

The first vegetational survey of Lake Sangchris was performed in 1969 (Limnetics, Inc. 1972), and seven aquatic vascular plant species were recorded (Table 1). The most common species, *Najas minor* All. (brittle naiad), formed an almost continuous bed around the shoreline, limited only in areas of severe shoreline erosion and in the extreme southern portions of the intake and control arms. Emergent plants were limited to sheltered bays. *Nelumbo lutea* was recorded in only a few bays, and *Potamogeton natans* L.(believed to be *P. nodosus*) was limited to a small area at the junction of the warmwater and control arms and near the mouth of the discharge canal.

Sagittaria latifolia Willd. (duck potato) was abundant along the shoreline. *Typha latifolia* L. (cattail) and *Eleocharis* sp. (spike rush) were uncommon.

In 1973, *N. minor* was recorded from only four sites, but *P. nodosus* had extended its range considerably. *N. lutea* had spread to several new sites, and *Eleocharis* sp. had become quite common along the shoreline. In all, 12 species were recorded. The five additional species usually occurred in close proximity to established plant beds, such as those of *P. nodosus,* probably indicating that these were areas of stable shoreline sheltered from current and wind-generated waves.

In 1974, 14 species were reported. By this time, some bays in the discharge arm and the southern extreme of the control arm were beginning to develop vascular plant communities or associations. *P. nodosus* had colonized the entire lake, and *N. lutea* was establishing extensive beds in the bays of the cooling loop.

In 1975, 18 species were recorded from Lake Sangchris. The only reported nuisance species was *N. minor,* which was abundant again and sometimes hampered small boat operation in shallow bays. *N. lutea* also formed rather impenetrable masses in some bays, but was not regarded as a problem. *Potamogeton pectinatus* L. (sago pondweed), originally found in 1974, was common but not abundant.

In 1976, 23 species were recorded. By that time, associations within bays were becoming better developed and more complex. In the first years of this study, from 1971 through 1974, the increase in diversity occurred in the submerged, floating-leaf, and emergent groups of plants, while in 1975 and 1976, the greatest increase occurred in the plants inhabiting the upper beach areas (wet-soil plants). Two factors may have been important: (1) as the emergent plants, and to a limited extent the floating-leaf and submerged plants, developed extensive beds, they lessened the impact of waves upon the shoreline, and (2) low water levels during 1975 and 1976 removed the effects of waves from the beaches, allowing colonization by new species.

After 12 years, only three submerged-leaf plants (hyphydates) have been described in Lake Sangchris, *Ceratophyllum demersum* L. (submerged hornwort), *Najas minor,* and *Potamogeton pectinatus.* Light is a major factor controlling the zonation and distribution of hyphydates, none of which descends to depths with less than 2 percent of the surface light remaining (Hutchinson 1975). Since in Lake Sangchris the 1-percent compensation point typically occurs at between 2 and 3 m (Moran 1976), it is reasonable to expect no vascular plants below 2.5 or 3 m.

It is interesting to note that the three hyphydates in Lake Sangchris all have a myriophyllid type of leaf (deeply dissected and very thin), thought to be a deep-water adaptation to increase the surface area of a leaf and, therefore, to increase net photosynthesis in low-light habitats. The absence of broadleaf hyphydates in Lake Sangchris is another indication of the limited photic zone.

Table 1.—Aquatic vascular plants in Lake Sangchris, 1971–1976.

Plant	Year				
Type	1971	1973	1974	1975	1976
Wet soil	*Eleocharis* sp. *Scirpus subterminalis*	*Eleocharis* sp. *Scirpus validus*	*Eleocharis* sp. *Scirpus validus* *Salix nigra* (?)	*Ammannia coccinea* *Eleocharis* cf. *acicularis* *E. obtusa* *E.* cf. *smallii* *Scirpus atrovirens* *S. validus* *Salix nigra*	*Alisma subcordatum* *Ammannia coccinea* *Cephalanthus occidentalis* *Cyperus* cf. *ferruginescens* *Eleocharis* cf. *acicularis* *E. obtusa* *E. cf. smallii* Graminoid *Polygonum lapathifolium* *Scirpus atrovirens* *S. validus* *Salix nigra*
Emergent (hyperhydates)	*Nelumbo lutea* *Sagittaria latifolia* *Typha latifolia*	*Jussiaea repens* *Nelumbo lutea* *Polygonum* sp. *Sagittaria latifolia* *Typha latifolia* *Veronica* sp.	*Jussiaea repens* *Nelumbo lutea* *Polygonum* sp. *Sagittaria latifolia* *Typha latifolia* *Veronica* sp.	*Jussiaea repens* *Lophotocarpus calycinus* *Nelumbo lutea* *Polygonum amphibium* *Sagittaria latifolia* *Typha latifolia*	*Jussiaea repens* *Lophotocarpus calycinus* *Nelumbo lutea* *Polygonum amphibium* *Sagittaria latifolia* *Typha latifolia*
Floating leaf (ephydates)	*Potamogeton natans*	*Bacopa rotundifolia* *Potamogeton nodosus*	*Bacopa rotundifolia* *Potamogeton nodosus*	*Bacopa rotundifolia* *Potamogeton nodosus*	*Bacopa rotundifolia* *Potamogeton nodosus*
Submerged (hyphydates)	*Najas minor*	*Ceratophyllum demersum* *Najas minor*	*Ceratophyllum demersum* *Najas minor* *Potamogeton pectinatus*	*Ceratophyllum demersum* *Najas minor* *Potamogeton pectinatus*	*Ceratophyllum demersum* *Najas minor* *Potamogeton pectinatus*
Total species	*7*	*12*	*14*	*18*	*23*

Another group of plants are the floating-leaf plants (ephydates) that grow rooted in the sediments but have at least some leaves floating on the water surface with one leaf surface exposed to the atmosphere. These plants are somewhat sensitive to current and wave action and are usually found in protected areas. Only two plants of this group have been described in Lake Sangchris, *Bacopa rotundifolia* (Michx.) Wettst. (water hyssop) and *Potamogeton nodosus.* In the ephydates it has been noted that those plants with smaller ovate or lanceolate floating leaves are commonly found in areas of more surface disturbance than are plants with larger rounded leaves (Hutchinson 1975). The vulnerability of Lake Sangchris to wind-generated waves may be a factor in limiting the colonization of plants of this group.

The emergent plants (hyperhydates) are rooted in the sediments but have a substantial portion of the vegetation above the water surface. Three such species were recorded in 1971 and six species in 1973, and that number has remained stable to date. All share a common requirement of shelter from wind and wave action and usually occur in bays. Four of these, *Lophotocarpus (Sagittaria) calycinus* (Engelm.) J. G. Sm. (arrowhead), *Nelumbo lutea, Sagittaria latifolia,* and *Typha latifolia* (cattail), make up a major portion of the aquatic vegetation in Lake Sangchris and provide valuable food and habitat for wildlife.

The wet-soil plants, the most diverse group in Lake Sangchris, are those plants inhabiting the mud banks and beach areas. In 1974, only two species were reported. By 1976, 12 taxa were present (Table 1). This group of plants seemed to benefit from low water levels that increased the available habitat and decreased the stress of wave action. Once established, most such plants can tolerate shallow inundation. Wet-soil plants often have rhizomatous growth habits and may prove valuable in decreasing shoreline erosion. Plants such as *Ammannia coccinea* Tothb.; *Eleocharis* cf. *acicularis* (L.) Roem & Schultes; *E. obtusa* (Willd.) Schultes; *E. smallii* Britt. (spike rushes); and *Scirpus validus* Vahl. (soft stem bulrush) have demonstrated their abilities to maintain themselves and spread once they have become established in Lake Sangchris. These plants and the

American lotus (Nelumbo lutea) in the middle (discharge) arm of Lake Sangchris.

emergents may play a significant role in reducing shoreline erosion in the years to come.

VEGETATION DEVELOPMENT

Twenty-three plant species have accrued in Lake Sangchris in 12 years, and the rate of accrual seems to describe a portion of an S-shaped or logistic curve (Fig. 2). Two expressions were applied to the data to estimate the maximum number of species that might be established in Lake Sangchris and when that number would be attained. A prediction of the maximum number of species to accrue (equilibrium number) was based upon the formula for a logistic curve given by Metcalf & Eddy (1972).

$$P = \frac{S}{1 + me^{bt}}$$

$$S \text{ (saturation population)} = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2}$$

$$b \text{ (a constant)} = \frac{S - P_0}{P_0}$$

$$m \text{ (a constant)} = \frac{1}{n} \ln \frac{P_0(S - P_1)}{P_1(S - P_0)}$$

P_0, P_1, P_2 = populations at times t_0, t_1, t_2

This formula, applied to the data describing the lower curve in Fig. 2, indicated that the equilibrium level will be about 28 species of aquatic vascular plants and that this number should be reached in about 21 years (1985). This number agrees with the range (20–34 species of aquatic vascular plants) reported for a wide variety of lakes by Beard (1973), Clovis (1971), Judd & Taub (1973), Modlin (1970), Nichols & Mori (1971), and Seddon (1972).

To verify the time period, the equilibrium number of 28 species was applied to an expression of a decreasing rate of increase, kd, as given by Metcalf & Eddy (1972), which predicts the length of time required to reach any given maximum population:

$$\frac{dP}{dT} = kd(S - P)$$

$$kd = \frac{-\ln \frac{S - P_2}{S - P_1}}{t_2 - t_1}$$

where

S = maximum population
P_1, P_2 = populations at times t_1 and t_2

The resulting curve (Fig. 3) shows good agreement with the logistic curve by predicting 26 years (1990) to reach equilibrium.

However, Harris & Silvey (1940) reported that in Texas reservoirs, 52–54

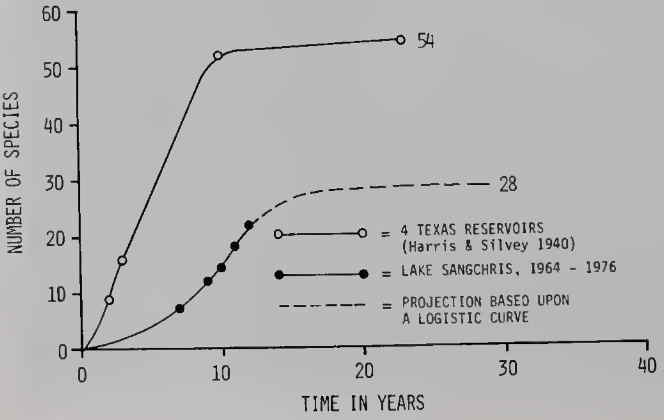

Fig. 2.—Number of aquatic vascular plant species in Lake Sangchris, 1964–1976, and a logistic projection of the maximum number of species to become established there compared with those in four Texas reservoirs.

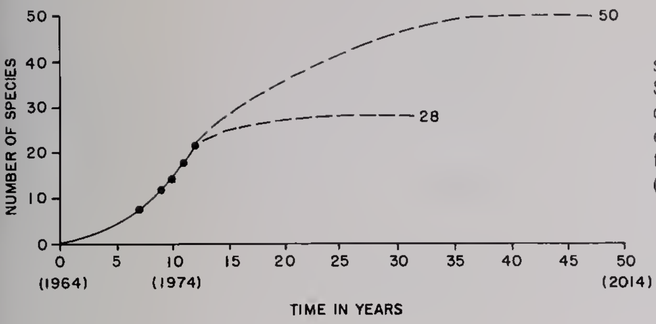

Fig 3.—Predicted rates of species accrual in Lake Sangchris based upon a decreasing rate of increase expression and two theoretical saturation (equilibrium) levels.

species seemed to be the equilibrium number, and Godwin (1923), Forest & Mills (1971), Judd & Taub (1973), and Seddon (1972) also reported finding some lakes with between 40 and 50 species. While those lakes may have been more suitable to macrophyte growth (shallow waters, soft bottoms, and protection from wave action), these findings suggest that 50 is about the maximum number of species that can be expected to occur within any given lake. In the case of Lake Sangchris, the decreasing rate of increase expression predicts that it would take 50 years (2014) to achieve that number (Fig. 3).

MacArthur & Wilson (1967) developed an expression to describe the rate of immigration and extinction of species on islands as they approached equilibrium. That rate (X) is calculated from the estimated number of species at equilibrium (S) and the time required to reach 90 percent of equilibrium ($t_{0.90}$):

$$X = \frac{1.16\ S}{t_{0.90}}$$

In Lake Sangchris the immigration-extinction rates derived from the above predictions ranged from X = 1.9/year to 2.3/year. Hutchinson (1975) applied this expression to Godwin's (1923) data on some British ponds (up to 222 years old, S = 44 species) and arrived at X = 0.23/year for ponds connected to a stream and X = 0. 16/year for isolated ponds. He also applied it to the Texas reservoirs data of Harris & Silvey (1940) and arrived at rates of X = 2.5 to 6.1/year. Hutchinson considered these rates too high, even when allowing for the much greater sizes of the reservoirs. However, since Lake Sangchris and Texas reservoir rates were determined during the active period of species immigration rather than long after equilibrium had been established, they may more accurately reflect the species immigration-extinction rate of aquatic vascular plants in new lakes.

NELUMBO LUTEA IN LAKE SANGCHRIS

The most conspicuous plant in Lake Sangchris is the American water lotus, *Nelumbo lutea.* This plant is primarily tropical, but extends into the subtropics and warm temperate regions of North and South America (Sculthorpe 1967). It grows best in organic soils in water up to 2.5 m deep. In 1971 *N. lutea* was recorded in seven small stands in the cooling loop (Fig. 4). Three years later, there were 26 stands within the cooling loop, and some of the plant beds were quite extensive.

The distribution of *N. lutea* is confined to the cooling loop, with the discharge and intake arms having similar quantities of the plant. In the area near and east of the dam, where the plant first appeared, only one stand remains. With the exception of the year 1975, *N. lutea* never progressed farther up the discharge arm than about 1 km south of Station 4 or farther down in the intake arm than Station 2.

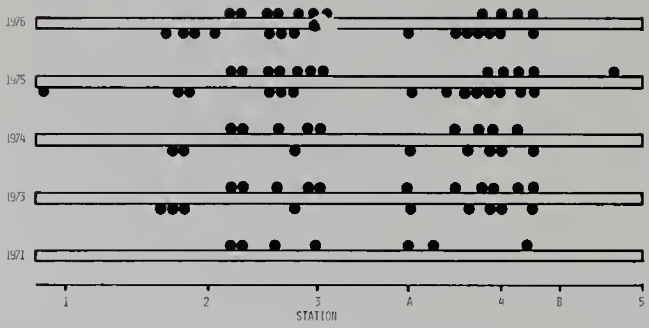

Fig 4.—Distribution of *Nelumbo lutea* within the cooling loop of Lake Sangchris, each dot representing a documented plant bed.

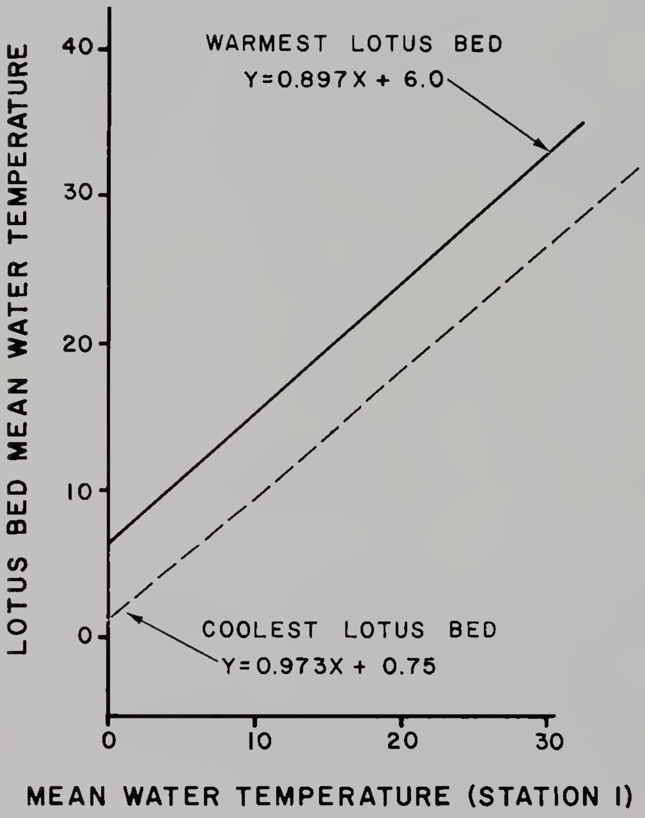

Fig. 5.—Linear regressions of water temperature (C) for the warmest and coolest *Nelumbo lutea* beds against ambient (Station 1) water temperature.

Water temperature data (Brigham 1977) showed that stations 1 and 7 were the coolest stations and both were areas devoid of lotus. Brigham's (1975) linear regressions of water temperatures at each station against that at Station 1 were used to estimate the water temperature regressions for the high and low temperature distribution limits of lotus. It was assumed that the regression lines would parallel that of the nearest water chemistry station given by Brigham. The Y intercept would then describe the relationship between water temperatures at the plant distribution limits and the water temperature at Station 1 (Fig. 5). The cold-water bed was 0.75°C warmer than ambient and the warmwater bed was 6.0°C warmer than the Station 1 temperature. The warmwater bed was about 2°C cooler than the discharge canal.

The overall thermal regimes at the distribution limits of *N. lutea* are

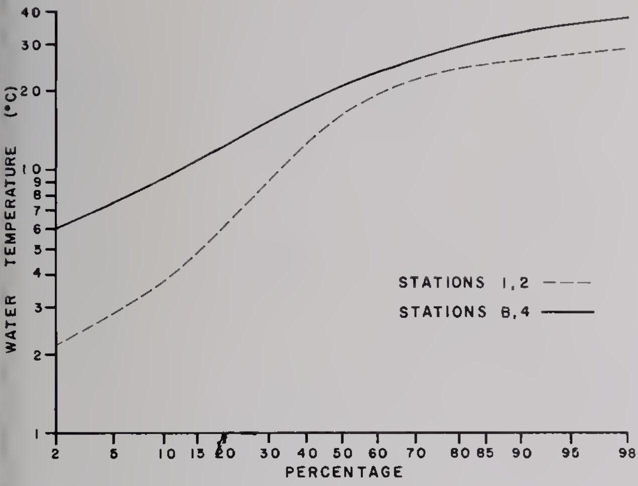

Fig. 6 — Log normal probability distributions of water temperature (C) at the warmest and coolest *Nelumbo lutea* beds in the cooling loop of Lake Sangchris, September 1973–July 1976.

described by log normal probability curves of water temperature (October 1973–July 1976), shown in Fig. 6. The cold-water limit was based upon water temperature data from stations 1 and 2, bracketing the coolest plant bed, and the warmwater limit from stations 4 and B, bracketing the warmest plant bed. The thermal regimes (0.95 probability) were 2.2°—28.0°C for the cold-water limit and 6.2°—37.6°C for the warmwater limit. Since several of the plant beds experienced ice cover during the winter, the lower temperatures are probably of no importance.

Also, since the warmwater beds were occasionally exposed to temperature extremes in excess of 37.6°C (Brigham 1977), transient high temperatures were undoubtedly tolerated also. Thus, the regimes rather than the extremes are suspected to be the determining factor. In Lake Sangchris *N. lutea* seems to require temperatures about 0.75°C warmer than ambient and with a thermal regime generally not exceeding 37.6°C for more than 2.5 percent of the growing season. In 1975 lotus beds were observed at the mouth of the discharge canal and south of the intake canal (Frakes & Moran 1975), but neither became established. Water temperature regime was evidently the principal cause of failure.

N. lutea was studied during the 1976 growing season to investigate the effects upon growth of the temperature regimes within the cooling loop. On 28 April 1976 nine lotus beds were examined for the presence of leaves and their stage of development (Table 2 and Fig. 7). The plants clearly presented a gradient of development around the cooling loop. No leaf spikes (leaf blades tightly rolled around the petioles) were breaking the surface at plant bed L9 in the coldest area. A great many spikes were up at plant bed L6, with 13 percent of them beginning to open. Plant beds L3, L2, and L1 in the discharge arm had 22–24 percent of the petioles supporting fully opened, but immature, leaves.

In May 1976 leaf-blade diameters were determined at stations in the intake arm (plant bed L8), in the main body of the lake (plant bed L4), and in the discharge arm (plant bed L2) (Table 3). The mean leaf diameter at the L2 bed (27.72 cm) was significantly greater than those of leaves from beds L4 and L8 (17.96 and 18.70 cm, respectively).

On 4 August 1976 the mean leaf-blade diameters were determined at seven beds, L1, L2, L3, L4, L6, L8, and L9. An analysis of these data indicated that stations L6, L8, and L9 (in the intake arm) and L1 (the closest bed to the discharge canal) had leaves of similar size, 42.33–44.08 cm (no significant difference). Mean leaf diameters at

Table 2.—*Nelumbo lutea* leaf development in Lake Sangchris, 28 April 1976

Station	Petioles Counted	Leaf Development Stage Percent Spike	Percent Opening	Percent Open	Mean Diameter of Open Leaves (cm)
L9	0		...	...	...
L8	40	100	...	...	...
L7	67	100	...	...	...
L6	100	87	13	...	...
L5	100	92	8	...	...
L4	100	75	23	2	8.89
L3	100	23	55	22	14.76
L2	200	26	52	22	14.76
L1	200	18	58	24	17.17

stations L2 and L3 in the discharge arm were significantly smaller (38.06 and 38.82 cm, respectively). The mean leaf diameter at Station L4 in the main body of the lake was significantly smaller (35.53 cm) than those at all other stations. The small leaf size at Station L4 may have been the result of stresses (wind and waves) upon the plants. Ultimate leaf size was greatest in the intake (cool-water) arm, indicating that while the onset of leaf production and growth was delayed there compared with that in the discharge (warmwater) arm,

Fig. 7.—Sampling sites for *Nelumbo lutea* leaf growth rates in Lake Sangchris, 1976.

Table 3.—Mean leaf diameter in centimeters of *Nelumbo lutea* from nine sampling sites in Lake Sangchris in 1976. Sample sizes are in parentheses.

	Sampling Site								
Date	L1	L2	L3	L4	L5	L6	L7	L8	L9
28 April 1976	17.1	14.8	14.8	8.9	. . .	. . .	. . .	. . .	. . .
	(21)	(20)	(22)	(2)	. . .	. . .	. . .	. . .	. . .
26 May 1976	. . .	27.72	. . .	17.96	. . .	. . .	. . .	18.70	. . .
	. . .	(50)	. . .	(50)	. . .	. . .	. . .	(50)	. . .
4 August 1976	42.76	38.06	38.82	35.53	. . .	42.33	. . .	43.69	44.08
	(100)	(100)	(100)	(100)	. . .	(100)	. . .	(100)	(100)

Table 4.—Mean biomasses of two selected aquatic macrophytes in Lake Sangchris, 1974-1975 (n = 3). Sample-area means are in parentheses.

	Potamogeton nodosus				*Nelumbo lutea*	
	5 August 1974		24 July 1975		6 August 1975	
Sampling Site	Fresh Weight in grams/m^2	Dry Weight in grams/m^2	Fresh Weight in grams/m^2	Dry Weight in grams/m^2	Fresh Weight in grams/m^2	Dry Weight in grams/m^2
Intake arm	901.9	170.8	1,680.5	317.8 (336.6)	1,601	231.1 (303.5)
			1,892.2	355.4	2,167	341.2
					2,220	338.3
Main body	1,326.8	225.4	1,446.0	312.8 (251.9)	1,621	275.2 (275.2)
			1,296.7	243.2		
			1,439.7	252.9		
			1,184.7	198.6		
Discharge arm	700.4	133.4	1,302.0	262.9 (261.4)	4,151	798.0 (604.8)
			1,156.6	259.8	2,363	411.7
Control arm	858.8	166.0	1,046.4	257.5 (214.8)		
			834.0	172.1		
Mean		*173.9*		*263.3*		*399.2*

ultimate leaf size was not adversely affected. The smaller final leaf sizes at stations L2 and L3 may indicate an inhibitory effect of the warmer water upon ultimate leaf size. The large leaves at Station L1 suggest that these plants were of a different ecotype.

On 6 August 1975 biomass samples of *N. lutea* were collected from three areas of Lake Sangchris, the discharge arm, the intake arm, and the main body of the lake (Table 4, Fig. 8). The lowest mean biomass, 275.2 g/m^2, was recorded from the plant bed in the main body of the

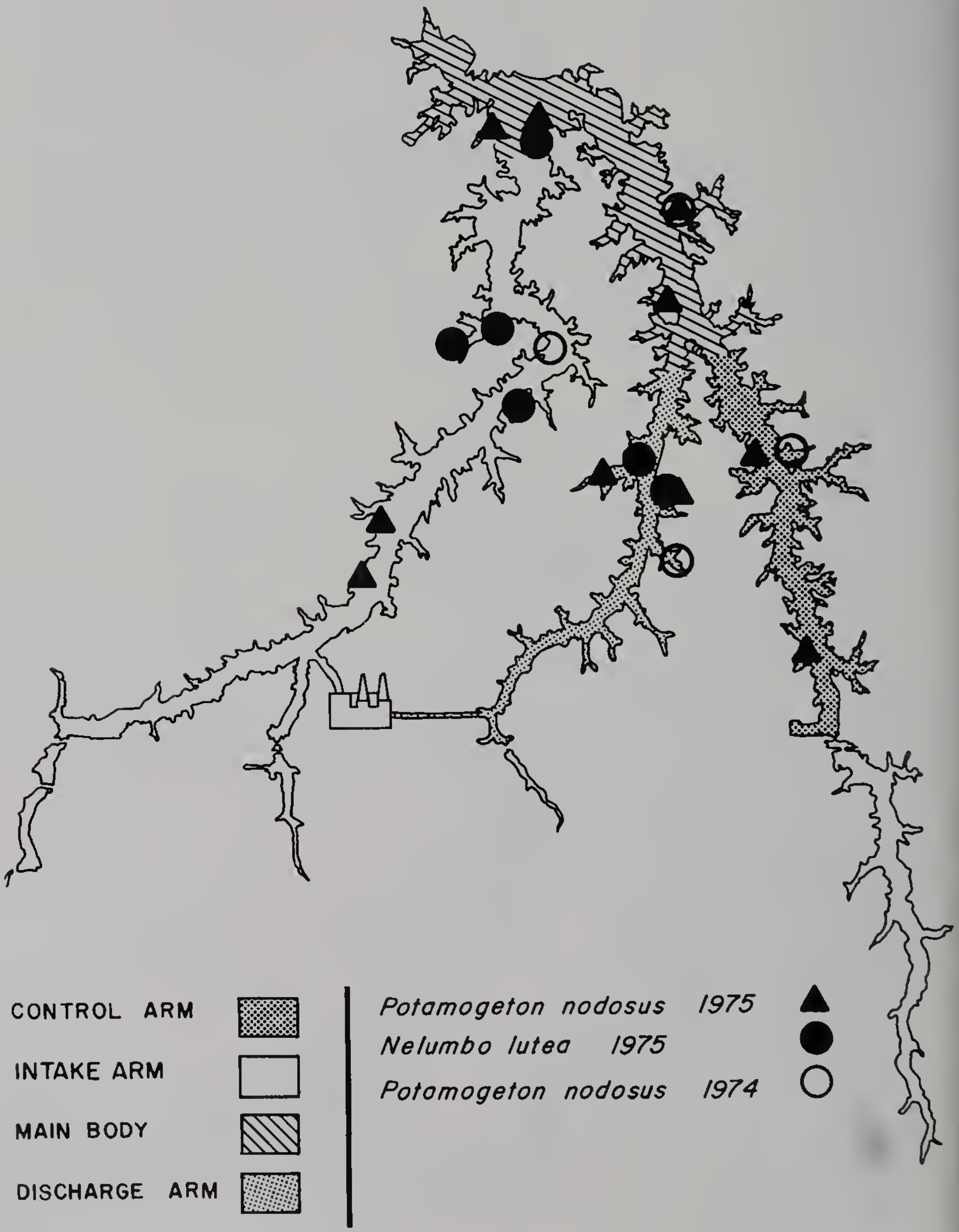

Fig. 8.—Sampling sites for *Nelumbo lutea* and *Potamogeton nodosus* biomass estimations in Lake Sangchris, 1974–1975.

lake, Station L4. This again was probably the result of stress by the wind and wave action in the area. The highest biomasses, 411.7 and 798.0 g/m^2 were recorded from Station L2 in the discharge canal. In the intake arm, stations L7, L8, and L9, the mean biomass of 303.5 g/m^2 was only 50 percent of that of the discharge arm.

POTAMOGETON NODOSUS IN LAKE SANGCHRIS

Potamogeton nodosus is common in Lake Sangchris, with a lakewide distribution in depths of 2 m or less. It is considered an alkophile, usually occurring in water with a pH range of 7.3–8.8 and alkalinities of 49–380 mg HCO_3/l (Moyle 1945). In 1971 *P. nodosus* was chiefly confined to a rather small area south of Station A (Fig. 9). In 1973 it extended southward down all three arms and northward to the dam. By 1976 it had occupied the entire cooling loop and control arm. The most important factor in the spread of *P. nodosus* in Lake Sangchris appeared to be the currents in the cooling loop.

In Lake Sangchris, *P. nodosus* has shown some morphological and physiological variations in response to the microclimatic variations within the lake. Growth rates in most of the lake appeared similar, but were accelerated in the southern (warmest) reaches of the discharge arm. On 28 April 1976, a bed at the mouth of the discharge canal was producing flower spikes, while a bed at the end of the discharge arm (about 400 m north of Station 4) had only a few leaves breaking the surface, and plants in the rest of the lake had not yet reached the surface. By 26 May 1976 plants in the discharge canal had set fruit, while plants

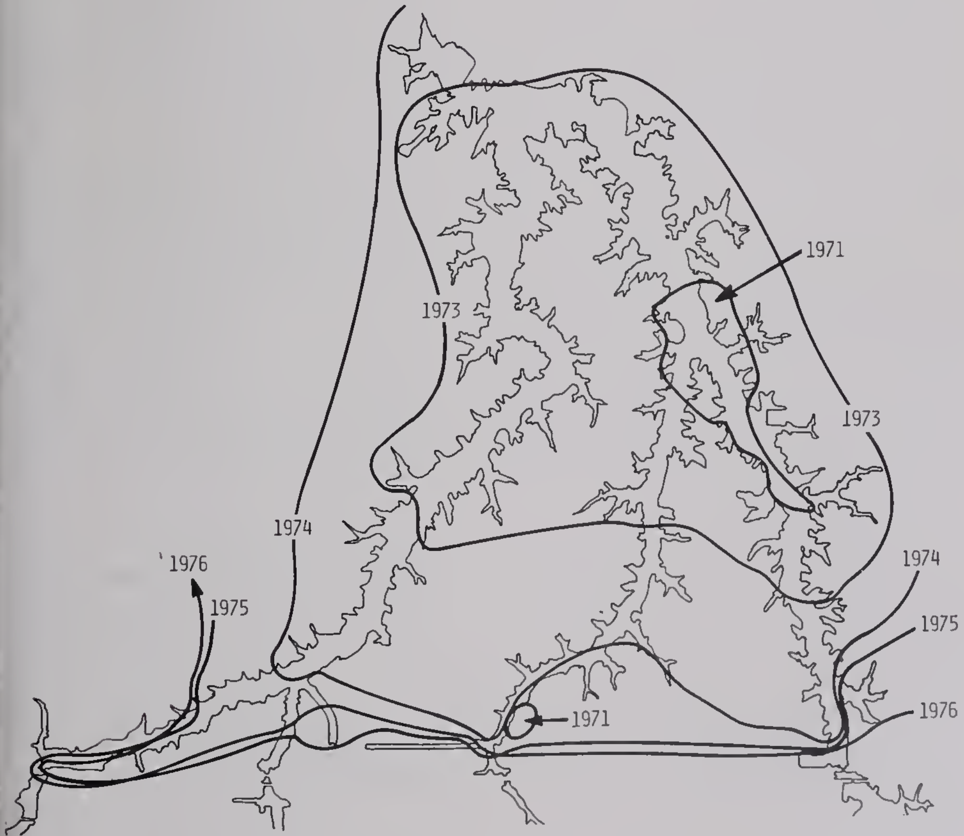

Fig. 9.—Distribution of *Potamogeton nodosus* in Lake Sangchris, 1971–1976.

400 m downstream and in the control arm were just sending up flower spikes.

In 1974 and 1975 biomass determinations were made in the discharge, intake, and control arms and the main lake body (Fig. 8 and Table 4). The mean biomass of *P. nodosus* stands increased from 173.9 g/m^2 in 1974 to 263.3 g/m^2 in 1975. In 1975 stands in the control arm had the lowest mean biomass (214.8 g/m^2), while the intake arm stands had the highest (336.6 g/m^2). Since these two areas have similar thermal regimes, it is believed the biomass of *P. nodosus* beds was not affected by temperature.

INORGANIC ANALYSES

In 1975 leaves, stems, and roots of *P. nodosus* were analyzed to determine the concentrations of 12 elements: aluminum, boron, calcium, copper, iron, magnesium, manganese, phosphorus, potassium, silicon, sodium, and zinc. Concentrations of these elements in the tissues of plants from various areas of the lake were compared to determine whether any relationship existed between them and location within the lake (Table 5).

The water content of *P. nodosus* in both 1974 and 1975 averaged about 81 percent. The inorganic ash content of the dry matter was more than 15 percent of the dry weight. Straskraba (1968) summarized the available data on aquatic plants and arrived at similar mean values for floating leaf plants, 82 percent of fresh weight as water and 16 percent of dry weight as ash.

Aluminum concentrations in the leaves, stems, and roots were all similar, (1,402–1,756 ppm), but concentrations in plants from the cooling loop were significantly higher than those in plants from the control arm. Plants from the discharge arm of the cooling loop had the highest aluminum concentrations. Hutchinson (1943) gave 200 ppm as a typical value for terrestrial plants and Bowen (1966) cited 500 as the best general value. Cowgill (1973) reported flowers of *Nymphaea odorata* to contain as much as 1,730 ppm of aluminum.

In Lake Sangchris the mean boron concentration of the roots (104 ppm) was significantly higher than that in the leaves (51 ppm) and stems (50 ppm). These values are similar to the 53–157 ppm that Hiltibran found in three species of *Potamogeton* (unpublished data, Illinois Natural History Survey). The highest mean boron concentrations were in plants from the discharge arm.

Calcium is an element that often precipitates during the photosynthetic uptake of bicarbonate in hard waters. Thus, some very high concentrations may be obtained in the photosynthetic tissues. Calcium concentrations in the leaves (2.69 percent) and stems (2.76 percent) were significantly higher than they were in the roots (1.22 percent). These values are generally lower than those reported by Riemer & Toth (1968) and are probably related to differences in the hardness of the waters involved. Plants from the control arm had the highest calcium concentration.

In Lake Sangchris plants the mean copper concentration ranged from 18 ppm in the stems to 26 ppm in the leaves and 30 ppm in the roots. Hutchinson (1975) presented data indicating 29 ppm to be typical for aquatic plants. The discharge-arm and main-lake-body plants had the highest mean concentrations of copper. Smith & Anderson (1977) also found the highest copper concentration in *P. nodosus* from the discharge arm.

In Lake Sangchris mean iron concentrations ranged from more than 2,500 ppm in the leaves to more than 11,400 ppm in the roots. These values are higher than those obtained by Hiltibran (unpublished data, Illinois Natural History Survey) but similar to those of Riemer & Toth (1968), who believed that such high iron concentrations were due to a fine precipitate adhering to plant tissues and not removed during washing. Hutchinson (1975) reported the mean value of 0.3 percent (3,000 ppm), similar

Table 5.—Dry-weight concentrations of 12 elements in *Potamogeton nodosus* taken from Lake Sangchris 24 July 1975.

Sampling Site	Ash %	Silicon %	Phosphorus %	Potassium %	Calcium %	Magnesium %	Manganese ppm	Iron ppm	Zinc ppm	Boron ppm	Copper ppm	Aluminum ppm	Sodium ppm
Intake arm													
Leaves	>15	>6.8	0.34	2.06	1.88	0.37	236	>2,046	36	46	14	1,324	>6,000
Stems	>15	>9.2	0.38	2.39	2.26	0.35	290	>2,846	43	51	18	1,669	>6,000
Roots	>15	>9.4	0.42	2.83	1.33	0.16	401	>13,900	46	89	16	1,795	>6,000
Mean	>15	>8.5	0.38	2.43	1.82	0.29	309	>6,264	42	62	16	1,596	>6,000
Main body													
Leaves	>15	>7.4	0.35	2.34	3.63	0.45	195	2,441	46	46	54	1,102	>6,000
Stems	>15	>9.4	0.26	2.40	2.22	0.31	347	>3,200	40	40	17	1,596	>6,000
Roots	>15	>9.4	0.54	2.82	1.23	0.16	611	>25,600	49	120	25	1,876	>6,000
Mean	>15	>8.7	0.38	2.52	2.36	0.31	384	>10.414	45	69	32	1,525	>6,000
Discharge arm													
Leaves	>15	>9.4	0.43	2.44	2.67	0.48	293	>3,200	48	66	25	1,964	>6,000
Stems	>15	>9.4	0.34	2.32	2.58	0.34	708	>3,182	48	53	24	2,017	>6,000
Roots	>15	>9.4	0.52	2.53	1.14	0.14	806	>3,178	44	118	48	1,941	>6,000
Mean	>15	>9.4	0.43	2.43	2.13	0.32	602	>3,187	47	79	32	1,974	>6,000
Control arm													
Leaves	>15	>7.6	0.32	1.96	2.58	0.39	208	>2,318	39	45	12	1,218	>6,000
Stems	>15	>9.4	0.28	1.68	3.98	0.35	351	>2,818	42	56	15	1,676	>6,000
Roots	>15	>7.7	0.36	1.90	1.20	0.14	490	>3,108	35	88	32	1,411	>6,000
Mean	>15	>8.2	0.32	1.85	2.59	0.29	350	>2,748	39	63	20	1,435	>6,000
Lake Sangchris means													
Leaves	>15	>7.8	0.36	2.20	2.69	0.42	233	>2,501	42	51	26	1,402	>6,000
Stems	>15	>9.4	0.32	2.20	2.76	0.34	424	>3,012	42	50	18	1,740	>6,000
Roots	>15	>9.0	0.46	2.52	1.22	0.15	577	>11,446	44	104	30	1,756	>6,000

to the leaf and stem data from Lake Sangchris.

Because of magnesium's relation to chlorophyll and photosynthesis, it is not surprising that the leaves and stems had significantly higher concentrations of magnesium (0.42 and 0.34 percent, respectively) than the roots (0.15 percent). Hutchinson (1975) gave 0.33 percent as the mean concentration for aquatic plants in eastern North America. Magnesium concentrations were highest in plants from the discharge arm of Lake Sangchris. Gauch (1972) reported that magnesium requirements for the reaction sequence in carbon dioxide fixation increase with temperature, which may account for the higher concentrations in discharge-arm plants.

Manganese concentrations were significantly higher in the roots (577 ppm) than in the leaves (233 ppm) or stems (424 ppm). These values are higher than the 52–118 ppm found by Hiltibran (unpublished material, Illinois Natural History Survey) but are much lower than the mean for eastern North America, 2,000 ppm (Hutchinson 1975). Manganese concentrations were highest in plants from the discharge arm.

In Lake Sangchris plants the mean concentration of phosphorus in the roots (0.46 percent) was significantly greater than those in the leaves (0.36 percent) or stems (0.32 percent). The concentration of phosphorus in plants from the cooling loop was significantly higher than that in plants from the control arm, with the discharge-arm plants having the highest concentrations of phosphorus. Riemer & Toth (1968) found the mean phosphorus concentration of 56 aquatic plants in New Jersey to be 0.45 percent, with a range of 0.16–1.87 percent.

Hutchinson (1975) reported a mean potassium concentration for eastern North American aquatic plants of about 2.6 percent dry weight, similar to those of terrestrial plants. In Lake Sangchris the mean value was about 2.3 percent. The roots had the highest mean concentration (2.52 percent), and within the lake, plants from the main body area had the highest overall concentration (2.52 percent).

Silicon levels were in excess of 6.8 percent of dry weight. Cowgill (1973) reported a range of silicon of from 1,910 to 19,350 ppm (up to 1.9 percent of dry weight). Scheutte & Alder (1927) found *Vallisneria americana* to contain up to 2.54 percent silicon. It is possible that the high silicon levels obtained in the analysis of Lake Sangchris plants have been due in part to epiphytic diatoms not completely removed by the rinsing process.

Sodium levels in *P. nodosus* exceeded 6,000 ppm (0.6 percent of dry weight). Riemer & Toth (1968 and 1969) and Hiltibran (unpublished material, Illinois Natural History Survey) found similar or lower levels in several species of *Potamogeton*. The mean sodium concentration for aquatic plants from various areas of eastern North America is about 0.10 percent (Hutchinson 1975).

In Lake Sangchris mean concentrations of zinc ranged from 42 ppm in the leaves and stems to 44 ppm in the roots. Plants from the cooling loop had significantly higher concentrations of zinc than plants from the control arm had. The highest mean concentration of zinc was in plants from the discharge arm. Smith & Anderson (1977) also reported zinc concentrations to be significantly higher in *P. nodosus* from the discharge arm.

Of the 12 elements examined, 3 (iron, silicon, and sodium) were usually present in amounts exceeding the capacity of the analysis. Two elements, calcium and magnesium, were significantly higher in the stems and leaves than in the roots. Three elements, boron, manganese, and phosphorus, were present in the roots in significantly higher concentrations than in the stems and leaves. Five other elements, aluminum, copper, iron, potassium, and zinc, also had their highest concentrations in the roots.

Plants from the discharge arm of the cooling loop had the highest concentration of aluminum, boron, copper, magnesium, manganese, phosphorus, and zinc. Three of these elements, aluminum, phosphorus, and zinc, were present in significantly higher concentrations in plants from the cooling loop than they were in plants from the control arm. Iron, magnesium, potassium, and silicon concentrations were also highest in cooling-loop plants. Plants from the main lake body had the highest concentrations of potassium.

SUMMARY

Lake Sangchris is a relatively new reservoir still undergoing a process of invasion by aquatic macrophytes. It is estimated that the maximum number of species to occur in Lake Sangchris will be about 28, which should be reached when the lake is 21 years old (1985). The species immigration-extinction rate is about 1.9–2.3 species per year. Some literature on Texas reservoirs suggests 50–54 as the maximum number of species. In Lake Sangchris, this number would be achieved by the year 2014.

Establishment and growth of aquatic macrophytes in Lake Sangchris are limited by the effects of shoreline instability and erosion and the consequent turbidity. As emergent plants became established, the increased stability encouraged further colonization by other plants. Areas of high shoreline erosion are still barren.

Water temperature variations within the cooling loop determined the distribution of *Nelumbo lutea* and had a definite effect upon its growth rate. Plants in the discharge arm began growth earlier and grew more rapidly than plants in the intake arm, but final leaf size was greatest in the intake-arm (cool-water) plants. Plant biomasses, however, were greatest in the discharge arm. The occurrence of *N. lutea* was restricted to those areas of the cooling loop with an annual thermal regime at least 0.75°C warmer than ambient water temperature but not exceeding 37.6°C for more than 2.5 percent (9 days) of the year.

The distribution of *Potamogeton nodosus* did not appear to be related to temperature in Lake Sangchris, but plants in the warmest portions of the cooling loop began growth and set fruit earlier than did plants in cooler areas of the lake. Mean stand biomass increased 51 percent (from 173.9 to 263.3 g/m^2) from 1974 to 1975.

Inorganic analyses of *P. nodosus* revealed that plants from the discharge arm had the highest concentrations of aluminum, boron, copper, magnesium, manganese, phosphorus, and zinc. Analyses of the leaves, stems, and roots indicated that the roots had the highest concentrations of aluminum, boron, copper, iron, manganese, phosphorus, potassium, and zinc, while calcium and magnesium concentrations were higher in the stems and leaves than they were in the roots.

REFERENCES CITED

BEARD, T. D. 1973. Overwinter drawdown: Impact on the aquatic vegetation in Murphy Flowage, Wisconsin. Wisconsin Department of Natural Resources Technical Bulletin 61. 14 p.

BOWEN, H. J. M. 1966. Trace elements in biochemistry. Academic Press, New York. ix + 241 p.

BRIGHAM, A. R. 1975. Water quality investigations at Lake Sangchris 5 September 1973 through 16 September 1975. Pages 1.1–1.100 *in* Annual Report for Fiscal Year 1975, Lake Sangchris Project. Illinois Natural History Survey, Urbana.

———. 1977. Water quality investigations at Lake Sangchris. Pages 1.1–1.5.18 *in* Annual Report for Fiscal Year 1976, Lake Sangchris Project. Illinois Natural History Survey, Urbana.

CLOVIS, J. F. 1971. Aquatic vascular plant distribution in Cheat Lake (Lake Lynn), West Virginia. Castanea 36:153–163.

COWGILL, U. M. 1973. The hydrogeochemistry of Linsley Pond. II. The chemical composition of the aquatic macrophytes. Archiv fur Hydrobiologie, Supplement, 45:1–119.

DREIER, H. 1974. Supplementary study. Lake Sangchris aquatic macrophyte distribution in 1973 and 1974. Pages 1–20 *in* Annual Report for Fiscal Year 1974, Lake Sangchris Project. Illinois Natural History Survey, Urbana.

EDWARDS, R. W., and M. OWENS. 1960. The effects of plants on river conditions. I. Summer crops and estimates of net productivity of macrophytes in a chalk stream. Journal of Ecology 48:151–160.

Fehrenbacher, J. B., R. S. Smith, and R. T. Odell. 1950. Christian County soils. University of Illinois Agricultural Experiment Station Soil Report 73. 64 p.

Forest, H. S., and E. L. Mills. 1971. Studies on the plants of the Genesee country (Western New York State): VI. The aquatic flora of Conesus Lake. Rochester Academy of Science Proceedings 12:110–138.

Frakes, M. A., and R. L. Moran. 1975. Lake Sangchris aquatic macrophyte studies. Pages 10.1–10.28 *in* Annual Report for Fiscal Year 1975, Lake Sangchris Project. Illinois Natural History Survey, Urbana.

Gauch, H. G. 1972. Inorganic plant nutrition. Dowden, Hutchinson & Ross, Inc., Stroudsburg, PA. 488 p.

Godwin, H. 1923. Dispersal of pond floras. Journal of Ecology 11:160–143.

Harris, B. B., and J.K.G. Silvey. 1940. Limnological investigations on Texas reservoir lakes. Ecological Monographs 10:111–143.

Hutchinson, G. E. 1943. The biogeochemistry of aluminum and of certain related elements. Quarterly Review of Biology 18:1–29.

______. 1975. A treatise on limnology. Vol. III, Limnological botany. John Wiley & Sons, New York. 660 p.

Judd, J. B., and S. H. Taub. 1973. The effects of ecological changes on Buckeye Lake, Ohio, with emphasis on largemouth bass and aquatic vascular plants. Ohio Biological Survey Biological Notes 6. 51 p.

Kramer, C. Y. 1956. Extension of multiple range tests to group means with unequal numbers of replications. Biometrics 12:307–310.

Limnetics, Inc. 1972. A limnological survey of Lake Sangchris, Illinois. Limnetics, Inc., Milwaukee. 247 p.

MacArthur, R. H., and E. O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, N. J. 203 p.

Metcalf & Eddy, Inc. 1972. Wastewater engineering. Collection, treatment, disposal. McGraw-Hill Book Co., New York. 782 p.

Modlin, R. F. 1970. Aquatic plant ecology of major lakes in the Milwaukee River watershed. Wisconsin Department of Natural Resources Research Report 52. 45 p.

Moran, R. L. 1977*a*. Macrophytes. Pages 8.1–8.48 *in* Annual Report for Fiscal Year 1976, Lake Sangchris Project. Illinois Natural History Survey, Urbana.

———. 1977*b*. Part 2. Phytoplankton dynamics of Lake Sangchris. Pages 2.25–2.59 *in* Annual Report for Fiscal Year 1976. Lake Sangchris Project. Illinois Natural History Survey. Urbana.

Moyle, J. B. 1945. Some chemical factors influencing the distribution of aquatic plants in Minnesota. American Midland Naturalist 34:402–420.

Nichols, S. A., and S. Mori. 1971. The littoral macrophyte vegetation of Lake Wingra. Wisconsin Academy of Sciences, Arts and Letters 59:107–119.

Riemer, D. N. 1969. A survey of the chemical composition of *Potamogeton* and *Myriophyllum* in New Jersey. Weed Science 17:219–223.

——— and S. J. Toth. 1968. A survey of the chemical composition of aquatic plants in New Jersey. New Jersey Agricultural Experiment Station Bulletin 820. 14 p.

Schuette, H. A., and H. Alder. 1927. Notes on the chemical composition of some of the larger aquatic plants of Lake Mendota. II. *Vallisneria* and *Potamogeton*. Wisconsin Academy of Sciences, Arts and Letters Transactions 23:249–254.

Sculthorpe, C. D. 1967. The biology of aquatic vascular plants. Edward Arnold Ltd., London. 610 p.

Seddon, B. 1972. Aquatic macrophytes as limnological indicators. Freshwater Biology 2:107–130.

Smith, K. E., and W. L. Anderson. 1977. Trace element studies at Lake Sangchris. Selected trace metals in lake sediment, air-borne particulate matter, and macrophytes. Pages 5.1–5.31 *in* Annual Report for Fiscal Year 1976. Lake Sangchris Project. Illinois Natural History Survey, Urbana.

Straskraba, M. 1968. Der Anteil der hoheren pflanzen an der produktion der stehenden Gewasser. Internationale Vereinigung fur Theoretische und Angewandte Limnologie Mitteilungen 14:212–230.

Population Dynamics of the Lake Sangchris Fishery

John A. Tranquilli, Richard Kocher, and John M. McNurney

ABSTRACT

Surveys were conducted in Lake Sangchris, a power plant cooling lake, to determine the effects of thermal discharge from Kincaid Generating Station on the fish community and its components. From 1974 to 1976 a total of 108 catch-per-unit-effort population samples were collected from six stations located in both heated and unheated areas. The average fish catch (biomass) was 59.1 kg. Nine species constituted 97.4 percent of the total weight of the catch. In order of decreasing abundance, they were carp (33.4 percent), gizzard shad (23.1 percent), largemouth bass (16.3 percent), bluegill (7.1 percent), yellow bass (5.3 percent), channel catfish (4.7 percent), white bass (4.6 percent), black bullhead (1.9 percent), and white crappie (1.0 percent). In Lake Sangchris, the largemouth bass population has not experienced the decline in production commonly observed in unheated Illinois reservoirs as they age.

Temporal and spatial distribution of fishes was analyzed by a three-way analysis of variance model which incorporated year, month, and station effects. Gizzard shad, blackstripe topminnows, and freshwater drum were significantly more abundant in heated than in unheated areas, while the opposite was true for black bullheads and white suckers. Seasonal aggregations of white bass and channel catfish in heated areas were indicated in significant station-by-month interactions and were related to important changes in the reproductive life histories of these species in cooling lakes. During early spring, white bass made pronounced upstream spawning migrations into the discharge canal of the power plant, and channel catfish reproduction and recruitment were unusually successful in comparison to those of other Illinois reservoirs. Seasonal reversals in fish distribution relative to the thermal effluent were documented in this field study. Gizzard shad, yellow bass, and largemouth bass were significantly more abundant in heated areas during cold months and in unheated areas during warm months. The distribution of these species appeared to be the result of behavioral thermoregulation.

In six cove-rotenone surveys, the average standing crop of fishes was 360.9 kg/ha. Only minor differences in the standing crop of fishes were found within the same cove during different seasons or among coves located in heated and unheated areas. The total standing crop of fish in Lake Sangchris was much the same as that found in chemically similar unheated reservoirs with comparable total dissolved-solids concentrations.

Gonosomatic indices and gonad maturity stages showed that largemouth bass spawning in 1975 and 1977 was advanced in heated areas by 1 to 3 weeks over that in unheated areas. During 1975, carp spawning apparently began at the same time in all areas of the lake, but in 1976 carp began to spawn approximately 1 month earlier in heated than in unheated areas. A degenerate ovarian condition was seen in approximately 20 percent of the carp examined and may have partially accounted for the lack of successful reproduction by that species. Results of

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chemical tests on carp tissues indicated the degenerate ovarian condition was probably not related to mercury or pesticide contamination.

Length-frequency distributions were used to assess the growth of fishes. The carp population was composed almost entirely of large individuals, whereas those of bluegill and yellow bass were mostly small, stunted fish. In comparison with their growth in other waters, the growth of carp, gizzard shad, bluegills, and yellow bass was slow, while the growth of white bass, largemouth bass, channel catfish, and freshwater drum was greater than average.

Species-specific weight-length relationships among heated and unheated sites were similar for eight species of fishes. Significant seasonal differences in weight-length regressions were evident for largemouth bass and bluegills. Body condition factors of gizzard shad, yellow bass, and bluegills collected at bimonthly intervals from heated and unheated stations were compared. Results indicated that (1) throughout the year gizzard shad from unheated areas were in significantly better condition than those from heated areas, (2) bluegills from all areas of the lake were in significantly better condition in July than in November, and (3) in July, bluegill condition was better in heated than in unheated areas, while the reverse was true during November.

No gas-bubble disease was observed in fishes from Lake Sangchris. The incidence of external parasitism and disease for fishes was 0.6 percent in the intake arm and 0.3 percent in the discharge arm. The incidence of internal parasitism in the intake and discharge arms was 37.3 and 30.2 percent, respectively. Heavy internal parasitic infestations in bluegills may have contributed to the stunted growth of that population.

Three fish kills occurred at Lake Sangchris during 1974, and two of them were related to power plant operations. Examination of dead fishes recovered from the discharge canal indicated that accidental chlorination may have been the causative agent. The fish kills had a minimal impact on the fish population.

GENERAL INTRODUCTION

Temperature is one of the most important environmental factors affecting the biota of an aquatic ecosystem. In recent years, rapid expansion of the steam-electric power industry has caused increasing concern for environmental degradation of aquatic habitats. Closed system cooling lakes represent a worst-case situation with respect to potential alterations of the ecosystem by thermal discharges and thus one in which perturbations can be most readily identified.

This multifaceted study presents a detailed description of the results of several ecological investigations regarding the effects of a thermal effluent on the fishes inhabiting a midwestern cooling lake. This study describes (1) species composition, fish distribution, and relative abundance; (2) standing crops; (3) spawning time and reproduction; (4) growth, weight-length relationships, and body condition indices; (5) incidence of parasitism and disease; and (6) fish kills. Results of fishery investigations at Lake Sangchris, along with studies conducted at lower trophic levels, have provided one of the most comprehensive data bases in the United States for the evaluation of cooling lake ecosystem effects.

DESCRIPTION OF THE STUDY AREA

Lake Sangchris lies in the northwestern corner of Christian County in central Illinois approximately 24 km southeast of Springfield. The lake is an artificial impoundment (876 ha) developed between 1964 and 1966 by the damming of Clear Creek, a tributary to the South Fork of the Sangamon River. The lake was built to provide cooling water for Commonwealth Edison's 1,232-megawatt coal-fired Kincaid Generating Station. Morphologically, the lake consists of three long narrow arms oriented in a north-south direction and converging at the northern end where the dam is located (Fig. 1). The power plant is located at the southern end of the lake between the western and middle arms. The plant draws water from the west (intake) arm and empties it into the middle (discharge) arm. A thermal gradient is thus created as the heated water flows around a 16-km cooling loop. The east (control) arm is connected to, but not directly involved in, the cooling loop and thus serves as a control area. This rather unique morphology made Lake Sangchris an ideal site for the study of thermal effects on aquatic organisms.

Fish sampling stations at Lake Sangchris were selected to represent different thermal habitats (Fig. 1). Station 7, in the control arm, and stations 1 and 2, in the intake arm, represented sampling areas with near-ambient water temperatures. The habitat at stations 2 and 7 is typical of the lake, with numerous coves and inlets. Station 1, the intake canal, is a steep-sided channel 0.65-km in length. Although the surface waters do not flow into the intake canal, there is a current near the bottom created by circulating water pumps, which withdraw water from a depth of 6 m below a skimmer wall. Stations 3, 4, and 5, in the discharge arm, represented artifically heated habitats. The discharge canal, Station 5, had the highest temperature of all stations in the cooling loop. The discharge canal is a 1.1-km channel with a very obvious current. Station 4, located between the power plant and the dam, is a typical lake station characterized by numerous coves, yet it was highly influenced by the thermal effluent. The dam area (Station 3), approximately halfway around the cooling loop, is another habitat

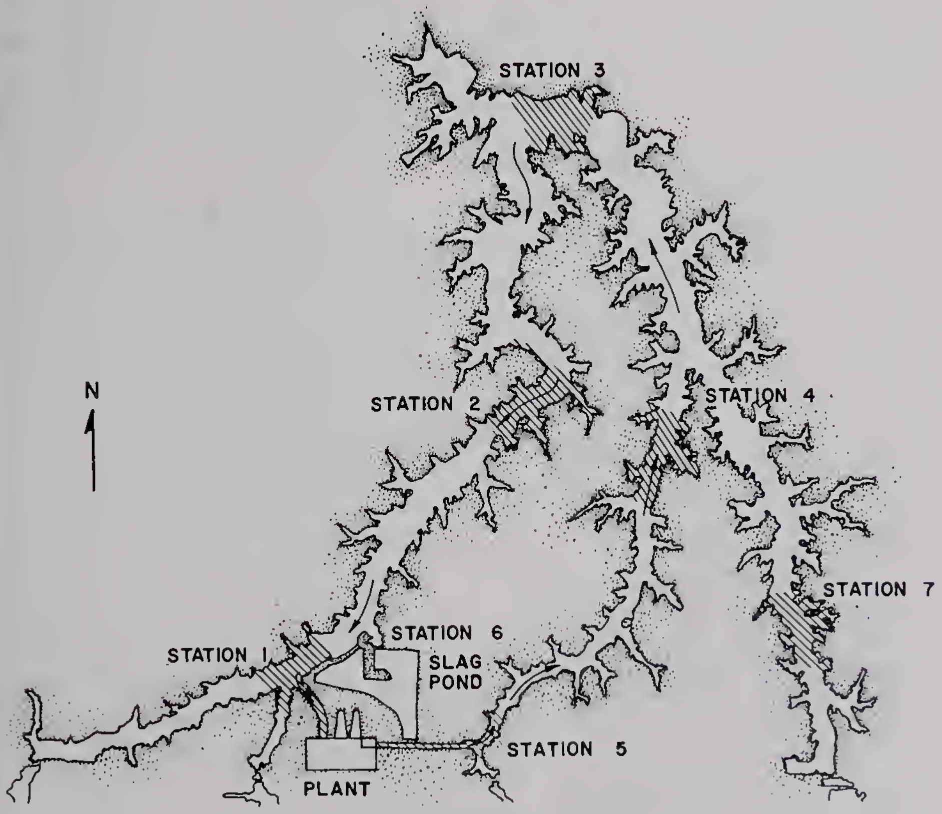


Fig. 1.—Fish sampling stations in Lake Sangchris.

influenced by the thermal effluent. The dam differs from the other stations in that it represents the deepest area of the lake and is extensively riprapped with rock along its northern shoreline. The slag pond (Water Quality Station 6) is not a part of the lake and was not a regular fish sampling station. The slag pond, adjacent to the power plant (Fig. 1), is a diked 32-ha reservoir, which serves as a settling basin and storage area for the residue of burned coal (slag). Excess water is returned from the slag pond to the lake through a large pipe emptying into the discharge canal. Station 1.5 (midway between stations 1 and 2) and Station 4.5 (midway between stations 4 and 5) were sampled to represent the intake and discharge arms, respectively, whenever supplementary collections for gonad development, etc., were needed to augment the regular bimonthly fish collections. The supplementary collections were taken between the regular stations to prevent very intensive sampling efforts from affecting the results of the bimonthly quantitative collections.

SPECIES COMPOSITION, RELATIVE ABUNDANCE, AND DISTRIBUTION

Fish population surveys were conducted in Lake Sangchris from 1974 to 1976 to describe the composition and structure of the fish community, to determine the relative abundance of species within the lake, and to observe their spatial and temporal distributions relative to the thermal effluent. The distribution and relative abundance of fishes in Lake Sangchris were related to the distribution of fishes in other waters receiving heated effluents. Contemporary fisheries data (1975–1977) collected by similar methods from nearby unheated Lake Shelbyville provided a basis for evaluating the abundance of fishes in Lake Sangchris (Tranquilli et al. 1979*b*).

MATERIALS AND METHODS

Quantitative fish population samples were collected every other month from January 1974 through November 1976. The bimonthly fish collections at each station consisted of alternating-current electrofishing for 1 hour along approximately 3 km of shoreline (30 minutes along each side), seining with a 25-foot (7.6-m) bag seine (two 25-step seine hauls along each shoreline), and fishing for 24 hours with a 300-foot (91.5-m) experimental gill net (monofilament) composed of two repeating series of 25-foot (7.6-m) panels of six different mesh sizes that ranged from 1.3 to 6.4 cm bar measure (0.5, 1.0, 1.25, 1.50, 2.0, and 2.5 inches). During 1974, electrofishing was conducted after dark, whereas during 1975 and 1976 the collections were made during the daylight. The areas of the shoreline covered while electrofishing at each station are indicated in Fig. 1. During each collection, numerical abundance and weights were recorded for all species of fishes. Species composition, relative abundance, and distribution were determined from these data. These data were further analyzed and expressed as catch (kg)/unit effort, percentage composition of the catch, and rank (biomass) of fishes.

Bimonthly fisheries population data collected from 1974 to 1976 were analyzed using the Statistical Analysis System (SAS) (Barr et al. 1976) General Linear Model (GLM) procedure on an IBM 360/75 computer on the University of Illinois campus. A three-way analysis of variance was performed using a mixed model with water temperature at the stations at the time of sampling as a co-variable; stations were fixed while months and years were assumed random. Data were analyzed by species, using the weight (biomass) of the catch for all comparisons, because, unlike the numerical catch, it was not believed to be highly affected by annual reproduction. Since our main interest was to evaluate the impact of thermal discharge on the fish population, five specific comparisons were made between fish catches at stations in the intake, discharge, and control arms. The five contrasts were:

(C1) Station 2 vs. 7, a comparison of similar stations (habitats) in the intake and control arms; (C2) Station 4 vs. 7, a comparison of similar habitats in the discharge and control arms; (C3) Station 1 vs. 5, a comparison of the intake canal with the discharge canal; (C4) stations 1 and 2 vs. 4 and 5, a comparison of the intake arm with the discharge arm; and (C5) stations 1, 2, and 7 vs. 3, 4, and 5, a comparison of all stations in the unheated or near-ambient-water-temperature zones of the cooling lake with all stations in the thermal zone. The average value of the fish catches in November and January were compared with those in July to test for (1) differences in catches during the coldest and warmest months of the year and (2) interaction with catches at specific heated and unheated stations. The catches for January and November were averaged to partially account for the reduced efficiency of electrofishing during cold months.

In this subsection, statistical significance refers to the $P < 0.05$ level, although higher levels may be indicated in some tables, and catch always refers to weight (biomass) unless numbers are specifically mentioned.

RESULTS AND DISCUSSION

During the 3 study years (1974–1976), 87,650 fish representing 20 species and two hybrids were collected in 108 quantitative collections. A complete listing of the number and weight of each species collected (by station and month) is presented in the Appendix (Tables A1–18 and B1–18). A composite species list was compiled to show the distribution of fishes at each station in Lake Sangchris (Table 1). Hornyhead chubs, striped shiners, bigmouth shiners, striped x golden shiner hybrids, and flathead catfish were uncommon. No endangered or threatened species (Smith 1979) were collected. The distribution of 14 species and the green sunfish x bluegill hybrid could be characterized as ubiquitous within the lake, because these species were collected from all six sampling stations. Although only 48 white suckers and 105 blackstripe topminnows were collected during the study period, their distribution in the lake appeared to be temperature related. White suckers were collected from all stations except those in the discharge arm (stations 4 and 5), indicating complete avoidance of the thermal effluent in all seasons. Blackstripe topminnows were not collected from the intake arm (stations 1 and 2), and although one individual was taken from the control arm, the skewed distribution of this species suggested an attraction for the heated area.

During the 3 study years, nine species constituted 97.4 percent of the total weight of the catch: carp (33.4 percent), gizzard shad (23.1 percent), largemouth bass (16.3 percent), bluegill (7.1 percent), yellow bass (5.3 percent), channel catfish (4.7 percent), white bass (4.6 percent), black bullhead (1.9 percent), and white crappie (1.0 percent) (Table 2). Carp was the dominant species, by weight, ranking first in biomass each year, followed by largemouth bass in 1974 and by gizzard shad in 1975 and 1976. The four piscivorous species in Lake Sangchris (largemouth bass, channel catfish, white bass, and white crappie) together constituted 26.6 percent of the total catch. Although the data are not directly comparable, in rotenone collections Jenkins (1975) found that predatory game fishes constituted 15 percent of the total standing crop in 173 reservoirs of the mid-South.

The average catch per unit effort in Lake Sangchris (59.1 kg) was only 69 percent as great as that found in comparable studies at nearby unheated Lake Shelbyville (85.7 kg), but the more diverse fauna and the greater abundance of carp and gizzard shad in Lake Shelbyville more than accounted for the difference (Tranquilli et al. 1979*b*).

Largemouth bass, the most important game fish in Lake Sangchris, ranked second or third in biomass during the 3 study years (Table 2) and constituted from 15.3 to 17.0 percent of the total catch. Annual trends in abundance of this species are thus one of the most useful indicators of the state of the sport fishery. Three years of intensive population

Table 1.—Species of fishes collected from six sampling stations at Lake Sangchris between January 1974 and November 1976. Eighteen fish population samples were collected from each station.

Species	Station 1	2	3	4	5	7
Gizzard shad *(Dorosoma cepedianum)*	X	X	X	X	X	X
Carp *(Cyprinus carpio)*	X	X	X	X	X	X
Hornyhead chub *(Nocomis biguttatus)*	X	. . .	. . .	. . .	X	. . .
Golden shiner *(Notemigonus crysoleucas)*	X	X	X	X	X	X
Striped x golden shiner hybrid	. . .	X	. . .	. . .	. . .	. . .
Striped shiner *(Notropis chrysocephalus)*	X	. . .	. . .	X	X	X
Bigmouth shiner *(Notropis dorsalis)*	. . .	. . .	. . .	. . .	X	X
Red shiner *(Notropis lutrensis)*	X	X	X	X	X	X
White sucker *(Catostomus commersoni)*	X	X	X	. . .	. . .	X
Black bullhead *(Ictalurus melas)*	X	X	X	X	X	X
Yellow bullhead *(Ictalurus natalis)*	X	X	X	X	X	X
Channel catfish *(Ictalurus punctatus)*	X	X	X	X	X	X
Flathead catfish *(Pylodictis olivaris)*	. . .	. . .	. . .	X	. . .	. . .
Blackstripe topminnow *(Fundulus notatus)*	. . .	. . .	X	X	X	X
White bass *(Morone chrysops)*	X	X	X	X	X	X
Yellow bass *(Morone mississippiensis)*	X	X	X	X	X	X
Green sunfish *(Lepomis cyanellus)*	X	X	X	X	X	X
Bluegill *(Lepomis macrochirus)*	X	X	X	X	X	X
Bluegill x green sunfish hybrid	X	X	X	X	X	X
Largemouth bass *(Micropterus salmoides)*	X	X	X	X	X	X
White crappie *(Pomoxis annularis)*	X	X	X	X	X	X
Freshwater drum *(Aplodinotus grunniens)*	X	X	X	X	X	X

Table 2.—Average annual catch (kg/unit effort), percentage composition of the catch, and rank (biomass) of fish species collected at bimonthly intervals from six Lake Sangchris stations, 1974–1976. Each sample (unit of effort) consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls. The average catch was calculated from 36 samples each year. The electrofishing portion of the sample was conducted at night during 1974 and during daylight in 1975 and 1976.

Species	Average Catch (kg) 1974	1975	1976	Percentage Composition 1974	1975	1976	Biomass Rank 1974	1975	1976
Gizzard shad	11.046	14.973	15.034	16.3	30.0	25.3	3	2	2
Carp	22.336	16.015	20.837	32.9	32.1	35.0	1	1	1
Hornyhead chub	0.001	tr[a]	0.0	0.0	0.0	0.0	18	18	. . .
Golden shiner	0.113	0.073	0.130	0.2	0.2	0.2	14	14	13
Striped x golden hybrid	0.0	tr	0.0	0.0	0.0	0.0	. . .	20	. . .
Striped shiner	tr	tr	0.005	0.0	0.0	0.0	20	19	18
Bigmouth shiner	0.003	0.0	0.0	0.0	0.0	0.0	17	. . .	. . .
Red shiner	0.045	0.020	0.018	0.1	0.0	0.0	15	15	16
White sucker	0.450	0.129	0.180	0.7	0.3	0.3	12	12	12
Black bullhead	2.720	0.454	0.224	4.0	0.9	0.4	7	9	11
Yellow bullhead	0.419	0.099	0.111	0.6	0.2	0.2	13	13	14
Channel catfish	3.865	3.079	1.304	5.7	6.2	2.2	6	4	7
Flathead catfish	0.0	0.0	0.049	0.0	0.0	0.1	. . .	. . .	15
Blackstripe topminnow	tr	0.001	0.001	0.0	0.0	0.0	19	17	19
White bass	2.598	1.845	3.690	3.8	3.7	6.2	8	6	4
Yellow bass	4.531	1.314	3.465	6.7	2.6	5.8	5	7	5
Green sunfish	0.544	0.285	0.410	0.8	0.6	0.7	10	11	9
Bluegill	6.824	2.852	2.987	10.0	5.7	5.0	4	5	6
Bluegill x green hybrid	0.018	0.011	0.013	0.0	0.0	0.0	16	16	17
Largemouth bass	11.262	7.621	10.101	16.6	15.3	17.0	2	3	3
White crappie	0.717	0.409	0.593	1.1	0.8	1.0	9	10	8
Freshwater drum	0.457	0.727	0.391	0.7	1.5	0.7	11	8	10
Total	*67.949*	*49.907*	*59.543*	*100.2*	*100.1*	*100.1*			

[a] tr = trace.

Sampling fishes at Lake Sangchris with alternating-current electrofishing equipment.

surveys demonstrated that the largemouth bass population remained stable at a consistently high level, a remarkable accomplishment considering the abundance of rough fish (carp and gizzard shad) and stunted bluegills.

The relatively high catch of largemouth bass in Lake Sangchris, an 11-year-old lake, indicated that the bass population in this cooling lake did not experience the decline in production commonly observed in unheated Illinois reservoirs as they age (Bennett 1951). Drew & Tilton (1970) similarly reported that two cooling lakes in Texas had remained highly productive over a long period in contrast to the reduction in game fish populations experienced in unheated Texas reservoirs. They attributed the continued productivity to substantial reduction of stratification in cooling lakes and improved distribution of nutrients. The results of the present study indicated that although these might have been contributing factors, the key element to the maintenance of a satisfactory bass population in Lake Sangchris was the beneficial effect of the thermal effluent upon annual reproduction and growth. The earlier spawn in the discharge arm, the extended growth season there, and the stabilizing of water temperature variations that might occur as a result of local climatic conditions in a cooling lake during the spawning season all contributed to the excellent annual reproduction and growth by largemouth bass in Lake Sangchris.

The average annual catch per unit effort of all species combined was higher during 1974 (67.949 kg), when electrofishing was conducted at night, than during 1975 (49.907 kg) or 1976 (59.543 kg), when electrofishing was conducted during daylight. Significant variation in the average annual catch among years occurred for three species: yellow bullhead, yellow bass, and bluegill (Table 3). For each of these species the highest catch occurred during 1974 (Table 2), when the electrofishing portion of the sample was conducted after dark. This fact was an indication that the differences in annual catch may have been related to the differential catchability by electrofishing of these species as a result of their behavior during the day and night rather than to a real difference in abundance from year to year.

The average monthly catch per unit effort for all species combined (Table 4)

Table 3.—Analysis-of-variance for the biomass (grams) of major fish species captured at bimonthly intervals from six Lake Sangchris stations (1974–1976). Water temperature was used as a covariable in the model. Asterisks denote significance at $P \leq 0.05$ (*) or $P < 0.01$ (**); multiple correlation coefficients (R^2) are given at the bottom of the table.

		Mean Square (by Species)								
Source of Variation	Degrees of Freedom	Gizzard Shad (x10^6)	Carp (x10^6)	Golden Shiner (x10^3)	Red Shiner (x10^3)	White Sucker (x10^6)	Black Bullhead (x10^6)	Yellow Bullhead (x10^6)	Channel Catfish (x10^4)	Blackstripe Topminnow
Years	2	187.97	392.80	30.89	8.50	1.07	68.49	1.19*	61.97	8.62
Months	5	599.50*	1,052.40**	67.65	2.26	1.22	21.33	0.16	54.44	16.17*
Warm vs. cold (WC)	1	1,054.74*	832.47*	3.26	4.09	0.95	0.03	0.02	43.52	33.33*
Station contrasts[a]										
C1(Sta 2 vs. 7)	1	0.60	1,043.02	18.09	9.38	0.88	15.07	0.16	7.05	0.03
C2(Sta 4 vs. 7)	1	7.94	131.11	1.84	10.82	2.30	2.96	0.13	68.20	1.00
C3(Sta 1 vs. 5)	1	1,322.66*	104.84	29.07	0.61	5.34*	12.80	0.52	44.16	106.78*
C4(Sta 1,2 vs. 4,5)	1	737.65	483.12	3.11	0.51	4.18*	42.14*	0.28	75.00	66.13
C5(Sta 1,2,7 vs. 3,4,5)	1	598.57	364.57	15.60	1.37	6.06*	27.97	0.00	44.64	88.93
Years vs. stations	10	88.99	164.65	12.90	4.24	0.52	5.94*	0.14*	4.30	12.78*
Years vs. months[b]	10	113.69	142.63	28.52	3.89	0.67	21.30	0.19	21.37	4.43
Stations vs. months	25	147.99**	162.23	40.54*	2.45	0.55	2.77	0.06	17.24*	13.23**
Stations vs. WC months										
C1 vs. WC	1	8.79	86.45	1.89	4.67	0.07	2.95	0.06	3.06	0.03
C2 vs. WC	1	333.94*	316.29	10.64	11.66*	0.32	0.00	0.12	0.12	0.03
C3 vs. WC	1	1,189.25**	5.52	2.26	0.10	0.47	1.60	0.04	1.60	132.25**
C4 vs. WC	1	1,552.59**	18.83	18.85	1.24	0.48	0.08	0.05	0.01	62.35**
C5 vs. WC	1	1,121.37**	2.18	7.22	4.24	0.65	0.09	0.04	0.56	35.59*
Residuals	49	59.20	119.99	18.48	2.32	0.45	2.68	0.06	6.49	5.51
Temperature	1	36.90	78.56	129.47*	0.23	0.06	1.74	0.07	0.06	16.73
Multiple correlation coefficient		0.79	0.72	0.69	0.64	0.67	0.83	0.75	0.79	0.75

[a] Stations were tested using Satterthwaite's approximation (Satterthwaite 1946).

[b] Years vs. months interaction was not testable.

was highest during May (80.6 kg) and lowest during January (28.4 kg). Results of the species-specific analysis of variance tests for monthly catch revealed significant differences for gizzard shad, carp, blackstripe topminnow, bluegill, and largemouth bass (Table 3). A further comparison of the expected difference in catch between the warmest month (July) and the average catch in the two coldest

Table 3.—Continued.

Source of Variation	Degrees of Freedom	White Bass ($x10^6$)	Yellow Bass ($x10^6$)	Green Sunfish ($x10^6$)	Bluegill ($x10^6$)	Bluegill x Green Hybrid ($x10^6$)	Largemouth Bass ($x10^6$)	White Crappie ($x10^6$)	Freshwater Drum ($x10^6$)
		Mean Square (by species)							
Years	2	30.99	96.70*	0.60	183.07**	0.49	124.52	0.86	1.14
Months	5	18.07	22.84	0.68	58.85*	2.12	483.07**	1.13	2.19
Warm vs. cold (WC)	1	9.15	18.59	0.18	60.18	0.07	2.22	0.82	3.76*
Station contrasts[a]									
C1(Sta 2 vs. 7)	1	10.11	3.92	0.03	12.78	0.75	49.35	0.00	0.01
C2(Sta 4 vs. 7)	1	1.53	4.27	0.01	25.15	0.10	296.96	0.48	0.77
C3(Sta 1 vs. 5)	1	147.11	123.12	0.13	6.15	0.12	10.46	0.03	5.89*
C4(Sta 1,2 vs. 4,5)	1	51.86	24.86	0.10	0.54	0.02	24.32	0.14	5.16*
C5(Sta 1,2,7 vs. 3,4,5)	1	151.73	22.80	0.49	0.04	0.15	89.61	0.02	4.33*
Years vs. stations	10	3.81	20.39*	0.13	5.16	0.75	26.74	0.27	0.37
Years vs. months[b]	10	11.86	19.69	0.35	16.83	1.13	75.62	0.63	0.67
Stations vs. months	25	38.68**	21.40**	0.20*	8.53	0.83	154.82**	0.73	0.63*
Stations vs. WC months									
C1 vs. WC	1	0.18	1.33	0.00	0.15	1.20	141.27	0.52	0.00
C2 vs. WC	1	5.03	0.38	0.00	6.93	0.16	649.37**	0.89	0.47
C3 vs. WC	1	8.67	40.56*	0.04	5.90	1.12	220.46	0.05	0.65
C4 vs. WC	1	11.36	33.07	0.01	0.18	1.54	404.56**	0.10	1.08*
C5 vs. WC	1	6.52	14.36	0.03	1.63	0.93	671.73**	0.08	0.52
Residuals	49	7.68	9.53	0.12	5.06	0.99	55.68	0.50	0.32
Temperature	1	0.82	0.85	0.08	25.57*	1.35	27.90	0.11	1.31*
Multiple correlation coefficient		0.81	0.77	0.79	0.82	0.54	0.75	0.62	0.76

months (January and November) revealed significant variation for gizzard shad, carp, blackstripe topminnow, and freshwater drum. The mean catches of

Table 4.—Average monthly catch (kg/unit effort) of fishes from Lake Sangchris, 1974–1976. Six stations were sampled in the designated months in each of 3 years, resulting in a total of 18 samples. Each sample (unit of effort) consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Jan	Mar.	May	July	Sept.	Nov.
Gizzard shad	6.849	7.378	20.267	18.960	16.333	12.320
Carp	13.744	31.011	22.384	10.990	15.355	24.893
Hornyhead chub	. . .	. . .	0.001	. . .	. . .	0.001
Golden shiner	0.040	0.192	0.166	0.053	0.082	0.100
Striped x golden hybrid	. . .	. . .	0.000	. . .	. . .	. . .
Striped shiner	0.000	. . .	0.004	. . .	0.003	0.003
Bigmouth shiner	0.006	0.000	. . .	. . .	. . .	. . .
Red shiner	0.035	0.012	0.028	0.017	0.039	0.035
White sucker	0.109	0.162	0.677	0.006	0.097	0.466
Black bullhead	0.381	3.227	1.378	0.551	0.439	0.821
Yellow bullhead	0.035	0.269	0.186	0.200	0.287	0.280
Channel catfish	0.452	4.473	4.679	2.649	3.207	1.037
Flathead catfish	. . .	. . .	. . .	. . .	0.098	. . .
Blackstripe topminnow	0.000	0.000	0.000	0.002	0.002	0.001
White bass	1.363	4.094	2.678	2.553	3.581	1.998
Yellow bass	2.005	4.142	4.286	1.627	2.822	3.738
Green sunfish	0.104	0.426	0.415	0.388	0.716	0.427
Bluegill	0.791	5.674	5.095	4.539	5.419	3.808
Bluegill x green hybrid	0.000	0.032	0.013	0.008	0.020	0.011
Largemouth bass	2.049	12.734	16.887	6.087	10.946	9.266
White crappie	0.375	0.485	0.571	0.460	0.480	1.067
Freshwater drum	0.082	0.202	0.887	0.788	0.818	0.374
Total	*28.420*	*74.513*	*80.602*	*49.878*	*60.744*	*60.646*

Table 5.—Average catch (kg/unit effort) of fishes at each of six sampling stations in Lake Sangchris, 1974–1976. Collections were made at bimonthly intervals each year, and 18 collections were made at each station. Each sample (unit of effort) consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station					
	1	2	3	4	5	7
Gizzard shad	10.041	12,105	13.168	12.785	22.164	11.846
Carp	21.231	27.117	15.690	20.169	17.818	16.352
Hornyhead chub	0.001	. . .	. . .	. . .	0.001	. . .
Golden shiner	0.086	0.119	0.120	0.089	0.143	0.075
Striped x golden hybrid	. . .	0.000	. . .	. . .	. . .	. . .
Striped shiner	0.003	. . .	. . .	0.003	0.004	0.000
Bigmouth shiner	. . .	. . .	. . .	. . .	0.000	0.006
Red shiner	0.016	0.023	0.044	0.021	0.007	0.055
White sucker	0.771	0.193	0.048	. . .	. . .	0.506
Black bullhead	1.734	2.243	0.956	0.375	0.541	0.949
Yellow bullhead	0.255	0.250	0.379	0.241	0.014	0.119
Channel catfish	1.732	2.736	1.626	4.604	3.947	1.851
Flathead catfish	. . .	. . .	. . .	0.098	. . .	. . .
Blackstripe topminnow	. . .	. . .	0.002	0.000	0.003	0.000
White bass	1.273	2.182	4.839	1.534	5.316	1.122
Yellow bass	3.162	2.714	2.461	1.366	6.861	2.054
Green sunfish	0.696	0.198	0.698	0.167	0.575	0.142
Bluegill	4.645	4.575	3.849	5.055	3.818	3.383
Bluegill x green sunfish hybrid	0.019	0.014	0.014	0.008	0.023	0.005
Largemouth bass	7.621	10.486	11.285	13.889	6.543	8.145
White crappie	0.336	0.672	0.572	0.905	0.278	0.674
Freshwater drum	0.325	0.340	0.440	0.602	1.134	0.310
Total	*53.947*	*65.967*	*56.191*	*61.911*	*69.190*	*47.594*

gizzard shad, blackstripe topminnow, and freshwater drum were greater during July, while the mean catch of carp was greater during the two colder months (Table 4). From March to November the mean catch of bluegill was fairly consistent, ranging from 5.6 to 3.8 kg per unit effort, but was exceptionally low (0.8 kg) in January. The mean catch of largemouth bass was highest during May (16.9 kg), when the fish were engaged in spawning activities near the shore, and much lower during extreme temperatures in January (2.1 kg) and July (6.1 kg).

Analyses of the total catch of all species combined among stations (Table 5) revealed that the highest average catch across all months occurred at Station 5 (69.2 kg) in the discharge canal, and the lowest at Station 7 (47.6 kg) in the control arm. When contrasts between specific stations were tested among species by analysis of variance, no significant differences were found between the catch at stations 2 and 7, or the catch at stations 4 and 7, station contrasts C1 and C2 of Table 3. Analyses of the difference in catch for the ramaining three station contrasts (C3, C4, and C5) demonstrated that gizzard shad, blackstripe topminnows, and freshwater drum were significantly more abundant in heated areas, while black bullheads and white suckers were significantly more abundant in unheated areas (Table 3). The mean catch (22.2 kg) of gizzard shad at Station 5 in the discharge canal was more than twice as large as the mean catch (10.0 kg) at Station 1 in the intake canal (Table 5). The mean catch (0.003 kg) of blackstripe topminnows was significantly greater in the discharge canal (Station 5) than it was in the intake canal (Station 1) because this species was never collected there. Significantly larger mean catches of freshwater drum were found in the discharge canal (Station 5), the discharge arm (stations 4 and 5), and the entire heated zone (stations 3, 4, and 5) when those areas were tested with corresponding unheated areas. In the intake canal (Station 1), the intake arm (stations 1 and 2), and the unheated zone (stations 1, 2, and 7) the mean catch of white sucker was significantly greater than it was in the heated area because this species was not collected from stations 4 and 5 (Table 5). For black bullhead, another species distributed throughout the lake, the mean catch (1.989 kg) from the intake arm (stations 1 and 2) was significantly greater than the mean catch (0.458 kg) from the discharge arm (stations 4 and 5).

The analysis of variance for the catch per unit effort data showed significant year vs. station interaction for black bullhead, yellow bullhead, blackstripe topminnow, and yellow bass (Table 3). These differences were likely the result of changes during the 3 years in the magnitudes of the catches of these species, which were not consistent for each station, and/or due to the change from night to day electrofishing collections.

Significant station vs. month interaction was found for nine species: gizzard shad, golden shiner, channel catfish, blackstripe topminnow, white bass, yellow bass, green sunfish, largemouth bass, and freshwater drum (Table 3). Significant differences in the catch of five of these species (gizzard shad, blackstripe topminnow, yellow bass, largemouth bass, and freshwater drum) will be partially explained in subsequent discussions of significant interaction between specific heated and unheated stations during warm and cold months. An explanation for the significant station vs. month interaction was not apparent for two of the minor species, green sunfish and golden shiner. However, the significant station vs. month interaction for white bass and channel catfish may be related to important biological differences in the reproductive life histories of these species in a cooling lake in comparison with those in unheated reservoirs.

The significant station vs. month interaction for the catch of white bass was believed to be related to the unusual spawning behavior of this species in Lake Sangchris. White bass were first stocked in this lake as breeding adults in 1971 and have since flourished, making an appreciable contribution to the overall sport fishery (McNurney & Dreier 1981). In large reservoirs, white bass normally migrate to headwaters and spawn in the flowing water of major tributaries (Webb & Moss 1968). If major tributaries are absent, they have been known to spawn on scattered wind swept points (Bonn 1953). At nearby Lake Shelbyville, a mainstream reservoir, upstream spawning migrations of white bass were observed in the major tributaries (Tranquilli et al. 1979*b*). In Lake Sangchris, which has no major tributaries, white bass in March and April made pronounced upstream migrations against the artificial current created by the power plant to spawn in the flowing waters of the discharge canal. This is illustrated (Fig. 2) by the exceptionally high mean catch (20.025 kg) of white bass which occurred in the discharge canal (Station 5) during March of the 3 study years in comparison with the mean catches from the other five stations. The spawning concentration in the discharge canal was further documented by reproduction studies, which showed that the white bass in the discharge canal were in spawning condition, and by creel results, which showed unusually high spring catches from the discharge canal area (McNurney & Dreier 1981). In addition, white bass tagged in the discharge canal during the early springs of 1975 and 1976 were subsequently recaptured from the intake and control arms, suggesting that white bass from all areas of the lake were attracted to the flowing water of the discharge canal to spawn during early spring (Tranquilli et al. 1981*b*). The well-established white bass population indicates that reproduction in the discharge canal was advantageous and successful for that species.

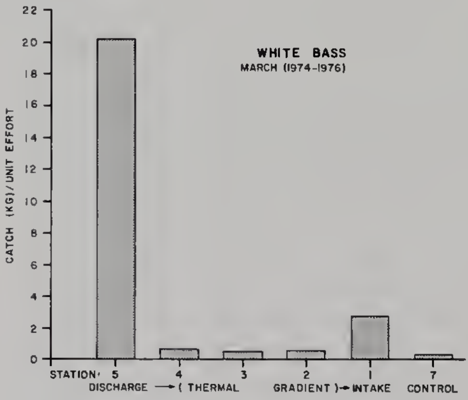


Fig 2.—Mean catch (kg/unit effort) of white bass at Lake Sangchris during March (1974-1976)

The significant station vs. month interaction for the catch of channel catfish (Table 3) was apparently the result of high mean catches in the discharge arm (stations 4 and 5) during the months of March and May (Table 6). Creel surveys conducted in 1973 and 1974 (McNurney & Dreier 1981) demonstrated that channel catfish were much more abundant in Lake Sangchris than our catch-per-unit-effort data indicate. This discrepancy probably occurred because channel catfish are highly sensitive to changes in light intensity and generally migrate to the surface, where they are

Table 6.—The distribution of channel catfish in Lake Sangchris relative to the thermal gradient demonstrated by catch (kg) per unit effort[a] from six stations at bimonthly intervals 1974-1976.

	Station					
	Heated	→	(Relative Thermal Gradient)		→	Unheated
Month	5	4	3	2	1	7
January	0.164	2.759	0.374	0.727	0.162	0.000
March	7.523	9.028	1.657	6.398	1.026	1.205
May	13.479	6.102	2.039	2.268	2.238	1.946
July	0.231	4.521	2.605	2.928	1.852	3.760
September	2.008	5.065	2.224	2.319	4.120	3.508
November	0.279	1.620	0.857	1.784	0.993	0.686

[a] One unit of effort consisted of 1 hour of electrofishing, one 24 hour experimental gill net set and four seine hauls

vulnerable to capture by electrofishing, only at night. Because of this behavioral pattern, the 24-hour gill net sets produced the most consistent, but still inadequate, catches of channel catfish in our population surveys. As expected, the largest biomass of channel catfish was collected during 1974 when the electrofishing portion of the sample was conducted at night (Table 2). Creel surveys (McNurney & Dreier 1981) also supported the hypothesis that channel catfish preferred the thermal effluent, since 65.2 percent of the total number caught by fishermen during 1973 and 1974 were from the discharge arm and 31.0 percent of that number were captured there during the summer.

In Illinois, channel catfish reproduction is normally unsuccessful in large reservoirs not fed by a major stream and containing substantial populations of predatory game fish, such as the largemouth bass (personal communication with Illinois Department of Conservation staff). Lake Sangchris was originally stocked with channel catfish in 1969 on a put-and-take basis, and the catfish population has since sustained itself through natural reproduction without supplemental stocking.

A comparison of the mean catch of individual species per unit effort from specific heated and unheated stations during warm (July) and cold (January and November) months from 1974 to 1976 revealed no differences between the two lake stations with similar cool water temperatures (stations 2 and 7, contrast C1 vs. WC of Table 3). The mean water temperatures were determined for each station by measurements taken as the fish were collected (Table 7). Among the remaining four contrasts of heated and unheated stations in warm and cold months, one or more significant interactions were found for each of three major species (gizzard shad, largemouth bass, and yellow bass) and three minor species (blackstripe topminnow, red shiner, and freshwater drum). For both major and minor species, significant interactions indicated that the catch per unit effort was not independent of the sampling month and that seasonal and spatial differences existed (Table 3). These differences were illustrated (Fig. 3) by a change in the magnitude of the catch and, at least for the major species, demonstrated a behavioral response to the heated effluent.

Among the three minor species, significant interactions between heated and unheated stations in warm and cold

Table 7.—Mean Celsius water temperature (± 1 SD) during fish collections taken in Lake Sangchris from January 1974 to November 1976. Temperatures recorded during the electrofishing, gill netting, and seining portions of the fish collections were used to determine the mean at each station during each of the 3 years (N = 9). No thermal discharge occurred during September 1976 because Kincaid Generating Station was out of operation.

	Station					
	Discharge ⟶	(Relative Thermal Gradient)	⟶		Intake	Control
Month	5	4	3	2	1	7
January	11.9 (2.2)	8.0 (2.0)	4.6 (1.6)	4.3 (1.8)	3.7 (1.9)	2.3 (1.9)
March	15.0 (3.7)	13.8 (1.5)	10.3 (2.2)	9.9 (1.9)	9.5 (2.0)	8.7 (2.9)
May	27.1 (2.3)	24.5 (3.3)	23.3 (2.7)	21.2 (3.4)	22.4 (2.9)	21.9 (2.0)
July	36.5 (1.6)	34.5 (2.2)	29.9 (1.3)	29.6 (1.8)	28.8 (1.3)	28.6 (1.6)
September	27.4 (4.2)	25.1 (5.4)	24.6 (4.6)	23.1 (3.8)	23.3 (3.6)	24.2 (4.5)
November	15.9 (4.7)	13.6 (5.3)	10.8 (5.8)	10.0 (4.2)	9.9 (4.3)	8.0 (5.0)

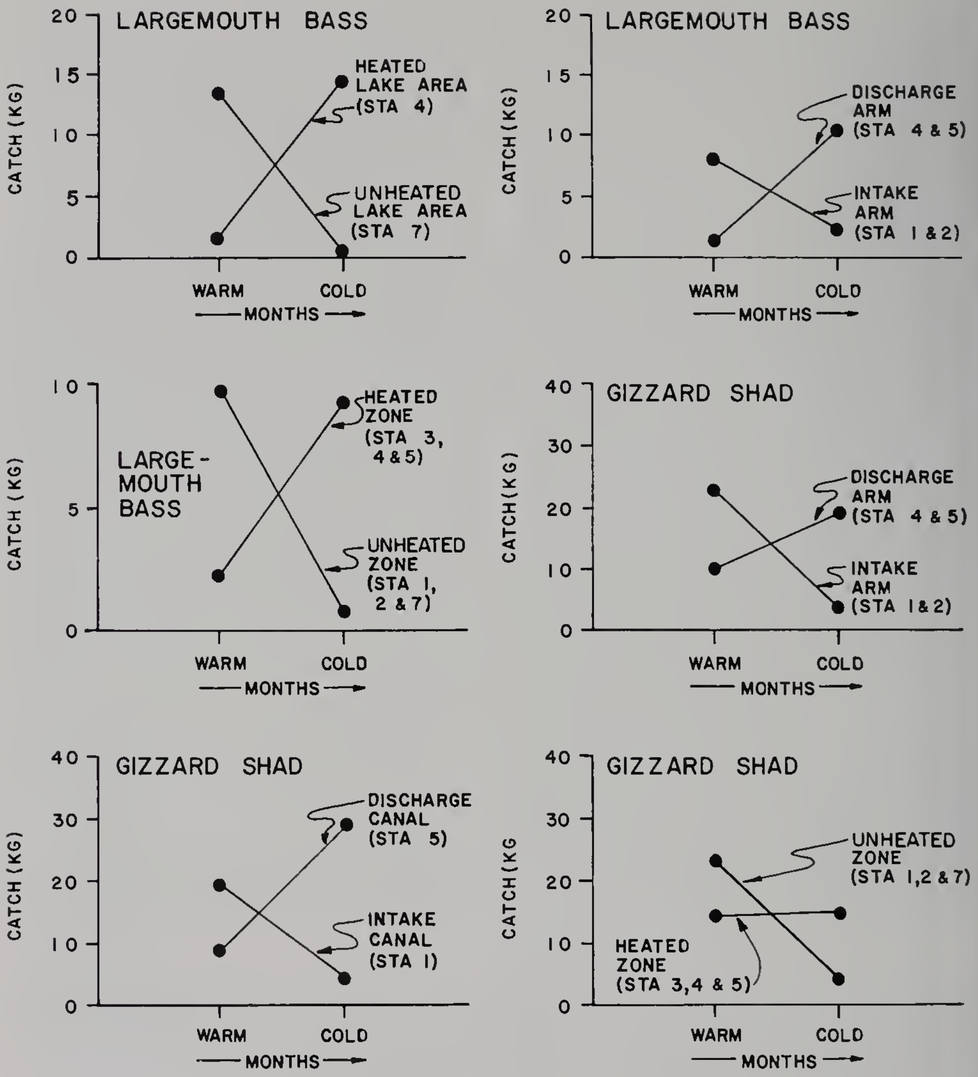


Fig. 3.—Significant interactions ($P < 0.05$) between mean catch (kg) of fishes per unit sampling effort at specific heated and unheated stations in Lake Sangchris during warm (July) and cold (January and November) months from 1974 to 1976. Each unit of effort consisted of 1 hour of alternating-current electrofishing, one 24-hour experimental gill net set, and four seine hauls.

months occurred for blackstripe topminnows because they were never collected from any unheated stations. Significant interactions for freshwater drum and red shiner were apparently the result of sampling bias, as very large standard deviations were associated with the mean catches of these species. Red shiners were more abundant in the heated area (Station 4) during July and in an unheated area (Station 7) during the cold months (Fig. 3). Great variation in catches of red shiner occurred because large schools of these minnows were occasionally captured in seine samples. Freshwater drum were more abundant in the intake area (stations 1 and 2) during July and in the discharge arm (stations 4 and 5) during November and January (Fig. 3). The large variation in catches of freshwater drum was hypothesized to have occurred because drum were relatively scarce and were usually found in deeper water where they were not

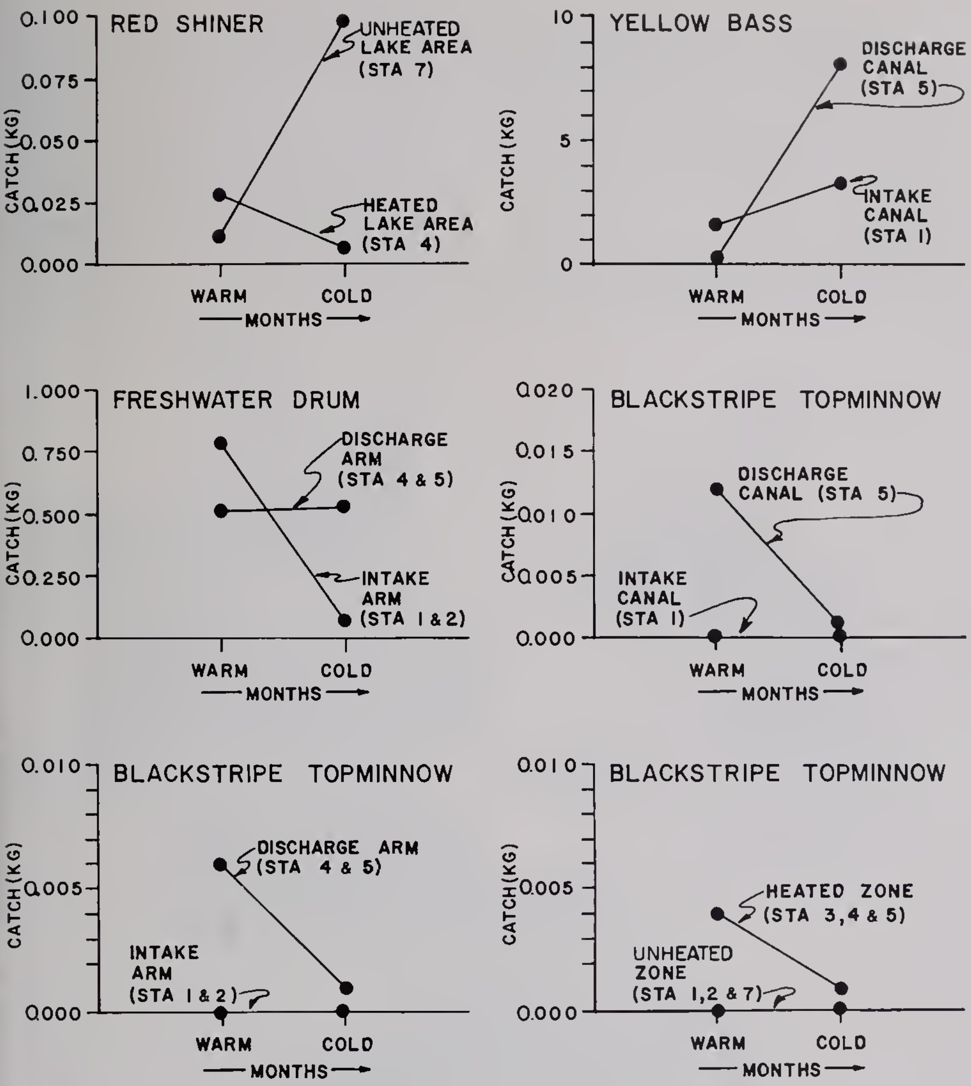


Fig. 3.—Continued

efficiently collected in either gill nets or electrofishing samples.

Temperature selection is an important behavioral response of fishes exposed to thermal effluents. For three of the major species—yellow bass, gizzard shad, and largemouth bass—the significant interactions (Fig. 3) show that these species were concentrated in unheated areas of the cooling lake during warm months and in heated areas during cold months. Furthermore, the interactions suggest that the distribution of these species reversed seasonally as a result of behavioral thermoregulation. For yellow bass, seasonal differences in catch-per-unit-effort samples were restricted to the intake and discharge canals, whereas for largemouth bass and gizzard shad, they occurred over a much broader area of the lake.

In July, the mean catch per unit effort of yellow bass in the discharge canal was 0.015 kg, much lower than the 1.651 kg mean catch per unit effort from the intake canal. During the colder months the mean catch in the discharge canal was 8.118 kg, much higher than the

3.385 kg mean catch from the intake canal (Fig. 3). This distribution suggests that yellow bass avoided the discharge canal during July when the water temperature was 36.5°C but were attracted to it during the cold months when it was the warmest area of the lake (Table 7).

The bimonthly distribution of gizzard shad at stations in heated and unheated areas of Lake Sangchris from 1974 to 1976 is graphically illustrated in Fig. 4. When catch-per-unit-effort data during warm and cold months were tested, significant interactions were found for all four contrasts between heated and unheated areas (Table 3). During July, gizzard shad were more abundant at the unheated lake station, the intake canal, the intake arm, and the entire unheated zone. During cold months, gizzard shad were more abundant at the heated lake station, the

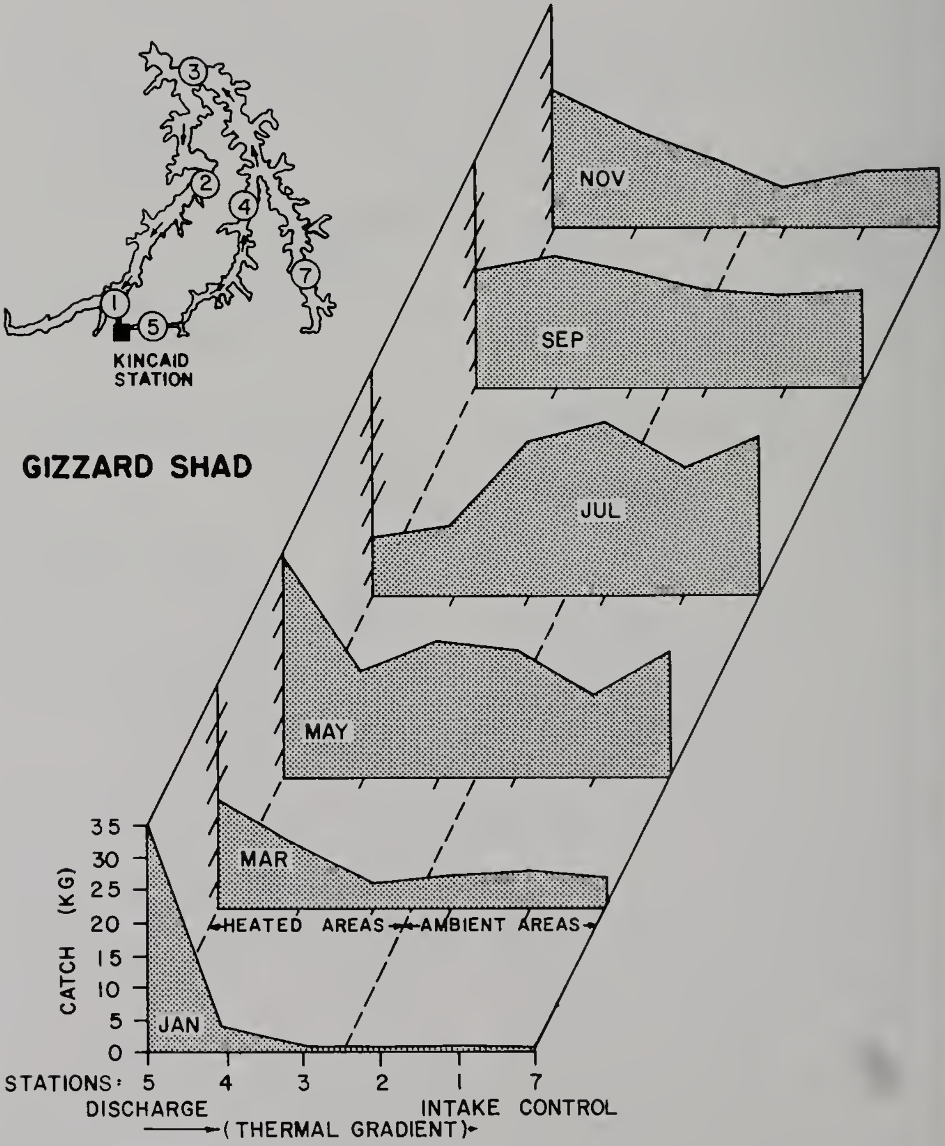


Fig. 4.—Distribution of gizzard shad in Lake Sangchris (1974–1976) in relation to the thermal gradient demonstrated by bimonthly changes in catch-per-unit-effort samples collected from six stations.

discharge canal, the discharge arm, and the entire heated zone (Fig. 3). Temperature appeared to be the major factor governing the distribution of gizzard shad.

The seasonal distribution of largemouth bass in Lake Sangchris was illustrated by plotting the average catch per unit effort during bimonthly periods from 1974 to 1976 in relation to the relative thermal gradient (Fig. 5). During January, largemouth bass were concentrated in the heated area of the lake. As the lake warmed naturally, the concentration shifted along the relative thermal gradient, and by July they were concentrated in unheated areas. When the lake began to cool naturally in the

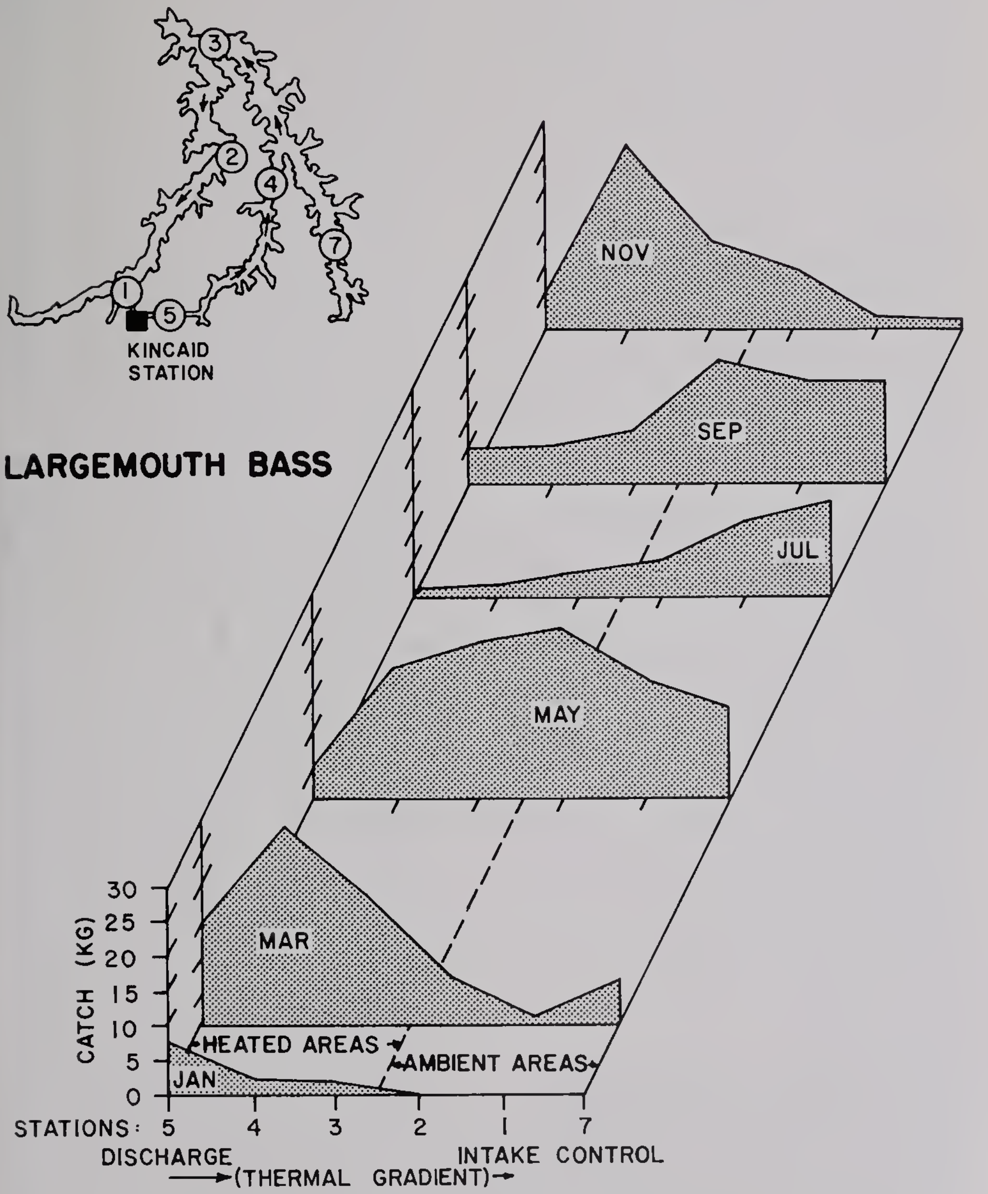


Fig 5.—Distribution of largemouth bass in Lake Sangchris (1974–1976) in relation to the thermal gradient demonstrated by bimonthly changes in catch-per-unit-effort samples collected from six stations.

fall, the concentration of bass began to shift back toward the heated areas. Statistical comparison of these catch-per-unit-effort data between heated and unheated areas in warm (July) and cold (November and January) months revealed significant differences for contrasts between (1) the heated and unheated lake stations, (2) the discharge and intake arms, and (3) the entire heated zone vs. the entire unheated zone. In all three of these interactions (Fig. 3), largemouth bass were more abundant in heated areas during cold months and in unheated areas during July.

The bimonthly distribution of largemouth bass in Lake Sangchris can be explained in several ways. Either temperature selection, the distribution of forage fish (gizzard shad), or a combination of these two factors could account for the seasonal shift in concentration of bass. Temperature selection was considered the major factor because gizzard shad were extremely abundant throughout the lake, and except for January, there was never a shortage of these forage fish at any station. Also, in comparison to the bimonthly distribution of gizzard shad relative to the thermal gradient, the shift in concentration of largemouth bass was much more distinct (Fig. 4 and 5). Thus, catch-per-unit-effort data for largemouth bass indicated that a substantial portion of the population was moving relatively long distances around the cooling loop (16.1 km) on a seasonal basis to select preferred water temperatures. Directed movements of this magnitude and type have been confirmed for individual largemouth bass in Lake Sangchris by recaptures of tagged fish (Tranquilli et al. 1981*b*) and by radiotelemetry observations (Tranquilli et al. 1981*a*).

In the analysis of variance model for the fish catch-per-unit-effort data, water temperature measured at each station at the time of sampling was used as a linear covariable. After the effects of years, months, stations, and interactions were removed, a significant relationship between water temperature and catch of individual species was found for bluegill, golden shiner, and freshwater drum (Table 3). The linear regression was positive for bluegill, a relatively abundant species, and demonstrated that each increase in temperature of 1°C resulted in an increased catch of 0.494 kg. More bluegill were captured in warmer water, because as temperature increased, these fish tended to move from deeper to more shallow water, where they were more vulnerable to capture, especially by electrofishing. For golden shiner and freshwater drum the linear regression was negative, indicating for each degree Celsius increase in temperature, there was a decrease in the catch of 0.042 and 0.133 kg, respectively. The negative relationships for the latter two species were believed to be related to high variablilty in the catch, which occurred because these species were relatively scarce in the lake, and because the sampling techniques employed were not efficient methods of collecting these species.

Results of field studies regarding the distribution of fishes near thermal discharges have generally been reported as concentrations of fish species in heated areas during cold months, avoidance of thermal discharge by heat-sensitive species during warm seasons, and orientation of species in a temperature gradient according to their individual thermal preferenda. Field effects of this type provide a common basis for comparison. Experimental data on temperature selection by fishes in laboratory studies can also be used for comparison, as they generally agree well with field data. Differences between laboratory and field data have often been related to differences in size or age of the fish (Ferguson 1958).

In field situations, widely different results can often be related to site-specific variables other than temperature. Some of these are differences in geographic location, riverine or lake environments, thermal load, design and location of intake and discharge structures, water quality, distribution of fish food resources, and faunal composition.

Over all 3 years and during all months, two species in Lake Sangchris, white suckers and black bullheads, were always more abundant at stations in unheated zones than in heated. Although white suckers were not abundant, their distribution was highly uneven, as no specimens were ever collected from any heated stations. Stauffer et al. (1976) in a field study of temperature selection by fishes in the New River, Glen Lyn, Virginia, collected more than 90 percent of the white suckers in water cooler than 23.3°C in 1973 and more than 80 percent in water cooler than 21.2°C in 1974, and reported that suckers avoided the heated discharge area when water temperatures exceeded 26.7°C. In the lower Connecticut River, Marcy (1976) captured white suckers at a maximum temperature of only 19.9°C and found that they avoided the discharge canal of the Connecticut Yankee Plant during warm months.

In Lake Sangchris, the mean catch of black bullheads was significantly greater in the intake arm than in the discharge arm. Except for temperature, we know of no difference in the habitats at those stations that would account for this distribution. A similar effect was found by Neill & Magnuson (1974), who reported that subadult black bullheads avoided the thermal discharge area in Lake Monona, Wisconsin. Thus for white suckers and black bullhads, our results paralled those reported for other heated waters, indicating that these species are thermally sensitive and that they avoid thermal discharges.

In this study, during all years and in all months, blackstripe topminnows, freshwater drum, and gizzard shad were significantly more abundant in some heated areas than they were in comparable unheated areas. The distribution of blackstripe topminnows was limited to the thermally affected area of Lake Sangchris. Consequently, they were more abundant in the discharge canal than in the intake canal. A high thermal tolerance might be expected for this species, as it is a member of the Cyprinodontidae, a group most abundant and diverse in tropical regions (Pflieger 1975).

In contrasts between heated and unheated sites in Lake Sangchris, freshwater drum were significantly more abundant in the discharge canal, the discharge arm, and the entire heated zone throughout the year. These data indicated that freshwater drum were attracted to heated effluents and had a high thermal tolerance, but results of other field studies did not support this view. In the Wabash River, Indiana, Gammon (1973) found that freshwater drum were represented about equally at both heated and reference stations and reported an upper preferendum of only 30°C. In the thermal discharge at Lake Monona, Wisconsin, afternoon body temperatures of freshwater drum were 29.5–30.3°C (Neill & Magnuson 1974). Since freshwater drum were not abundant in Lake Sangchris and were not effectively sampled, our data indicating a definite attraction to the thermal effluent may be biased.

The comparison of fish catches at heated and unheated sites in Lake Sangchris also indicated that throughout the 3-year study period, gizzard shad were always significantly more abundant in the discharge canal than in the intake canal. Statistical significance was found for this comparison because unusually large catches of gizzard shad occurred in the discharge canal during cooler months. However, this conclusion was inconsistent with the significant interactions which showed that gizzard shad were more abundant in the heated areas during cold months and in the unheated areas during July.

Other investigators have reported concentrations of gizzard shad in thermal discharge areas. In Thomas Hill Reservoir, a Missouri cooling lake, Witt et al. (1970) reported that gizzard shad were attracted to the heated discharge during winter. Coutant (1974) found that during spring, gizzard shad were attracted to heated effluents of the Bull Run Steam Plant on the Clinch River, Tennessee, but that they quickly dispersed when heating ceased. In the Wabash River, Indiana, Gammon (1973) noted a marked discrepancy of gizzard shad distribution in thermal effluents with reference to size and age. He found an upper thermal preferendum of 30°C for fish averaging 240 mm in length, but observed that large numbers of smaller shad averaging 175 mm packed the discharge canal and vacated it only when the temperature exceeded 34°C.

Seasonal concentrations of white bass and channel catfish were revealed in the analysis of variance model by significant station vs. month interactions. These seasonal aggregations were subsequently related to important changes in the reproductive life histories of these species in cooling lakes in comparison with those in unheated reservoirs.

During March, unusally large catches of white bass occurred in the discharge canal (Fig 2). A number of factors, including increased water temperature, an abundance of gizzard shad forage, or rapid water currents, could have attracted the white bass. The timing of the aggregation during early spring and the active reproductive condition of the fish jointly indicated that the observed concentration was the result of a spawning migration. White bass in large reservoirs normally migrate to headwaters during early spring to spawn in flowing waters (Webb & Moss 1968). The rapid current was considered the major factor that attracted the white bass to the discharge canal in Lake Sangchris, as other headwater spawning areas were absent in this cooling lake. Similar spawning concentrations have not been documented at thermal discharges of rivers or other cooling lakes in the United States. Barkley & Perrin (1971) reported that white bass concentrated in an effluent bay of Lake Catherine, Arkansas, during June but felt that they were attracted by an abundance of threadfin shad *(Dorosoma petenense)*.

Channel catfish were concentrated at stations 4 and 5 in the discharge arm of Lake Sangchris during March and May. They apparently vacated the discharge canal (Station 5) during July, when the mean water temperature reached 36.5°C (Tables 6 and 7). At Station 4 in the discharge arm, the catfish catch remained fairly high throughout the summer. The highest mean temperature found at Station 4 was 34.5°C in July. A similar seasonal distribution was found by Dryer & Benson (1957), who reported that both blue catfish *(Ictalurus furcatus)* and channel catfish concentrated in the discharge harbor of the New Johnsonville Steam Plant on Kentucky Lake from 15 March through June but had left the area by July. Gammon (1973) found that channel catfish preferred the moderately elevated temperature below a thermal discharge in the Wabash River, Indiana, to either the effluent canal or the area above the plant.

The distribution of channel catfish in Lake Sangchris can also be related to their thermal preferendum and upper avoidance temperature. In laboratory studies, Cherry et al. (1974) found that channel catfish were quite flexible in adjusting to a wide range of temperatures and that when acclimated to 30°C, their upper avoidance temperature was 35°C. A field estimate of temperature preference for channel catfish of 33.9–35°C was made at New River, Virginia, by Stauffer et al. (1976), and Gammon (1973) reported an upper preferendum of 32°C in the Wabash River, Indiana. Our data suggest that channel catfish vacated the discharge canal during July because 36.5°C was above their upper avoidance temperature and that they remained abundant at Station 4 because 34.5°C was within their range of temperature preference.

As mentioned previously, the channel catfish population in Lake Sangchris has sustained itself through natural reproduction since its original stocking. This is unusual because reproduction by this species is normally unsuccessful in large reservoirs not fed by a major stream and which contain large populations of predatory game fish, such as the largemouth bass. Tranquilli et al. (1979*b*) reported that reproduction and recruitment by channel catfish were relatively more successful in Lake Sangchris than in Lake Shelbyville, a mainstream reservoir. The successful recruitment in Lake Sangchris can probably be attributed to the beneficial effects of the elevated temperature and artificial current of the cooling loop. Sule et al. (1979) demonstrated that channel catfish from the discharge arm of Lake Sangchris were more fecund than catfish of equal size from the intake arm. In findings that parallel ours, Gammon (1973) reported that due to improved reproductive success populations of flathead catfish *(Pylodictis olivaris)* and possibly channel catfish had increased in thermally affected areas of the Wabash River, Indiana.

Results of this field study have provided the first documentation of seasonal reversals in fish distribution in the vicinity of a thermal discharge over an extended time (3 years). This effect appeared to be the result of behavioral thermoregulation and was most apparent for yellow bass, gizzard shad, and largemouth bass. These species were significantly more abundant in heated areas of Lake Sangchris during cold months and in unheated areas during warm months. The seasonal distribution of these fishes in Lake Sangchris was therefore somewhat different from that reported for these same species in other heated waters.

Neill & Magnuson (1974) reported that subadult yellow bass avoided the thermal effluent in Lake Monona, Wisconsin, but that largemouth bass and adult yellow bass were occasionally or usually concentrated in the discharge area relative to reference areas. They also noted that these tendencies generally did not reverse from season to season or from day to night. In Lake Arlington, Texas, Rutledge (1975) found no significant differences in relative abundance among stations for largemouth bass or between seasons for largemouth bass and gizzard shad, but shad were more abundant in a thermal mixing zone than at two heated stations. In Thomas Hill Reservoir, Missouri, Witt et al. (1970) reported increased catches of gizzard shad and largemouth bass in heated areas during winter. In contrast to these results, McNeely & Pearson (1974) found that gizzard shad were rather evenly distributed throughout a northeastern Texas cooling lake in all seasons. Gibbons et al. (1972) caught significantly more largemouth bass per cast (using fishing rods) in the vicinity of the heated effluent in Par Pond, South Carolina, than in the same area when the effluent was not heated.

Although water temperature measurements were obtained during each fish population survey at Lake Sangchris, these investigations were not designed to make a precise determination of field temperature preferences for each species. However, temperature selection was believed to be the major factor affecting the spatial and temporal distribution of most species of fishes in Lake Sangchris. Integration of field and laboratory results by Neill & Magnuson (1974) indicated that various species of fishes were distributed within a thermal discharge area according to their temperature preferenda.

Dynamic seasonal changes in relative abundance of fishes occurred between heated and unheated areas of Lake Sangchris. Gizzard shad, yellow bass, and largemouth bass were apparently attracted to the heated areas during cold months and repelled from them during warm months as a result of behavioral thermoregulation. Results of this study underscore the importance of movement by fishes as a response to heated effluents and the need to provide adequate refuge areas wherever thermal discharges occur.

STANDING CROPS

Standing crop data determined from rotenone samples in lake coves are one of the most useful of all fish inventory methods used in the United States, because they are the most standardized and thus permit data comparison over a wide geographic range. In addition, several models have been formulated (Ryder 1965; Jenkins 1967 and 1977) for the prediction of fish standing crops according to various physical and/or chemical measurements of reservoirs. While the use of cove samples to represent populations of an entire reservoir has limitations, we are following the recommendations of Hayne et al. (1967), who concluded that the total standing crop determined by sampling coves was a reliable estimate. The objectives of our study were to compare seasonal changes in fish biomass within and between individual coves in heated and unheated areas and to provide an overall estimate of the standing crop of fish in the cooling lake by sampling coves in the intake, discharge, and control arms. Comparisons of these data with Jenkins' (1967 and 1977) models were used to demonstrate the relationship between standing crops of fishes in cooling lakes and in other types of reservoirs. Standing-crop estimates of fish in Lake Sangchris were needed to assess the impact of impingement and entrainment of fishes by the power plant intake structure. In addition, an accurate description of the fish population was obtained by comparing population data determined by rotenone sampling with results from other quantitative fish samples.

MATERIALS AND METHODS

Six standing-crop surveys were conducted in Lake Sangchris during the 3 years, 1974–1976. Variance petitions were filed with and approved by the Illinois Pollution Control Board, allowing the Illinois Natural History Survey to use rotenone for the five standing-crop surveys conducted during 1975 and 1976.

Sorting, measuring, and weighing fishes collected in cove rotenone samples to determine the standing crop.

Prior to 1975 a variance to do such studies was not required.

Coves ranging in size from 0.43 to 1.7 ha were studied; the average size was 1.1 ha. In 1974, a low concentration (1 ppb) of antimycin A was applied to a cove in the discharge arm to test its effectiveness as a fisheries management tool for the selective removal of excess numbers of stunted and/or undesirable species. Two days after the antimycin A treatment, rotenone was applied to eliminate the remaining fishes in the cove, thereby providing an estimate of the total standing crop (biomass). Standing crop surveys were conducted in coves from both the intake and discharge arms during the fall of 1975 and were repeated in those same coves during the spring of 1976. The control arm was sampled during the summer of 1976.

In preparation for each rotenone sample, a block net (300 m x 3 m) was placed across the mouth of the cove to serve as a barrier to fish movement. Polyethylene sheeting (300 m x 4 m) was attached to the block net and to steel rods driven into the mud to isolate the rotenone from the rest of the lake. The embayed coves were detoxified with potassium permanganate approximately 6 hours after the introduction of the rotenone to reduce the danger of kills out in the lake. The polyethylene barrier was allowed to remain in place until bluegills survived 48 hours of exposure in live-boxes placed within the treated area. On the first day of the study, all fishes were collected, indentified, counted, weighed, and measured. Dead fish were collected and processed daily until no more were found (usually 4 or 5 days). After the first day, the fish were identified and counted, but their weights were calculated from fresh weights recorded on the first day of the study.

The effectiveness of the sampling method was tested during one standing-crop survey by releasing marked largemouth bass within the embayed area immediately prior to the application of the rotenone. An alternating-current electrofishing survey was also conducted in the treated cove at the end of the first day to determine whether any fish had survived the chemical application. In another standing crop survey, the barrier was placed across the bay the evening before the chemical application, rather than during the morning of the study as was the normal practice. Then after dark the embayed area was electrofished, and a number of bluegill and largemouth bass were marked and returned to the cove as a test of recovery efficiency and numbers of fish that escaped. All standing-crop values were based upon actual numbers and weights of fishes retrieved; no extrapolations were made to account for fishes not recovered.

RESULTS AND DISCUSSION

In the six standing-crop surveys conducted in Lake Sangchris, the smallest standing crop (70.8 kg/ha) was found in the first sample, taken in September 1974, in a 0.43-ha cove of the discharge arm. Antimycin A was applied before the rotenone to test its effectiveness in selectively removing excess numbers of small, overabundant, and/or undesirable species (bluegills, yellow bass, and gizzard shad). Results of the treatment were disappointing, because the antimycin A killed only 9.7 percent by number and 3.1 percent by weight of the total standing crop of all species. Considering the species composition of the cove, an effective treatment would have removed approximately 85 percent of the fish by number. Since the toxicity of antimycin A is altered by small changes in pH and water temperature (Walker et al. 1964), the applied concentration of the chemical may have been below the lethal threshold of the target species.

The total standing crop of fishes found in the first survey (70.8 kg/ha) was much lower than the 3-year average determined from all six surveys (360.9 kg/ha). Several factors may have accounted for this difference: (1) the first survey was conducted in the smallest cove sampled, (2) greater numbers of fish may have escaped as a result of the pretreatment with antimycin A and the longer time period involved in the study, and (3) predatory fishes, unaffected by the low level antimycin A treatment, may have consumed some of the dead or dying fishes.

The next four standing-crop surveys were conducted in only two coves; one in the discharge and one in the intake arm. The original objective was to study the same coves in heated and reference areas during the fall of 1975 and again during the spring and summer of 1976 to obtain estimates of fish biomass in a cooling lake ecosystem in three seasons of the year. This study was terminated during the summer of 1976 before the last two samples in the series of six were collected, because the power plant ceased operation and there was no thermal discharge for a 6-week period. Although the experimental design was altered, this series of four rotenone collections still provided a spring and fall comparison within the same cove and, perhaps more importantly, allowed a comparison of fish biomass in the intake and discharge arms.

Within rotenone samples collected from the same cove in spring and fall, only minor differences in the weight of the standing crop were observed. Spring and fall samples from the 0.8-ha cove in the intake arm were 260 and 308 kg/ha, respectively, the difference being due to a larger weight of carp and yellow bass in the fall. Spring and fall samples from the 1.5-ha cove in the discharge arm were very similar at 299 and 295 kg/ha, respectively. Although the weight of the standing crop within each cove was fairly stable during spring and fall, twice as many fish were found per hectare during the fall samples. This difference was most evident for gizzard shad and bluegill and reflected the effect of reproduction by these species during the summer.

A comparison of fish standing crops in the intake and discharge arms (Table 8) revealed a slightly higher average biomass from the heated cove (297.6 kg/ha) than in the unheated cove (284.4 kg/ha). The species compositions of the intake and discharge arm coves were quite similar, with one species occurring exclusively in each arm. However, the relative abundance of individual species

Table 8.—The average standing crop of fishes in the intake and discharge arms of Lake Sangchris. The same cove in each arm was sampled during the fall of 1975 and the spring of 1976. The coves in the intake and discharge arms were 0.8 and 1.5 ha, respectively.

	Average Number of Fish per Hectare		Average Biomass in kg per Hectare	
Species	Intake	Discharge	Intake	Discharge
Gizzard shad	3,842	7,151	154.8	248.0
Carp	42	8	53.5	12.9
Hornyhead chub	< 1	1	0.0	0.0
Golden shiner	211	108	6.4	1.9
Striped shiner	7	. . .	0.0	. . .
Red shiner	89	39	0.1	0.1
Black bullhead	20	52	2.1	2.6
Yellow bullhead	34	9	2.4	0.8
Channel catfish	40	39	4.7	7.7
Blackstripe topminnow	. . .	16	. . .	0.0
White bass	2	12	0.0	0.5
Yellow bass	482	190	19.6	3.5
Green sunfish	255	88	3.0	1.0
Bluegill	2,730	1,523	25.9	15.3
Bluegill x green sunfish	2	1	0.0	0.0
Largemouth bass	94	34	5.1	3.0
White crappie	4	1	0.3	0.2
Freshwater drum	48	< 1	6.5	0.1
Total	*7,903*	*9,273*	*284.4*	*297.6*

in the two arms was quite different (Table 8). In the discharge arm, gizzard shad were much more abundant. Carp, yellow bass, bluegills, and freshwater drum were much more abundant in the intake arm, but their combined total weight was more than offset by the total weight of gizzard shad from the discharge arm.

The sixth rotenone sample was conducted during the summer of 1976 in a 1.7-ha cove in the control arm and yielded an unusually large standing crop of fishes (932.1 kg/ha). In that sample, gizzard shad accounted for 809.4 kg/ha and constituted 86.8 percent of the total standing crop. This cove was the largest and deepest of any sampled, and the study was conducted during late summer when young-of-the-year fish were most abundant. Since the power plant was out of operation for several weeks before this cove was sampled, the unusual concentration of gizzard shad in this control-arm cove could not be related to the distribution of waste heat in the cooling lake.

The best overall estimate of the standing crop of fishes in Lake Sangchris was found by taking the average of all six cove rotenone samples, which included at least one survey conducted (1) in the intake, discharge, and control arms, (2) during the spring, summer, and fall seasons, (3) in each of 3 years (Table 9). The 275.3 kg/ha average standing crop of gizzard shad was unusually large, accounting for 76.3 percent of the total standing crop biomass. In contrast, clupeids constituted only 46 percent of the standing crop in 161 reservoirs of the mid-South (Jenkins 1975). The standing crop of carp in Lake Sangchris (27.0 kg/ha) was unusually low in comparison to the 112 kg/ha found in midwestern reservoirs by Carlander (1955), but it was similar to the 25.5 kg/ha standing crop found in reservoirs of the mid-South by Jenkins (1975). The biomass of sport fishes in Lake Sangchris totaled 14.4 kg/ha, consisting of channel catfish (9.5 kg/ha), white bass (0.9 kg/ha), largemouth bass (3.5 kg/ha), and white crappie (0.5 kg/ha). When compared with the total standing crop, the biomass of sport fishes was also relatively low, constituting only 4.0 percent of the total biomass. Jenkins (1975) found that

Table 9.—Averages of six standing-crop surveys conducted with rotenone in Lake Sangchris coves, 1974–1976. Coves ranged in size from 0.43 to 1.7 ha. Ranges of values are given in parentheses.

Species	Average Number of Fish per Hectare	Average Biomass kg per Hectare	Percent of Total Biomass
Gizzard shad	8,309(1,584–26,281)	275.3(36.9–809.4)	76.3
Carp	23(5–53)	27.0(7.2–69.4)	7.5
Hornyhead chub	<1(0–1)	0.0(0.0–<0.1)	tr[a]
Golden shiner	108(3–249)	2.8(0.0–8.0)	0.8
Striped shiner	2(0–14)	0.0(0.0–<0.1)	tr
Red shiner	44(0–167)	0.1(0.0–0.3)	tr
Black bullhead	26(0–86)	1.8(0.0–4.1)	0.5
Yellow bullhead	22(5–43)	1.5(0.5–2.9)	0.4
Channel catfish	102(11–314)	9.5(1.7–25.0)	2.6
Blackstripe topminnow	8(0–29)	0.0(0.0–0.1)	tr
White bass	18(0–46)	0.9(0.0–2.8)	0.3
Yellow bass	329(19–614)	9.2(0.4–32.3)	2.6
Green sunfish	213(29–482)	2.7(0.7–7.2)	0.7
Bluegill	1,899(701–4,374)	22.8(11.9–42.6)	6.3
Bluegill x green sunfish	2(0–5)	0.0(0.0–0.1)	tr
Miscellaneous sunfishes	107(0–643)	0.1(0.0–0.8)	1.7
Largemouth bass	88(23–175)	3.5(1.4–5.6)	1.0
White crappie	6(0–22)	0.5(0.0–1.2)	0.1
Freshwater drum	25(0–60)	3.3(0.0–6.9)	0.9
Total	*11,331(3,128–30,523)*	*360.9(70.8—932.1)*	*100.0*

[a] tr = trace

predatory sport fishes constituted about 15 percent of the total standing crop in reservoirs in the mid-South.

Tranquilli et al. (1979*a*) reported that the average standing crop in Lake Sangchris (360.9 kg/ha) was lower than that found in nearby unheated Lake Shelbyville (449.6 kg/ha). The lower standing crop in the cooling lake was related to a less diverse fauna and a smaller biomass of gizzard shad and carp.

A comparison of the relative abundance of fishes found in catch-per-unit-effort collections made by the use of experimental gill nets, seines, and alternating-current electroshocker with the relative abundance of fishes found in cove rotenone samples showed general agreement for gizzard shad, but not for carp or largemouth bass. The carp population of Lake Sangchris consisted almost entirely of large individuals, which were highly vulnerable to capture by electrofishing and gill netting. Consequently, their real abundance was probably overestimated in catch-per-unit-effort samples, in which they ranked first in weight and constituted 33 percent of the entire catch. In 1976, the standing crop of carp in Lake Sangchris was estimated by mark-and-recapture methods to be 20.1 kg/ha (Tranquilli et al. 1981*a*), comparable to the 27.0 kg/ha standing crop determined in rotenone samples. Thus for carp, it appeared that rotenone samples gave a better estimate of true abundance than did netting and electrofishing.

Adult largemouth bass were also found to be highly vulnerable to capture by electrofishing, and in quantitative catch-per-unit-effort collections bass constituted 16.3 percent of the total catch. However, in rotenone samples largemouth bass constituted only 3.5 kg/ha and accounted for only 1 percent of the total standing crop. To further clarify this discrepancy in relative abundance, the standing crop of largemouth bass in Lake Sangchris during 1974 and 1975 was estimated by mark-and-recapture methods. The average standing crop of largemouth bass determined for Lake Sangchris by mark-and-recapture estimates during those 2 years was 8.8 kg/ha, which excluded fish $\leq$150 mm in total length during 1974 and fish $\leq$200 mm in total length during 1975 (Tranquilli et al. 1981*b*). Since smaller fishes were excluded, this extimate was conservative. The standing crop of bass in Lake Sangchris estimated by mark-and-recapture methods (8.8 kg/ha) was similar to the 10.0 kg/ha average standing crop of bass found in reservoirs of the mid-South by Jenkins (1975) and was consistent with our quantitative netting and electrofishing data, which suggested that this cooling lake contained a relatively high bass population. The low average standing crop of bass observed in rotenone samples (3.5 kg/ha) was partially explained by the skewed size distribution of bass in those samples. The average weight of the 88 bass collected per hectare was only 39 grams (Table 9), indicating that rotenone samples consisted almost entirely of young-of-the-year fishes. The mark-and-recapture estimate for the standing crop of largemouth bass in Lake Sangchris was therefore considered to be more reliable than data obtained in rotenone samples. Apparently, larger bass were able to escape past the block nets, or the shallow coves selected for study were not preferred habitats for larger bass.

The effectiveness of cove sampling technique was tested on one occasion by releasing seven marked largemouth bass, which had been captured from a different area, within the embayed cove immediately before the application of the rotenone. All seven fish were recovered. Electrofishing within this cove after the treatment by rotenone indicated that no fish of any species escaped the toxic effect of the chemical. In another study, which tested the effectiveness of the barrier, nine bass and 72 bluegills were captured, marked, and released in an embayed cove the night before the chemical was applied; five bass and 52 bluegills were recovered after the rotenone application, a sampling efficiency of 55 and 72 percent, respectively. Since the standing-crop surveys were conducted in relatively shallow coves, where water clarity permitted the observation of a substantial portion of the bottom, we concluded that most unrecovered fishes escaped by passing the barrier.

Hayne et al. (1967) examined the problem of how well cove samples represent populations of an entire reservoir and found that young fish were usually, but not always, overestimated in both numbers and weights, while harvestable fish were often underestimated. While the true abundance of individual species was found to be biased in rotenone cove samples, the total standing crop determined by sampling coves was found to be a reliable estimate. Carlander (1955) concluded that since the annual rate of turnover probably varied less from one population to another than did the standing crop, standing-crop data were probably fairly good estimates of fish production.

The average biomass of fishes found in rotenone samples at Lake Sangchris of 360.9 kg/ha thus represents our best estimate of fish standing crop for this midwestern cooling lake (Table 9). Witt et al. (1970) reported a lower standing crop of 202 kg/ha for Thomas Hill Reservoir, a cooling lake in Missouri. The standing crop in Lake Sangchris was intermediate between the 202 kg/ha average found in reservoirs of the mid-South by Jenkins (1975) and the 449 kg/ha average found for midwestern reservoirs by Carlander (1955).

Jenkins (1967) examined data from 127 reservoirs across the United States and determined by multiple regression analyses that total dissolved solids (TDS) were an important variable exerting positive influence on fish standing crops and harvest. Although the nature of this relationship is not well understood, it is apparently related to nutrient loading and has been suggested as a useful predictor of fish biomass. As a method of comparison, Jenkins' (1967) model, a curvilinear regression of the standing crop on Ryder's (1965) morphoedaphic index (dissolved solids in ppm/mean depth in feet), was applied to Lake Sangchris physicochemical data. Using 315.5 ppm as the average TDS (Brigham 1981) and 16.2 feet as the average depth, this equation predicted a standing crop of 214.3 kg/ha, a value lower than the 360.9 kg/ha found in our rotenone samples. To reduce variability and increase predictive value, Jenkins (1977) formulated additional regression equations based on TDS concentrations according to reservoir types. Application of his regression equation determined from 43 nonhydropower reservoirs, in which carbonate-bicarbonate ions are dominant, predicted a standing crop of 383 kg/ha for Lake Sangchris, similar to the value determined by our rotenone samples. As a result, it was concluded that the production of fish biomass in Lake Sangchris, an Illinois cooling lake, is not unlike that to be expected in chemically similar unheated reservoirs with comparable total dissolved solids concentrations.

SPAWNING TIME AND REPRODUCTION

Reproduction by some warmwater fish species occurs only once per year during the spring when extrinsic factors, such as photoperiod and temperature, induce spawning. Increased water temperatures in the vicinity of a thermal discharge could thus alter the reproductive cycle of some fishes that inhabit a cooling lake. The primary objective of this study was to compare the dates of first spawning by largemouth bass, white bass, and carp in heated and unheated areas of Lake Sangchris and to assess observed and potential effects of heated effluents on the reproduction of those species.

During this investigation we observed in some carp an abnormal physiological condition of the ovaries, which we descriptively defined as degenerate. Catch-per-unit-effort sampling had also revealed a lack of carp recruitment in Lake Sangchris for several years. Carp tissues were subsequently analyzed for mercury and pesticide residues in an attempt to determine the cause of the degenerate ovarian condition. Other laboratory and field studies were conducted to determine whether the lack of carp recruitment was related to the reproductive physiology of the fish or to environmental variables.

METHODS

The beginning of the spawning period was determined by the stage of gonad development. As water temperatures increase during the spring, the weight of the gonad increases relative to the total weight of the individual fish. The weight of the gonad reaches its peak value just before spawning and declines as gametes are expelled. Males usually undergo sexual maturation and arrive in spawning areas before the females. Consequently, only data from female fish were used in our analysis, because (1) ovaries are much larger than testes and changes in gonad weight relative to total body weight are more pronounced and (2) maturation of female sex products allows a more accurate determination of the actual time of spawning.

Sexually mature largemouth bass, white bass, and carp were captured by alternating-current electrofishing at approximately 3-week intervals during the spring of 1975 to determine the effect of increased water temperatures upon the time of reproduction. Gonads of fish from the intake arm (stations 1, 1.5, and 2) were compared with gonads of fish from the discharge arm (stations 4, 4.5, and 5). The gonads were dissected and weighed to the nearest gram. A gonosomatic index (GSI) was calculated and expressed as a percentage of body weight [(gonad weight/body weight) x 100]. Gupta (1975) demonstrated that the values of the gonosomatic index and the maximum ova diameter follow similar courses and reach their peaks when the ovaries are ripe. The ovaries were also subjectively assigned a numerical classification indicating their stage of maturity according to a scale suggested by Nikolsky (1963) and translated by Bagenal & Braum (1971), where:

Stage 3. Maturation—Eggs distinguishable to the naked eye; a very rapid increase in weight of the gonad is in progress.
Stage 4. Maturity—Sexual products ripe; gonads have achieved their maximum weight, but the sexual products are still not extruded when light pressure is applied.
Stage 5. Reproduction—Sexual products are extruded in response to very light pressure on the belly; weight of the gonads decreases rapidly from the start of spawning to its completion.
Stage 6. Spent Condition —The sexual products have been discharged; genital aperture inflamed; gonads have the appearance of deflated sacs, the ovaries usually containing a few leftover eggs.

These studies were repeated for carp in 1976 and for largemouth bass in 1977, using the same techniques but with a shorter time interval between sampling dates.

During the 1975 study of fish reproductive cycles, a number of female carp were found with degenerate ovaries. Since these fish were obviously abnormal, they were not used in the analysis of spawning time. It was hypothesized that the abnormal ovarian condition was associated with mercury contamination. Muscle tissues from carp with normal and degenerate ovaries were analyzed for total mercury according to analytical methods described by Anderson & Smith (1977).

Another hypothesis was formed for testing in 1976 after 3 years of catch-per-unit-effort sampling revealed almost no evidence of successful reproduction by carp. Food-habit studies showed that carp were feeding heavily on bottom organic material; so we hypothesized that pesticide residues were being concentrated in carp tissues, causing the degenerate ovarian condition and affecting the viability of gametes. Consequently, carp of both sexes and females with normal and degenerate ovaries were collected from both the intake and discharge arms for pesticide analysis. Gonad, liver, and muscle tissues were examined from 20 fish. Aldrin; dieldrin; chlordane; DDT; o,p^1-DDT; p,p^1-DDT; DDD; o,p^1-DDE; p,p^1-DDE; lindane; heptachlor; heptachlor-epoxide; and polychlorinated biphenols (PCB's) were tested for by the Illinois Natural History Survey Pesticide Laboratory, using gas-liquid chromatography techniques. For simplicity, the pesticides, pesticide degradation products, and PCB's will hereafter be referred to collectively as pesticides.

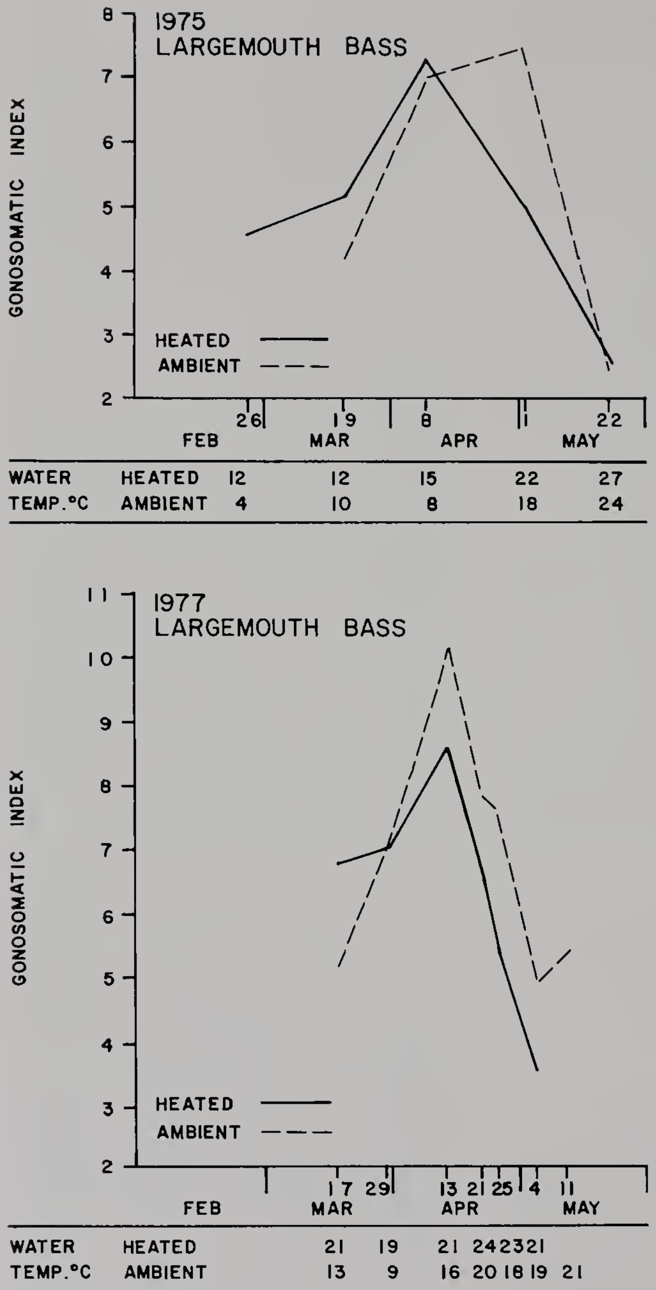
Investigations concerning the lack of reproduction by carp continued during 1977. A 0.2-ha pond, containing no other fishes, was stocked in early May with three male and five female carp from Lake Sangchris to determine whether reproduction would occur in an environment where food was plentiful and predation by other fishes was not a factor. In a second study during 1977, a pair of carp observed spawning on 11 May in Lake Sangchris were captured by electrofishing and taken to the laboratory. Carp eggs were stripped into shallow dishes, covered with water, and manually fertilized with milt from the male to determine whether normal development to the free-swimming stage would occur.

RESULTS AND DISCUSSION

When gonosomatic indices are used to determine the time of first spawning by a fish population, the sampling frequency becomes a source of experimental error. The onset of spawning may have occurred on, just before, or just after the sampling date on which the peak mean GSI value was observed. The analyses of gonad maturity stages supported the interpretation that peak GSI values occurred near the onset of spawning. The sampling dates on which fish first appeared with ovaries in the reproductive stage (stage 5) or spent condition (stage 6) were also used to determine more accurately the time of first spawning in each area.

During 1975, peak mean GSI values of largemouth bass (GSI = 7.31) in heated areas occured on 8 April at 15°C and in unheated areas (GSI = 7.58) on 1 May at 18°C (Fig. 6). A comparison of GSI values with gonad maturity stages (Table 10) suggested that the difference in time of spawning in heated and unheated areas in 1975 was somewhat less than the 3-week interval between samples. In 1977 highest mean GSI values for largemouth bass were found on 13 April in both heated (GSI = 8.58) and ambient (GSI = 10.21) areas (Fig. 6) at temperatures of 21° and 16°C, respectively. Gonad maturity stages recorded on 13 April showed that four of six fish from the heated area were spawning, while none of the fish from the unheated area were running eggs (Table 10). On 21 April, only one of six fish from the unheated area had begun spawning, whereas three of six from the heated area were running eggs, and some additional spent females were captured and returned to the lake. Thus, although peak GSI values were found on the same date in both areas in 1977, the gonad maturity stages indicated that the onset of spawning occurred about 8 days earlier in the heated area. Results for both years can be summarized by stating that in Lake Sangchris elevated temperatures in heated areas advanced the date of largemouth bass spawning by 1–3 weeks in comparison with that of unheated areas. The water temperatures at which largemouth bass began spawning in Lake Sangchris were similar to those reported for this species from unheated waters (15.6°–23.9°C) by Heidinger (1975).

Early spawning of largemouth bass in heated areas of the cooling lake was considered beneficial, as it provided a head start in growth. There was no evidence to suggest that young produced earlier than normal were out of phase with their natural food resources. Sule et al. (1979) also found that there was no difference in the fecundity of largemouth bass from heated and unheated areas of



1975

WATER TEMP.°C					
HEATED	12	12	15	22	27
AMBIENT	4	10	8	18	24

1977

WATER TEMP.°C							
HEATED	21	19	21	24	23	21	
AMBIENT	13	9	16	20	18	19	21

Fig. 6.—Gonosomatic indices for female largemouth bass in 1975 and 1977 from heated and unheated areas of Lake Sangchris and surface water temperatures on sampling dates.

Lake Sangchris. Fish which are spawned early have an advantage over smaller fish in intraspecific competition. Sule (1981) demonstrated how this advantage was exploited in Lake Sangchris. He found that when young-of-the-year largemouth bass from heated areas reached 90 mm in length, they were able to consume fish, and their average length increased more than did that of smaller, predominately insectivorous bass from unheated areas.

The thermal effluent in Lake Sangchris also benefits largemouth bass reproduction by stabilizing water temperature variations which might occur as a result of local climatic conditions during spawning season. Water temperature is an important factor affecting year class strength of largemouth bass. Kramer & Smith (1962) determined that year class strength was set after egg deposition and before the

Table 10.—Mean gonosomatic index (GSI) and numerical classification of gonad maturity stages for female fishes from heated and unheated areas of Lake Sangchris in 1975, 1976, and 1977.

	Unheated Area							Heated Area						
		Mean	Mean	Gonad Stage					Mean	Mean	Gonad Stage			
Date	N	Temp. (°C)	GSI	3	4	5	6	N	Temp. (°C)	GSI	3	4	5	6
1975		Largemouth Bass												
26 Feb.	0	4	...	...	...	...	...	2	12	4.72	2	...	...	...
19 Mar.	3	10	4.19	3	...	...	...	12	12	5.19	12	...	...	...
08 Apr.	3	8	7.02	...	3	...	...	4	15	7.31	1	3	...	...
01 May	10	18	7.58	...	10	...	...	5	22	5.00	...	4	1	...
22 May	9	24	2.58	...	...	...	9	14	27	2.66	...	...	1	13
1977		Largemouth Bass												
17 Mar.	4	13	5.22	4	...	...	...	7	21	6.68	7	...	...	...
29 Mar.	4	9	7.14	4	...	...	...	6	19	7.12	6	...	...	...
13 Apr.	6	16	10.21	...	6	...	...	6	21	8.58	...	2	4	...[b]
21 Apr.	6	20	7.83	...	5	1	...	6	24	6.46	...	3	3	
25 Apr.	6	18	7.52	...	4	2	...	6	23	5.41	...	...	3	3
04 May	6	19	4.77	...	2	2	2	4	21	3.56	...	...	...	4
11 May	6	21	5.42	...	...	...	6	...	...	...	...	...	...	...
1975		White Bass												
26 Feb.	0	...	...	...	...	...	...	1	12	9.48	1	...	...	...
20 Mar.	2	6	9.48	2	...	...	...	22	14	10.48	...	12	10	...
08 Apr.	1	8	8.33	1	...	...	...	8	15	14.94	...	6	2	...
01 May	0	...	...	...	...	...	...	3	22	6.05	...	...	...	3
1975		Carp												
26 Feb.	4	4	11.08	4	...	...	...	12	12	12.60	12	...	...	...
19 Mar.	13	10	6.78	13	...	...	...	8	13	12.04	8	...	...	...
01 May	5	18	9.44	...	5	...	...	6	22	15.64	...	6	...	...
22 May	7	24	13.44	...	6	...	1	14	28	16.64	...	9	3	2
10 June	11	24	7.77	...	3	...	8	9	26	9.58	...	7	...	2
02 July	4	32	10.08	...	1	...	3	1	36	2.60	...	...	...	1
1976		Carp												
24 Feb.	6	9	12.58	6	...	...	...	7	9	11.50	3[a]	...	...	...
19 Mar.	12	9	11.01	12	...	...	...	14	14	14.38	14	...	...	...
08 Apr.	8	14	11.16	7	1	...	...	5	10	11.60	3	2	...	...
30 Apr.	4	17	11.79	3	1	...	...	5	22	17.84	1	4	...	...
19 May	7	17	15.39	3	4	...	...	15	23	17.14	1	9	4	1
09 June	2	25	16.32	...	1	1	...	10	30	13.51	...	4	2	4
30 June	10	26	4.95	...	2	...	8	5	29	18.04	...	3	1	1

[a] Gonad maturity stages were not assigned to four fish in the sample.

[b] Several obviously spent females were returned to the lake.

young were 2 weeks old. They found a major cause of egg mortality was a drop in water temperature during this critical period. In Lake Sangchris, short-term adverse weather conditions would have less effect on year class strength because (1) there were two separate spawning periods from 1 to 3 weeks apart and (2) a sudden drop in air temperature has little effect on the water temperature in the discharge arm. Production of consistent year classes had undoubtedly been a key element in maintaining a satisfactory largemouth bass population in this cooling lake over an extended time.

Results of this study which show earlier reproduction by largemouth bass in the heated area differ somewhat from those of Bennett & Gibbons (1975). They were unable to demonstrate a difference in the reproductive cycle of largemouth bass between heated and unheated areas of Par Pond by using a gonosomatic index; however, they did find that young-of-the-year bass in the heated area were significantly larger, suggesting that reproduction in the thermal area may have been accelerated. Accelerated gonadal development has been shown by fishes inhabiting other waters warmed by thermal discharges. At Thomas Hill Reservoir in Missouri, Witt et al. (1970) reported that a thermal discharge affected the rate of gonad development and accelerated the time of spawning by largemouth bass. Marcy (1976) found that ovaries of female brown bullheads (*Ictalurus nebulosus)* and white catfish (*I. catus)* developed unseasonably early during winter in the discharge canal of a nuclear power plant on the Connecticut River as compared with those of females overwintering in the cooler waters outside.

In 1975, insufficient numbers of white bass were captured from the intake arm of Lake Sangchris to permit a comparison of spawning time between heated and unheated areas. Results of catch-per-unit-effort sampling suggested that white bass migrated to the heated area to spawn in the flowing water of the discharge canal. Peak GSI values were found in fish from the discharge canal on 8 April (GSI = 14.94), but analysis of gonad maturity stages showed that 10 of the 22 fish captured on 20 March were already running eggs (Table 10). The discrepancy between the two methods may have occurred because the congregation of fish in the discharge canal was part of a spawning migration, and the fish vacated the canal shortly after spawning. No spent fish were collected in the 20 March or 8 April samples. In 1975, spawning by white bass apparently began near 20 March at a water temperature of 14°C and continued through 8 April.

This spawning date compares favorably with that of Webb & Moss (1968), who found that white bass spawning began in mid-March at a water temperature of 12°C and lasted for 1–1.5 months at Center Hill Reservoir in Tennessee. Spawning by white bass probably occurs earlier in Lake Sangchris than in nearby reservoirs because of the unusual migration to the discharge canal, where water temperatures are elevated.

Analysis of gonadal development by female carp revealed that peak GSI values occurred on 22 May in heated and unheated areas in 1975 (Fig. 7). Data on gonad maturity were in agreement and indicated that carp spawning began on 22 May in both heated and unheated areas at 28° and 24°C, respectively (Table 10). In 1976, two peaks in gonosomatic indices were found for carp from the heated area. The first occurred on 30 April at a temperature of 22°C and the second on 30 June at 29°C (Fig. 7). In the unheated area a single peak in the gonosomatic index occurred on 9 June at 25°C. Comparison of these data with the gonad maturity stages suggested that in 1976 carp spawning began in the heated area during the first week of May, approximately 1 month earlier than in the unheated area. These data also indicated that during 1976 there was either an extended spawning period in the heated area, or two distinct spawning periods, approximately 2 months apart.

A second spawning by carp in one season is not unusual in North American waters (Carlander 1969). Shields (1957)

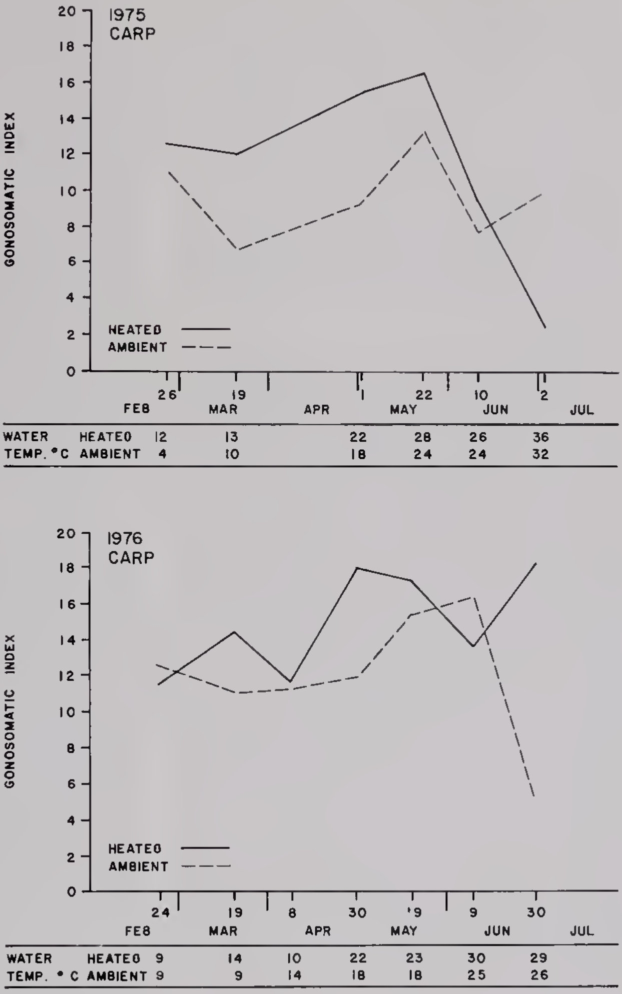


Fig. 7.—Gonosomatic indices for female carp in 1975 and 1976 from heated and unheated areas of Lake Sangchris and surface water temperatures on sampling dates.

WATER TEMP. °C	HEATED	12	13	22	28	26	36
	AMBIENT	4	10	18	24	24	32

WATER TEMP. °C	HEATED	9	14	10	22	23	30	29
	AMBIENT	9	9	14	18	18	25	26

found that observing the progressive gonadal development of adult female carp was a good method of predicting the major period of spawning, and he considered water temperature to be the primary environmental stimulus affecting maturation. In Lake Sangchris, carp spawning began in both heated and unheated areas at water temperatures between 22° and 28°C, somewhat higher than the range (16.1°–23.3°C) within which carp had been reported to spawn in other waters (Shields 1957, Swee & McCrimmon 1966, Mauck & Summerfelt 1971, Jester 1974). Comparison of those temperatures suggested that carp spawned late in Lake Sangchris relative to the advanced spawning periods of other species. As a result, the lower suvival rate of carp may have occurred due to higher predation and greater competition for food resources from the advanced young of other species, which may partially account for their poor reproductive success.

Quantitative fish population surveys (catch-per-unit-effort samples) provided evidence of unsuccessful reproduction by carp in Lake Sangchris. Of the 1,837 carp collected from 1974 to 1976, less than 1 percent were smaller than 260 mm in total length. A difference in the fecundity of carp from the cooling lake was eliminated as a factor affecting reproductive success because (1) no difference was found between carp from heated and unheated areas and (2) carp from Lake Sangchris contained significantly more eggs than carp of similar sizes from a nearby unheated reservoir (Sule et al. 1979). Since field observations and/or the examination of gonads confirmed that annual spawning by carp occurred in Lake Sangchris, we concluded that extremely high mortality rates in the vulnerable egg, fry, and fingerling stages were responsible for the lack of recruitment.

Stable water levels, a characteristic of Lake Sangchris, could be related to the poor reproductive success of the carp population. Studies by Shields (1957) and Swee & McCrimmon (1966) indicated that fluctuating water levels were a major environmental variable affecting carp spawning and the survival of carp eggs. Carp prefer to spawn in shallow, freshly inundated, vegetational areas, a type of habitat normally unavailable in Lake Sangchris. Consequently, carp in Lake Sangchris probably spawned in aquatic vegetation, where their eggs encountered excessively high predation by a large population of stunted bluegills. Mraz & Cooper (1957*a* and *b*) found that the reproduction of young carp was surprisingly low in ponds containing bass, bluegills, and crappies in comparison with that in ponds stocked with carp alone.

In 1975, an abnormal physiological condition in the reproductive organs of female carp was found during the study of carp reproductive cycles in Lake Sangchris. The abnormal condition occurred in large carp, averaging 540 mm in total length and 1.876 kg in weight, which should have been sexually mature. Since there was no indication of the normal process of sex cell maturation in the ovaries, the condition was descriptively defined as degenerate. The degenerate ovaries consisted of flaccid sacs containing gelatinous material and loose connective tissue interspersed with a few undeveloped eggs. Female carp with degenerate ovaries were not emaciated and could not be distinguished from normal females by external examination.

A total of 117 female carp was examined during 1975, and 23 (19.6 percent) had degenerate ovaries. Degenerate ovaries occurred in 5 of 55 carp from the heated area and in 18 of 62 carp from the unheated area. The proportion of carp with normal and degenerate ovaries from the intake and discharge arms was compared by chi-square analysis in a 2 x 2 contingency table. Results of this test showed that there were significantly more ($P \leq 0.05$) carp with degenerate ovaries in the unheated area (chi-square = 6.13, 1 df), indicating that the abnormal condition was not related to the discharge of heated water into the lake.

It was hypothesized that the degenerate ovarian condition of the carp in this cooling lake was related to mercury contamination from the coal burned by the Kincaid Generating Station. During the combustion process, mercury is vaporized and distributed through the air to the watershed surrounding the power plant. Anderson & Smith (1977) found significantly higher concentrations of mercury in sediments from Lake Sangchris deposited after the plant had begun operation in 1967 than in those deposited in earlier years.

Analyses of three carp with normal ovaries and three with degenerate ovaries revealed a mean concentration of total mercury of 0.194 ppm (range 0.126–0.252 ppm) for fish with normal ovaries and 0.256 ppm (range 0.188–0.375 ppm) for carp with degenerate ovaries. Mercury levels in carp with both normal and degenerate ovaries were relatively low, below the 0.5 ppm tolerance limit established for mercury in fish by the U. S. Food and Drug Administration. The mean concentration of mercury found in carp with both normal and abnormal ovaries was, however, slightly higher than that found in seven other species of fishes from Lake Sangchris by Anderson & Smith (1977), who concluded that some unidentified factor was suppressing mercury accumulation by the fish. The small difference in mercury concentrations between carp with normal and carp with degenerate ovaries suggested that mercury contamination was not the cause of the abnormal condition. During *in vitro* incubation of carp eggs, Huckabee & Griffith (1974) found that 3.0 ppm of mercury was the lowest concentration of mercury that had an effect on hatchability. Although we realize that these data are not directly comparable to the much lower concentration of mercury we found in carp muscle tissue, they do indicate that mercury contamination probably had little effect on the reproductive success of carp in Lake Sangchris.

Since carp were assumed to be feeding heavily on bottom organic material, we hypothesized that pesticide residues were being concentrated in the carp, causing the degenerate ovarian condition and affecting the viability of gametes. Of the 13 pesticides tested for in carp tissues, only dieldrin and p,p^1-DDE showed any appreciable accumulations, the concentrations of the others all being less that the detection limit (Table 11). Among the three tissues examined, the greatest pesticide concentration was usually found in the gonad, with liver having intermediate levels, and muscle having the least residue. In a comparison of males and females, there was little difference between pesticide levels in liver and muscle tissue, but male gonads contained much higher residues than female gonads. In general, normal carp (males and females) from the heated areas had slightly higher average pesticide concentrations than normal fish from unheated areas. Female carp with degenerate ovaries contained lower levels of DDE and dieldrin in their tissues than did female carp with normal ovaries.

The pesticide levels found in carp muscle tissue were quite low, much less than the U. S. Food and Drug Administration limit of 0.3 ppm for dieldrin in fish flesh intended for human consumption. No comparable data on pesticide residues in carp reproductive tissues or their effects on reproduction were found; so we could not exclude the possibility that the level of residues found was affecting the viability of gametes. However, the results of this analysis did indicate that the degenerate ovarian condition of carp was not related to pesticide accumulation.

Mercury and pesticide contamination were thus eliminated by results of chemical analyses as factors affecting the degenerate ovarian condition of carp. The heated effluent was disregarded as the causative factor, because carp with degenerate ovaries were significantly more abundant in unheated areas. These data allowed us to discount a relationship between the degenerate ovarian condition and several variables peculiar to cooling lakes. The age and growth of carp in Lake Sangchris was then suspected as being the primary factor associated with the degenerate ovarian condition, but the fish could not be accurately aged. Annuli on carp scales were indistinct and difficult to interpret due to the influence of the thermal effluent and because carp growth was apparently very slow. Numerous annuli were present on the scales of almost all carp, and there was a good possibility that many of these fish were between 10 and 15 years of age. Recaptures of tagged carp indicated that some individuals actually lost weight over a year's time and that the overall growth of carp was very slow (Tranquilli et al. 1981*b*). By comparing the growth of tagged and untagged carp in a controlled pond environment, Tranquilli et al. (1979*c*) determined that the tagging procedure had no adverse effect on growth. From this limited age and growth information, we surmised that carp with degenerate ovaries were old individuals which were not growing and had perhaps passed the peak reproductive age. In the early spring, it seemed likely that some of these fish would not have the large energy reserves required for egg production.

Investigations concerning the lack of successful carp reproduction continued during 1977, when a pond containing no other fishes was stocked on 4 May with four male and five female carp from Lake Sangchris. On 14 June, more than 6,000 young-of-the-year carp, ranging in size from 25 to 60 mm in total length, were collected in one shoreline seine haul from the 0.2-ha pond. Reproduction was obviously highly successful in this pond, where food was plentiful and predation by other fishes was not a factor.

Table II.—Pesticide residues (ppm) in carp from Lake Sangchris. Carp with normal (N) and degenerate (D) gonads were collected from heated (H) and unheated (U) areas.

Fish Number	Sex	Lake Area	Gonad Type	Length(mm)	Weight(g)	Gonad DDE	Gonad Dieldrin	Liver DDE	Liver Dieldrin	Muscle DDE	Muscle Dieldrin
1	M	U	N	523	1,590	0.1022	0.0438	0.0202	. . .	0.0066	0.0033
2	M	U	N	513	1,880	0.0302	0.0104	. . .	. . .	0.0052	0.0052
3	M	U	N	525	1,615	0.0445	0.0636	0.0128	. . .	0.0046	0.0074
Average						0.0590	0.0393	0.0110	0.0000	0.0055	0.0053
4	M	H	N	515	1,480	0.0970	0.0970	0.0677	0.0112	0.0055	0.0093
5	M	H	N	528	1,660	0.0385	0.0385	0.0218	0.0083	0.0134	0.0144
6	M	H	N	558	2,250	0.0381	0.0858	0.0491	0.0491	. . .	0.0098
Average						0.0579	0.0738	0.0462	0.0229	0.0063	0.0112
7	F	U	N	532	1,945	0.0010	0.0010	0.0020	. . .	. . .	0.0031
8	F	U	N	562	2,025	0.0120	. . .	. . .	. . .	. . .	0.0159
9	F	U	N	521	1,790	0.0053	0.0049	. . .	. . .	. . .	0.0069
10	F	U	N	450	1,310	0.0123	0.0146	0.0049	0.0212	0.0098	0.0172
11	F	U	N	530	1,570	0.0086	0.0100	0.0089	. . .	. . .	0.0048
Average						0.0078	0.0061	0.0032	0.0042	0.0020	0.0096
12	F	H	N	527	1,840	0.0102	0.0204	0.0155	0.0283	. . .	0.0100
13	F	H	N	562	2,190	0.0102	0.0110	0.0089	. . .	0.0050	0.0109
14	F	H	N	515	1,515	0.0168	0.0168	0.0187	. . .	0.0140	. . .
Average						0.0124	0.0161	0.0150	0.0094	0.0063	0.0105
15	F	U	D	560	1,980	0.0024	0.0020	. . .	. . .	. . .	. . .
16	F	U	D	513	1,645	0.0018	0.0201	0.0042	. . .	0.0022	. . .
Average						0.0021	0.0111	0.0021	0.0000	0.0011	0.0000
17	F	H	D	564	2,565	0.0063	0.0096	0.0010	. . .	0.0019	0.0019
18	F	H	D	528	1,560	0.0038	0.0114	. . .	. . .	0.0014	0.0031
19	F	H	D	413	900	0.0100	0.0250	. . .	. . .	0.0146	. . .
20	F	H	D	544	1,580	0.0046	0.0052	. . .	. . .	0.0045	. . .
Average						0.0062	0.0128	0.0003	0.0000	0.0057	0.0013

Eggs stripped from a ripe female carp captured from Lake Sangchris on 11 May 1977 were fertilized and incubated in the laboratory at 26°C. A subsample of the eggs from this female (N = 193 eggs) gave an *in vitro* hatchability of 87 percent. Apparently normal development of these larvae occurred until they reached the free-swimming stage, at which time the experiment was terminated.

In summary, the lack of successful carp reproduction in Lake Sangchris appears to be related to a number of factors operating concurrently. These include a relatively late spawn by carp in relation to the advanced spawn of other species; stable water levels, which were not conducive to carp spawning success; excessively high predation on eggs and larvae by a stunted bluegill population; and a degenerate ovarian condition which apparently prevented spawning by approximately 20 percent of the females.

GROWTH, WEIGHT-LENGTH RELATIONSHIPS, AND CONDITION INDICES

Growth rates of fishes in Lake Sangchris were extremely difficult to determine by conventional methods because (1) the thermal discharge affected annual growth marks on scales (Tranquilli et al. 1981*b*), and (2) results of fish population surveys (catch-per-unit-effort samples), recapture of tagged individuals (Tranquilli et al. 1981*b*), and observations of fish via radiotelemetry (Tranquilli et al. 1981*a*) all showed considerable movement by fishes between heated and unheated areas. Consequently, most of the information regarding the growth of Lake Sangchris fishes appears elsewhere as the result of independent studies. These specialized studies included the results of tagging (Tranquilli et al. 1981*b*, Joy & Tranquilli 1979*a*), an analysis of growth by juvenile largemouth bass in heated and unheated areas (Sule 1981), and a comparison of length-frequency distributions of the first two year classes with contemporary data gathered from Lake Shelbyville, a nearby unheated reservoir (Joy & Tranquilli 1979*b*). A major objective of this study was to present some typical length-frequency distributions to characterize growth and to bring together the available growth information for fishes of Lake Sangchris.

Two growth related indices, condition factors K(TL) and weight-length relationships, are often used by fishery biologists as measures of the relative plumpness or well-being of fishes in particular habitats and as general growth descriptors. In this study these growth indices were used to evaluate effects of thermal discharge on Lake Sangchris fish populations.

MATERIALS AND METHODS

Length-frequency distributions for all species except channel catfish were compiled from fish surveys taken in September 1976. Fishes were collected by the combination of quantitative methods previously described for fish population samples, including the use of seines, experimental gill nets, and alternating-current electrofishing. Too few channel catfish were collected by these methods in September 1976 to provide a representative sample; so the length-frequency distributions for that species were compiled from data from a sample collected in a cove by the use of rotenone on 17 August 1976. The rationale for presenting length-frequency distributions from September population samples was that catches for most species were relatively high at that time and young-of-the-year fish were well represented.

The use of length-frequency distributions as the basis for growth assessment of fishes in Lake Sangchris rather than calculated length at each age was largely unavoidable. Although several disadvantages of this method were pointed out by Joy & Tranquilli (1979*b*), including the fact that fish were still growing in September, frequency distributions did provide some basis for the generalized description of growth patterns by the most abundant species.

Linear least-squares regressions for evaluation of weight-length relationships were computed by regressing log weight (g) on log total length (mm) (Carlander 1977) for eight of the more abundant species in the lake. The species examined were carp, gizzard shad, largemouth bass, bluegill, white bass, yellow bass, channel catfish, and freshwater drum. The formula used was:

$$\log wt = B0 + B1 \log TL$$

where B0 represents the intercept and B1 the slope. In this type of analysis, the slope serves as a measure of change in body form relative to total length. For each species studied, a weighted weight-length relationship was determined from all individuals collected in population surveys taken at bimonthly intervals (July, September, and November 1975) from each of the six sampling stations (Fig. 1). The regressions were weighted by the number of observations involved in calculating B0 and B1.

The intercepts and slopes of these regressions were tested and found to be normally distributed, and we assumed normality of variance. The data were then analyzed using the Statistical Analyses System (SAS) General Linear Model (GLM) procedure on an IBM 360/75 computer (Barr et al. 1976). A multivariate analysis of variance, which simultaneously considered the relationship between the intercepts and slopes, was used to compare the weight-length regressions derived for each species. In the statistical model, months were assumed random and stations fixed. Since there was unequal replication among the samples, type III regression sums of squares were used. The intercepts and slopes were reported as least-squares means, which are estimates of the arithmatic means that would be expected if equal replication had been obtained.

Condition factors were calculated for bluegill, gizzard shad, and yellow bass. To reduce variation in fish condition values for these species resulting from differences in size (age), sex, and state of sexual maturity, only males falling within a specified size range were included in the sample. Those size ranges (total length) were for bluegill 100–140 mm, for gizzard shad 160–200 mm, and for yellow bass 100–140 mm. Each month we attempted to collect a sample of 25 fish of each species at each station.

The condition factor was calculated according to this formula given by Carlander (1977):

$$K(TL) = \text{weight (grams)} \times 100{,}000/\text{total length (mm)}^3$$

Condition indices were tested and found not to be normally distributed for bluegill and gizzard shad. As a result, power transformations (Box & Cox 1974) were applied to the data prior to statistical analyses. With these transformations, as the observed value increased, the transformed value decreased; therefore, the relationships observed on the transformed scale were opposite those observed on the real scale. For ease of interpretation, however, presentation and discussion of condition indices for all three species will be in untransformed terms. Since the condition index data were not normally distributed, arithmatic means were presented without standard deviations as estimates of variability.

Condition data were analyzed using the SAS system GLM procedures (Barr et al. 1976) on an IBM 360/75 computer. A two-way analysis of variance was performed using a mixed model, with stations being fixed and months assumed random. Type III (estimable hypotheses) regression sums of squares were used because the data were imbalanced.

The following comparisons among stations were made for each species to test hypotheses about condition indices of fish from heated and unheated stations: (C1) Station 1 vs. Station 5, a comparison of the intake and discharge canals; (C2) stations 1 and 2 vs. stations 4 and 5, a comparison of the intake arm with the discharge arm; (C3) stations 1, 2, and 7 vs. stations 3, 4, and 5, a comparison of the entire unheated or nearly unheated zone with the entire thermally affected area of the cooling lake; (C4) Station 2 vs. Station 7, a comparison of similar habitats in the intake and control arms;

and (C5) Station 4 vs. Station 7, a comparison of similar stations in the discharge and control arms. Index values determined for fish in November were compared with those in July to test for (1) differences in warm and cold months (K1) and (2) seasonal effects occurring at specific heated and unheated locations.

RESULTS AND DISCUSSION

Growth

The Lake Sangchris carp population was composed almost entirely of large individuals (Fig. 8). Results of quantitative fish surveys taken at bimonthly intervals over a 3-year period revealed that less than 1 percent of the 1,837 carp collected were less than 260 mm in total length. These data showed that reproduction by this species was unsuccessful from 1974 to 1976. Additional information regarding the lack of recruitment by carp is presented in this report in the section entitled "Spawning Time and Reproduction." An analysis of carp growth based on the recapture of tagged fish indicated that little, if any, growth by larger individuals of this species was occurring (Tranquilli et al. 1981*b*).

The length-frequency distribution for gizzard shad shows one mode near 90 mm, which probably represents growth of age 0 fish (Fig. 9). In a comparison of growth by gizzard shad in Lake Sangchris and unheated Lake Shelbyville, Joy & Tranquilli (1979*b*) reported little difference in growth at age 0, but found that in Lake Sangchris growth of age I+ and older shad was slow in relation to their growth in Lake Shelbyville and perhaps in relation to their growth in other waters. This fact could be very important, because larger shad are less desirable as forage fish and because the age of a reservoir is positively correlated with shad crops and negatively correlated with sport fish harvest (Jenkins 1967). The possibility that the life span of these forage fish may be shortened in cooling lakes is suggested as an area worthy of further investigation.

Despite their uniformly small size (Fig. 10), yellow bass were one of the most abundant species in Lake Sangchris. They ranked fifth among all species in order of abundance (biomass) and by weight constituted 5.2 percent of the total catch per unit effort. As depicted in Fig. 10, the growth of yellow bass was severely limited. Although reproduction by this species was good, by September only a single mode was apparent in the length-frequency distribution. In fish population

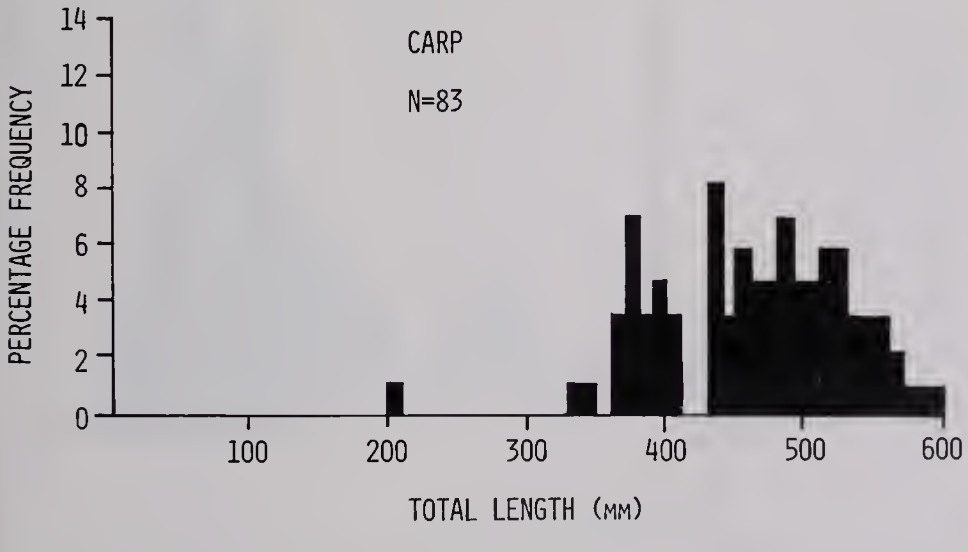


Fig. 8.—Length-frequency distribution for 83 carp collected from Lake Sangchris in September 1976.

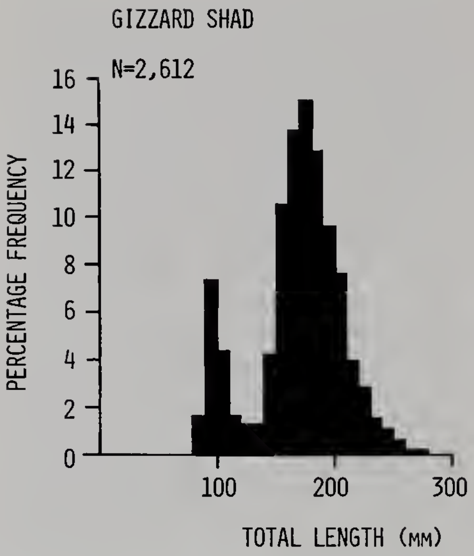


Fig. 9 —Length-frequency distribution for 2,612 gizzard shad collected from Lake Sangchris in September 1976.

surveys conducted from 1974 to 1976, less than 6 percent of the more than 15,000 yellow bass collected were larger than 160 mm (6.3 in.). Sule et al. (1981) reported that as a result of food resource partitioning among the various fishes in Lake Sangchris, the relatively small-sized yellow bass were relegated to feeding primarily upon zooplankton throughout their life history rather than switching to fish (a more nutritious food) at larger sizes. This type of niche segregation was suggested as a mechanism which may have suppressed growth and contributed to further stunting of the yellow bass population.

Although comprised of small individuals, the bluegill population in Lake Sangchris ranked fourth in abundance (biomass) and constituted 7.1 percent of the total catch per unit effort by weight. The September length-frequency distribution revealed a mode near 50 mm, which apparently reflected growth of age 0 fish, and another mode at approximately 90 mm, which probably represented growth of age 1+ and older fish (Fig. 11). Joy & Tranquilli (1979*b*) concluded that the growth of bluegill at age 0 in Lake Sangchris in 1976 was equal to, but thereafter was probably less than,

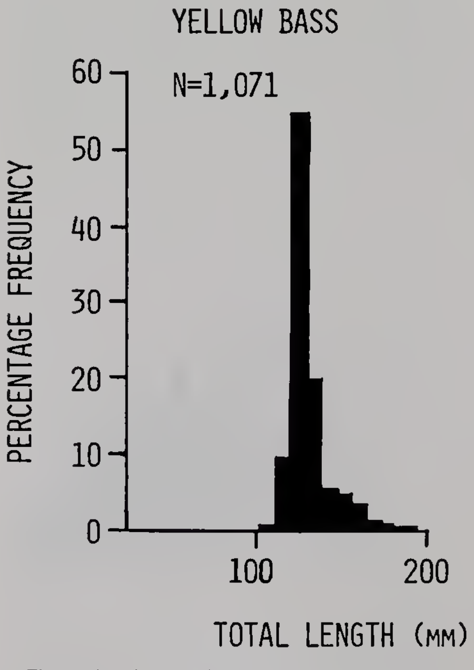


Fig. 10.—Length-frequency distribution of 1,071 yellow bass collected from Lake Sangchris in September 1976.

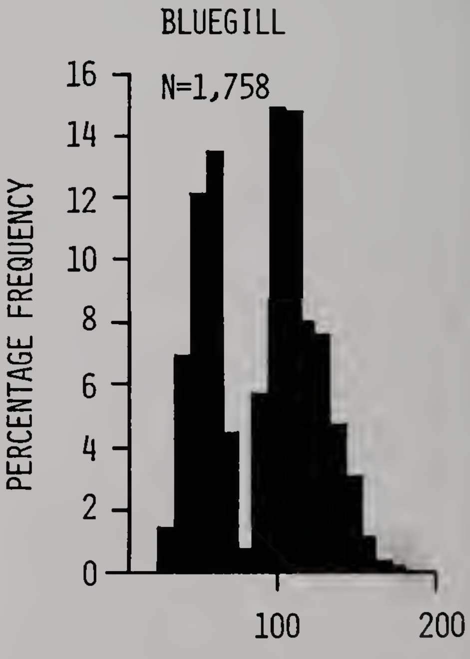


Fig. 11.—Length-frequency distribution for 1,758 bluegill collected from Lake Sangchris in September 1976.

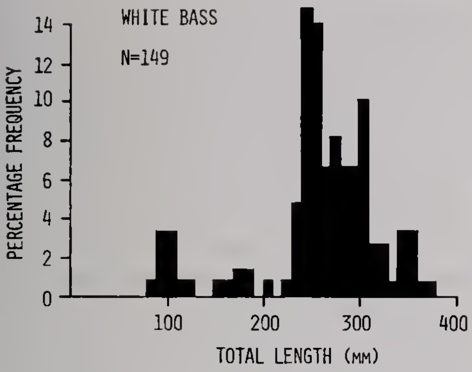


Fig. 12.—Length-frequency distribution for 149 white bass collected from Lake Sangchris in September 1976.

the average annual growth of bluegill in Lake Shelbyville and other waters. More than 20,000 bluegills were captured from Lake Sangchris in fish population surveys (1974–1976), and less than 2 percent were larger than 160 mm, providing further evidence of the severe stunting of this species. Food habit analyses (Sule et al. 1981) indicated that the stunting of bluegills in Lake Sangchris was partially the result of extensive intra- and interspecific competition among large populations of small fishes (particularly yellow bass) for limited aquatic insect food resources.

The white bass length-frequency distribution (Fig 12) showed a bimodal distribution for age 0 fish, ranging in size from 80 to 190 mm. Another mode at approximately 240 mm represented age I + fish. Joy & Tranquilli (1979*b*) reported that in 1975 and 1976 white bass achieved about the same growth to age II in both Lake Sangchris and Lake Shelbyville, and that this growth was greater than the average growth for white bass in other waters. The recapture of 14 tagged white bass revealed that growth was unaffected by movements between heated and unheated areas in Lake Sangchris and that growth was relatively rapid (Tranquilli et al. 1981*b*).

Age 0 largemouth bass were represented in the September 1976 length-frequency distribution by fish ranging from 50 to 190 mm (Fig. 13). It was assumed that fish between 190 and 290 mm represented the growth of age 1 + fish. Consistently strong year classes of largemouth bass were produced in Lake Sangchris; dominant year classes were never observed.

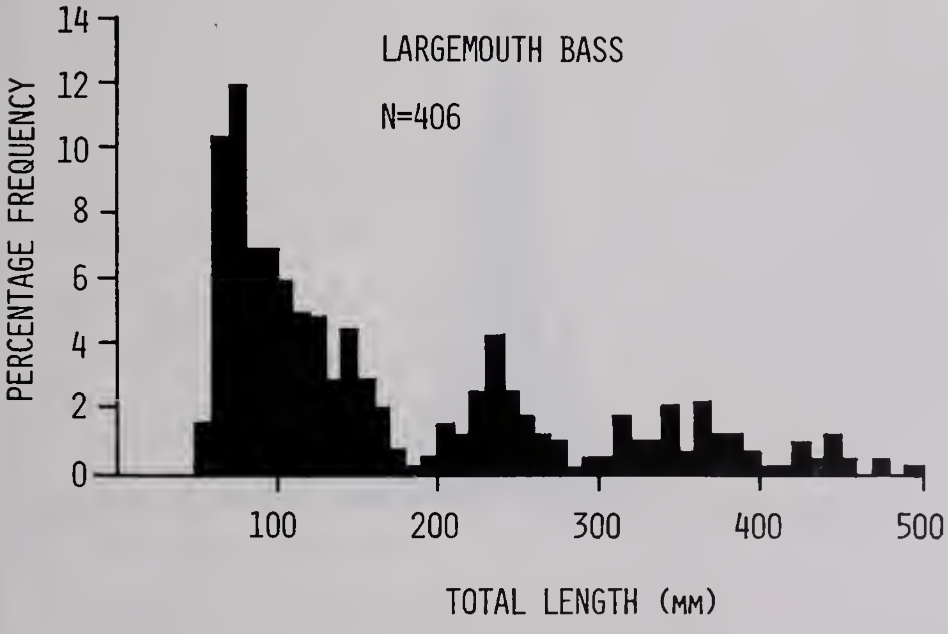


Fig. 13.—Length-frequency distribution for 406 largemouth bass collected from Lake Sangchris in September 1976.

Comparison of length-frequency distributions determined from September 1975 and 1976 samples suggested that largemouth bass growth at ages 0, I+, and II+ was more rapid in Lake Sangchris than in Lake Shelbyville (Joy & Tranquilli 1979*b*). However, this analysis allowed no precise determination of average annual growth by largemouth bass in Lake Sangchris which could be compared with that in other waters. Therefore, a curve was generated from growth data obtained from tagged fish recaptured after one growing season (Joy & Tranquilli 1979*a*). It indicated that in Lake Sangchris bass reached mean lengths of 121, 274, 358, 411, 444, and 465 mm at ages I through VI, respectively. From these data it was determined that after age I the estimated annual growth of Lake Sangchris largemouth bass was more rapid than the average annual growth of the species in Lake Shelbyville, other Illinois waters in general (Bennett & Thompson 1939, Starrett & Fritz 1965, and Carlander 1977), and waters of the upper Midwest, including Illinois (Carlander 1977). Joy & Tranquilli (1979*a* and 1979*b*) suggested that the extended growing season caused by the heated discharge was the major reason for the greater growth exhibited by largemouth bass in Lake Sangchris in comparison with their growth in Lake Shelbyville.

Sule (1981) examined the growth of young-of-the-year largemouth bass in heated and unheated areas of Lake Sangchris. He found that growth rates of juvenile fish in the two areas were similar throughout most of the study period. However, at the end of the normal growing season fish from the heated area continued to grow, whereas those from the unheated area did not.

Annual growth of tagged largemouth bass in heated and unheated areas of Lake Sangchris was also studied by Joy & Tranquilli (1979*a*) and was found to be significantly greater in heated areas. Estimated lengths at ages I through VI, respectively, were 138, 278, 380, 434, 462, and 477 mm in heated areas and 100, 260, 325, 378, 415, and 441 mm in

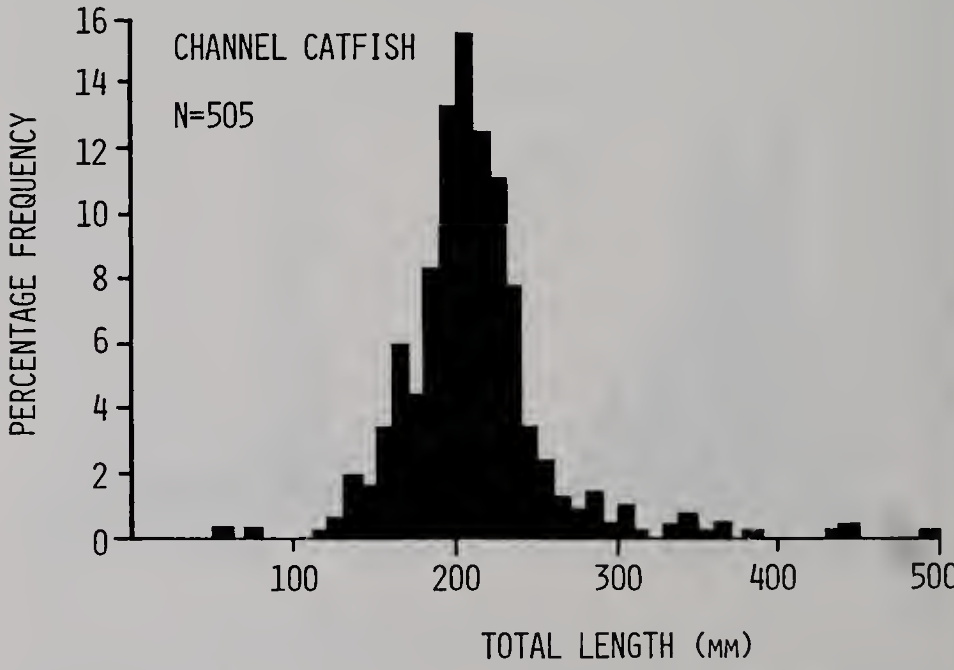


Fig. 14.—Length-frequency distribution for 505 channel catfish collected from Lake Sangchris in August 1976.

unheated areas. These growth differences were attributed to differences in length of the growing season in Lake Sangchris, which was approximately 245 days in heated areas and 194 days in unheated areas.

As mentioned earlier, the channel catfish population of Lake Sangchris has been able to sustain itself through natural reproduction under somewhat unusual circumstances since the original stocking. Age 0 channel catfish were represented in the August 1976 length-frequency distribution (Fig. 14) by a few fish ranging in size from 50 to 80 mm, while age I+ fish were represented by the mode occurring at 210 mm. By the comparison of samples collected in September 1975 and 1976, Joy & Tranquilli (1979*b*) concluded that the mean length of channel catfish at age II was slightly greater in Lake Sangchris than in Lake Shelbyville and that the growth of this species (at least to age II) in Lake Sangchris was therefore greater than its average growth in other waters.

In September 1976 only 20 freshwater drum were collected, and so a representative length-frequency distribution was not compiled. From analysis of September 1975 samples, Joy & Tranquilli (1979*b*) reported that age 0 drum exhibited a bimodal distribution ranging from 110 to 140 mm and that age I+ fish were represented by a mode at 200 mm. From this information, they concluded that the growth of freshwater drum to age II was greater in Lake Sangchris than in Lake Shelbyville.

Weight-Length Relationships

Weight-length relationships were derived for eight species of fishes collected from six sampling stations (Fig 1) located in heated and unheated areas of Lake Sangchris during July, September, and November 1975 (Table 12). As expected, the slopes of the regressions for all eight species were near 3.0 (Carlander 1969 and 1977).

The multivariate statistical analysis, which simultaneously considered the relationship of the slope and the intercept of each regression, showed that there was no significant difference among stations for the weight-length relationship of any species examined (Table 13). However, significant differences were found among months for the bluegill ($P < 0.01$) and largemouth bass ($P < 0.05$) regressions. While difficult to interpret, these data suggested that seasonal variation (availability of food resources or the appearance and growth of young-of-the-year fish in the samples) had more effect on weight-length regressions of these species than the presence of a thermal effluent.

Working with five of the species examined in this study, Rutledge (1975) found no significant differences in calculated weights of condition (derived by weight-length regressions) for seven species of fish captured in heated and unheated areas of Lake Arlington, Texas. Bennett (1972) reported that black crappies (*Pomoxis nigromaculatus*) from heated areas of a reservoir receiving a thermal effluent in South Carolina had a significantly higher weight-length relationship, indicating that the heated water provided a more suitable environment.

Condition Indices

Condition factors were determined for 632 bluegills, 684 gizzard shad, and 294 yellow bass in 1976. Mean condition values ranged from 1.481 to 2.001 for bluegills (Table 14), from 0.776 to 1.016 for gizzard shad (Table 15), and from 0.986 to 1.204 for yellow bass (Table 16). To assess thermal discharge effects accurately, we reduced variation in condition values by including only male fish of a given size range (age) in our samples. Consequently, our condition values are not directly comparable to those found in the literature, which include fish of many sizes and of both sexes.

Yellow bass condition factors were normally distributed, but power transformations were needed to establish the normality of bluegill and gizzard shad index values. Analysis of variance revealed no difference in condition indices among stations for either bluegill or yellow bass (Table 17). Gizzard shad condition factors were significantly different ($P < 0.01$) among stations. Additional contrasts between heated and unheated stations revealed that (1) mean

Table 12.—Least-squares mean and standard error for the intercept (B0) and slope (B1) of the weight-length relationship (log wt = B0 + B1 log TL) for fishes collected from Lake Sangchris in 1975.

		Gizzard Shad	Largemouth Bass	White Bass	Yellow Bass	Bluegill	Channel Catfish	Carp	Freshwater Drum
Month									
July	B0	-10.8535 ± 0.5107	-11.2986 ± 0.2878	-12.5244 ± 0.8825	-10.3851 ± 0.7119	-10.2127 ± 0.3601	-13.2781 ± 0.5205	-9.8380 ± 0.7472	-11.4273 ± 0.7782
	B1	2.8611 ± 0.0955	2.9935 ± 0.0599	3.2183 ± 0.1566	2.8060 ± 0.1401	2.8400 ± 0.0765	3.2601 ± 0.0891	2.7550 ± 0.1207	2.9991 ± 0.1473
Sept.	B0	-10.5941 ± 0.5107	-12.6025 ± 0.2878	-12.0877 ± 0.7740	-11.4078 ± 0.5381	-11.5622 ± 0.3601	-13.5634 ± 0.7080	-8.9288 ± 0.5493	-11.2492 ± 0.5651
	B1	2.8115 ± 0.0955	3.2490 ± 0.0599	3.1218 ± 0.1373	3.0021 ± 0.1059	3.1131 ± 0.0765	3.3117 ± 0.1212	2.6070 ± 0.0887	2.9655 ± 0.1070
Nov.	B0	-11.6560 ± 0.5107	-12.1356 ± 0.2878	-12.3391 ± 0.7740	-11.7952 ± 0.5381	-12.2362 ± 0.3601	-14.8385 ± 0.6159	-9.9907 ± 0.6500	-12.2562 ± 1.1826
	B1	3.0115 ± 0.0955	3.1587 ± 0.0599	3.1945 ± 0.1373	3.0730 ± 0.1059	3.2476 ± 0.0765	3.5319 ± 0.1055	2.7831 ± 0.1050	3.1418 ± 0.2238
Station									
1	B0	-11.4183 ± 0.7222	-12.1709 ± 0.4070	-11.0587 ± 1.0946	-11.9390 ± 0.9701	-10.8197 ± 0.5092	-13.7092 ± 0.7361	-10.0542 ± 0.7769	-11.4178 ± 1.5062
	B1	2.9582 ± 0.1350	3.1719 ± 0.0847	2.9291 ± 0.1942	3.1056 ± 0.1909	2.9547 ± 0.1082	3.3421 ± 0.1260	2.7921 ± 0.1255	2.9971 ± 0.2851
2	B0	-12.0029 ± 0.7222	-12.2757 ± 0.4070	-11.4646 ± 1.0946	-11.4372 ± 0.7610	-10.5343 ± 0.5092	-14.9021 ± 0.7361	-9.3527 ± 0.7769	-12.2490 ± 1.0702
	B1	3.0862 ± 0.1350	3.1900 ± 0.0847	3.0291 ± 0.1942	3.0099 ± 0.1498	2.8981 ± 0.1082	3.5339 ± 0.1260	2.6768 ± 0.1255	3.1427 ± 0.2026
3	B0	-11.1540 ± 0.7222	-12.0482 ± 0.4070	-10.9516 ± 1.0946	-12.0238 ± 0.7610	-11.5593 ± 0.5092	-13.5145 ± 0.9384	-10.0456 ± 0.7769	-11.3465 ± 1.0702
	B1	2.9252 ± 0.1350	3.1493 ± 0.0847	2.9351 ± 0.1942	3.1321 ± 0.1498	3.1125 ± 0.1082	3.2966 ± 0.1607	2.7956 ± 0.1255	2.9908 ± 0.2026
4	B0	-10.3983 ± 0.7222	-12.2018 ± 0.4070	-15.8131 ± 1.0946	-9.9011 ± 0.7610	-11.3131 ± 0.5092	-13.7123 ± 0.7361	-9.9612 ± 0.9903	-11.9180 ± 0.7992
	B1	2.7730 ± 0.1350	3.1706 ± 0.0847	3.8110 ± 0.1942	2.7086 ± 0.1498	3.0556 ± 0.1082	3.3410 ± 0.1260	2.7739 ± 0.1600	3.0869 ± 0.1513
5	B0	-10.8527 ± 0.7222	-11.3331 ± 0.4070	-11.8506 ± 1.3846	-9.4677 ± 0.9701	-11.4547 ± 0.5092	-13.9317 ± 1.3623	-8.9084 ± 1.4377	-10.5469 ± 1.0388
	B1	2.8560 ± 0.1350	2.9853 ± 0.0847	3.0922 ± 0.2456	2.6118 ± 0.1909	3.1066 ± 0.1082	3.3814 ± 0.2333	2.6097 ± 0.2322	2.8316 ± 0.1966
7	B0	-10.3808 ± 0.7222	-12.0437 ± 0.4070	-12.7638 ± 1.0946	-12.4074 ± 0.7610	-12.3411 ± 0.5092	-13.5901 ± 0.7361	-9.1930 ± 0.7769	-12.3872 ± 1.0702
	B1	2.7693 ± 0.1350	3.1353 ± 0.0847	3.2727 ± 0.1942	3.1942 ± 0.1498	3.2739 ± 0.1082	3.3124 ± 0.1260	2.6420 ± 0.1255	3.1638 ± 0.2026
Grand	B0	-11.0345 ± 0.2948	-12.0122 ± 0.1662	-12.3323 ± 0.4598	-11.3590 ± 0.3295	-11.3370 ± 0.2079	-13.8944 ± 0.3292	-9.5905 ± 0.3474	-11.5181 ± 0.3996
mean	B1	2.8947 ± 0.0551	3.1337 ± 0.0346	3.1809 ± 0.0816	2.9924 ± 0.0649	3.0669 ± 0.0142	3.3674 ± 0.0564	2.7153 ± 0.0561	3.0136 ± 0.0756

K(TL) values of gizzard shad from the intake canal (Station 1) were significantly higher ($P < 0.01$) than those from the discharge canal (Station 5) and (2) index values of shad from the entire unheated zone were significantly greater ($P < 0.05$) than those of shad from the entire heated zone (Table 17).

In a study of gizzard shad food habits, Coutant (1979) found that mean concentrations of identifiable food organisms in gizzard contents of shad from the unheated areas of Lake Sangchris were more than twice as high as in fish from heated areas. The lower condition factors observed for gizzard shad were, therefore, primarily attributed to reduced food resource availability in the thermally affected zone. Increased metabolic activity by the fish inhabiting the heated area is another variable which may have contributed to the relatively low condition factors found there.

A highly significant difference ($P < 0.001$) among months was found for condition values of all three species

Table 13.—Multivariate analysis of variance for weight-length relationship of fishes collected from six Lake Sangchris sampling stations during July, September, and November 1975. Significance at the 0.05 and 0.01 level is indicated by 1 and 2 asterisks, respectively.

Species		Source of Variation	
		Stations	Months
Bluegill	df	10[a]/16[b]	4/16
	F	0.48	0.01**
Channel catfish	df	10/10	4/10
	F	0.90	0.53
Carp	df	10/10	4/10
	F	0.50	0.66
Freshwater drum	df	10/4	4/4
	F	0.79	0.76
Gizzard shad	df	10/16	4/16
	F	0.85	0.75
Largemouth bass	df	10/16	4/16
	F	0.78	0.05*
White bass	df	10/14	4/14
	F	0.08	0.12
Yellow bass	df	10/12	4/12
	F	0.48	0.58

[a] Numerator

[b] Denominator.

Table 14.—Mean coefficient of condition, K(TL), of male bluegills (100–140 mm in total length) collected from Lake Sangchris at bimonthly intervals during 1976. The means are followed by the sample size (in parentheses).

	Heated	⟶	(Relative Thermal Gradient)	⟶	Cool	Unheated
			Lake Sangchris Station			
Month	5	4	3	2	1	7
Jan.	. . .	1.586(21)	1.495(13)	. . .	. . .	. . .
Mar.	1.534(25)	1.599(25)	1.641(25)	. . .	. . .	1.590(7)
May	1.808(15)	1.715(25)	1.838(21)	1.702(25)	1.651(25)	1.746(25)
July	1.956(11)	1.713(25)	1.831(25)	1.647(24)	1.708(18)	2.001(18)
Sept.	1.656(25)	1.602(25)	1.529(25)	1.680(25)	1.559(25)	1.680(25)
Nov.	1.609(25)	1.481(11)	1.719(22)	1.788(13)	1.722(13)	1.699(25)

Table 15.—Mean coefficient of condition, K(TL), of male gizzard shad (160–200 mm in total length) collected from Lake Sangchris at bimonthly intervals during 1976. The means are followed by the sample size (in parentheses).

	Heated	⟶	(Relative Thermal Gradient)	⟶	Cool	Unheated
			Lake Sangchris Station			
Month	5	4	3	2	1	7
Jan.	0.789(25)	0.815(25)	. . .	. . .	. . .	. . .
Mar.	0.861(25)	0.965(25)	. . .	. . .	0.961(12)	. . .
May	0.898(25)	0.906(25)	0.927(25)	0.956(25)	0.940(26)	0.937(25)
July	0.923(25)	0.967(25)	0.976(25)	0.928(25)	1.016(25)	0.988(25)
Sept.	0.870(25)	1.004(25)	0.905(25)	0.956(25)	0.883(25)	1.009(25)
Nov.	0.776(25)	0.876(25)	0.883(12)	0.902(10)	0.877(25)	0.939(25)

Table 16.—Mean coefficient of condition K(TL), of male yellow bass (100–140 mm in total length) collected from Lake Sangchris at bimonthly intervals during 1976. The means are followed by the sample size (in parentheses).

	Heated	⟶	(Relative Thermal Gradient)	⟶	Cool	Unheated
			Lake Sangchris Station			
Month	5	4	3	2	1	7
Jan.	1.141(25)	. . .	. . .	. . .	. . .	. . .
Mar.	1.204(25)	1.122(11)	. . .	. . .	1.153(19)	. . .
May	1.143(25)	1.045(16)	1.145(25)	1.018(25)	0.986(24)	1.038(25)
July	. . .	. . .	. . .	. . .	. . .	. . .
Sept.	1.193(25)	. . .	. . .	. . .	. . .	. . .
Nov.	1.090(25)	. . .	. . .	. . .	1.000(24)	. . .

(Table 17). For bluegills and gizzard shad, July values were significantly ($P < 0.001$) greater than November values. Insufficient numbers of yellow bass were collected for specific monthly comparisons. The higher condition factors of bluegills and gizzard shad in July were most likely the result of increased seasonal availability of food resources for these species.

The analysis of variance (Table 17) indicated significant ($P < 0.001$ or $P < 0.01$) station-by-month interactions for condition factors of all three species. None of the hypotheses we tested regarding condition values of gizzard shad at heated and unheated stations during warm and cold months were found to be significantly different, however, and too few yellow bass were collected for detailed analysis. For bluegills, the three comparisons (K1 C1, K1 C2, K1 C3) between heated and unheated areas in warm and cold months were significantly different ($P < 0.001$). In July mean condition values of bluegills were higher in heated than in unheated areas, while the opposite was true during

Table 17.—Analysis of variance table for the coefficient of condition, K(TL), of male bluegill, gizzard shad, and yellow bass captured at bimonthly intervals from six Lake Sangchris stations. Significance at the 0.05, 0.01, and 0.001 level is indicated by 1, 2, and 3 asterisks, respectively; coefficients of determination (R^2) are given at the bottom of the table.

Source of	Bluegill		Gizzard Shad		Yellow Bass	
Variation	df	Mean Square[a]	df	Mean Square[b]	df	Mean Square[c]
Stations	5	0.0113	5	0.4409**	5	0.1230
C1(Sta 1 vs. 5)	. . .	. . .	1	0.9461**	. . .	. . .
C2(Sta 1,2 vs. 4,5)	. . .	. . .	1	0.3109	. . .	. . .
C3(Sta 1,2,7 vs. 3,4,5)	. . .	. . .	1	0.6737*	. . .	. . .
C4(Sta 2 vs. 7)	. . .	. . .	1	0.2819	. . .	. . .
C5(Sta 4 vs. 7)	. . .	. . .	1	0.0496	. . .	. . .
Months	5	0.0570***	5	0.6155***	4	0.1270***
Kl (July vs. Nov.)	1	0.0647***	1	1.8776***	1	. . .
Stations vs. months	19	0.0118***	18	0.0997***	3	0.0241**
K1 C1	1	0.0288***	1	0.0000	1	. . .
K1 C2	1	0.0650***	1	0.0306	1	. . .
K1 C3	1	0.0201***	1	0.0792	1	. . .
K1 C4	1	0.0556***	1	0.0042	1	. . .
K1 C5	1	0.0012	1	0.0316	1	. . .
Residuals	*602*	*0.0015*	*655*	*0.0265*	*281*	0.0050
Coefficient of determination		*0.38*		*0.32*		*0.53*

[a] Transformation necessary to establish normality was $(KTL)^{-0.65}$.
[b] Transformation necessary to establish normality was $(KTL)^2$.
[c] No transformation was needed.

November (Tables 14 and 17). The analysis of variance also revealed that bluegills collected from two similar unheated habitats (K1 C4) were in significantly ($P < 0.001$) better condition in the control arm (Station 7) during July and in the intake arm (Station 2) in November (Table 17).

The percentage composition of aquatic insects in the diets of small bluegills from Lake Sangchris was greater in the heated area during July and August and in the unheated area during November and December (Sule et al. 1981). Since aquatic insects were one of the most important food items in bluegill diets, we can only surmise that the differential use of these organisms had some effect on body condition factors of fish inhabiting the heated and unheated zones. The percentage of empty stomachs in the samples indicated more frequent feeding by bluegills in heated than in unheated areas during July and August (Sule et al. 1981). This frequent feeding may have allowed bluegills in heated areas to gain weight during midsummer in spite of higher metabolic requirements. Conditon factors of bluegills from the heated zone may have declined in November in relation to those from the unheated zone, because even if they continued feeding, their maintenance requirements would have been much higher than in unheated areas. A similar relationship was shown by Massengill (1973), who reported that even though brown bullheads (*Ictalurus nebulosus*) inhabiting a thermal effluent fed throughout the winter, their body condition was poorer than that of those found at ambient temperatures in a cove of the Connecticut River.

Sule (1981) compared the condition factors of young-of-the-year largemouth bass in heated and unheated areas of Lake Sangchris and found on five of eight sampling dates that fish from the intake arm were in significantly better condition than those from the discharge arm. However, fish from the heated area were not in poor condition, and by the end of the growing season they had gained a competitive advantage in size over fish from the unheated area as a result of the extended growing season.

From an examination of the literature regarding effects of thermal discharges on condition indices of fishes inhabiting thermal effluents, it is apparent that effects vary widely among species, among fish of different sizes, and among study sites.

Several studies have been conducted in Par Pond, a reservoir receiving cooling water from a nuclear production reactor in South Carolina. Bennett (1972) reported no difference in condition values of adult bluegills from heated and unheated areas, but found that condition factors were significantly higher for fingerling bluegills from control areas and for adult black crappies from heated areas. Bennett & Gibbons (1974) examined the growth and condition of juvenile largemouth bass in Par Pond and found that although bass from the heated area were generally larger and grew significantly faster than young bass from unheated areas, their body condition factors were generally similar.

With data compiled over a 10-year period, Gibbons et al. (1978) demonstrated that adult largemouth bass from unheated areas of Par Pond exhibited significantly higher mean condition factors than those from heated areas and showed that bass with lower body condition values were low in stored energy reserves. The authors implied that these findings were evidence of subtle biological effects of thermal pollution that might go unnoticed without critical systematic examination on a long-term basis. However, the authors fail to point out that Par Pond represents a highly unusual aquatic ecosystem with an extremely large bass population resulting from restricted access and a ban on sport fishing. Although standing crop information is apparently unavailable, Gibbons & Bennett (1973) estimated largemouth bass density in Par Pond at 29,000 fish in the vicinity of the cold dam, and 35,000 fish in the vicinity of the hot dam. At these population levels, it is not surprising that the body condition of largemouth bass was significantly lower in heated regions or that some bass remained in the heated area throughout the year. In Lake Sangchris, which has a more normal largemouth bass population density, this species was shown via fish population surveys and by radiotelemetry observations to be particularly adept at avoiding the thermal discharge areas during the most stressful summer periods.

In a small cooling lake, North Lake, located in northeastern Texas, the size and condition of five species of fishes collected at the mouth of the effluent canal were not significantly different from those of fish collected at other stations in the reservoir, but condition factors of channel catfish, river carpsucker (*Carpiodes carpio*), gizzard shad, threadfin shad, and bluegill were lower than those reported for these species in other parts of the United States (McNeely & Pearson 1974). The authors suggested that in a small reservoir such as North Lake, the effects of a heated effluent may be generalized over the entire body of water, particularly when a cool-water refuge area is present beneath the surface stratum.

Marcy (1976) reported that brown bullheads and white catfish (*Ictalurus catus*) living in the discharge canal of the Connecticut Yankee Plant on the Connecticut River during the winter weighed significantly less and were in significantly poorer condition than those in two cooler overwintering areas outside the canal. In the White River at Petersburg, Indiana, studies revealed that centrarchids [longear sunfish (*Lepomis megalotis*), spotted bass (*Micropterus punctulatus*), bluegill, and white crappie] did not have significantly different condition factors in heated and unheated sections (Benda & Proffitt 1974).

Our study showed that (1) throughout the year, gizzard shad from unheated areas of Lake Sangchris were in significantly better condition than those from heated areas, that (2) bluegills and gizzard shad from all areas of the lake were in significantly better condition in July than in November, and that (3) in July mean condition factors of bluegills were higher in heated than in unheated areas, while the opposite was true during November. These differences were related to the relative abundance and/or use of fish food resources in heated and unheated areas and to greater metabolic requirements of fishes inhabiting thermally affected zones. Results of this investigation and those of other researchers regarding fish condition factors in the vicinity of thermal effluents show few similarities between different ecosystems and reveal that, except under unusual circumstances, observed differences cannot easily be categorized as either beneficial or detrimental to the fish populations over extended time periods.

INCIDENCE OF PARASITISM AND DISEASE

Fish parasites, as well as their hosts, are affected by changes in water temperature. Seasonal cylces in the abundance of fish parasites are well known and are often associated with water temperature fluctuations (Rawson & Rogers 1972). Heated effluents discharged into an artificial cooling lake could affect fish parasites or disease organisms directly by causing an increase or decrease in their population levels, or indirectly by making fishes more or less susceptible to infestation. Our objective in this study was merely to compare the incidence of internal and external parasitism and disease in fishes from heated and unheated areas, relating any differences to the effects of water temperature. A comprehensive investigation of fish parasitism was not conducted at Lake Sangchris.

The incidence and intensity of fish parasitism in artifically heated reservoirs and streams have been studied by other investigators, and their results with respect to the effects of thermal discharges have been mixed. Smith (1971) attributed the high degree of fish parasitization that he found in a Texas cooling lake to the year-round optimum temperatures for parasites. In heated and unheated areas of the White River, Indiana, the incidence of fish infestation by a parasitic copepod (*Lernaea cyprinacea)* was examined in different years by Benda & Proffitt (1974) and Whitaker & Schlueter (1973). Benda & Proffitt could not relate the variation in centrarchid infestations they observed in 1969 and 1970 to the effect of increased heat. In 1971 and 1972, Whitaker & Schlueter studied the incidence of *Lernaea* infestation in relation to heated water for a larger number of fish species and found that some species were affected positively and some negatively and that the overall influence was rather minor. In Par Pond, near Aiken, South Carolina, Eure & Esch (1974) found that the number of helminth parasites per host fish was significantly higher in largemouth bass from the heated areas compared with those from normal areas. The intensity of parasitism of mosquitofish (*Gambusia affinis*) by two strigeid trematodes was studied in a variety of thermally stressed habitats at the Savannah River Plant near Aiken, South Carolina, by Aho et al. (1976). They found that the density of *Diplostomum scheuringi* was higher in fish from unheated areas, while the density of *Ornithodiplostomum ptychocheilus* was higher in fish from heated areas. Hagele & Tranquilli (1979) found that while there was no difference in the rate of fish infestation by parasites in the heated and unheated areas of Lake Sangchris, there was a significant difference between the unheated areas of the cooling lake and unheated Lake Shelbyville, with Lake Shelbyville fish having a higher infestation rate by monogenetic trematodes.

MATERIALS AND METHODS

The incidence of internal and external parasitism or disease among Lake Sangchris fishes was studied from January 1974 through July 1975. Fishes were collected at bimonthly intervals by alternating-current electrofishing, experimental gill netting, and seining. The incidence of fish infestation at stations 1 and 2 in the intake arm was compared with that at stations 4 and 5 in the discharge arm. A total of 10 fish collections was taken from each station in each arm. Fishes were given a cursory examination for evidence of infestation by external parasites or disease as they were weighed and measured. Internal organs (liver, heart, intestine, and gonads) of fishes dissected for sex determination or for food-habit analyses were examined for infestation by internal parasites. All examinations were made with the unaided eye; internal organs were not dissected and examined under a microscope to determine whether parasites were present.

RESULTS AND DISCUSSION

The kinds of external parasites and diseases observed among fishes from Lake Sangchris included protozoans *(Ichthyophthirius)*, parasitic copepods, leeches, fungi, and a virus *(Lymphocystis)*. These parasites and diseases are commonly found on fishes in Illinois waters.

The eight species of fishes studied, the numbers of fish examined, and the percentage infested from heated and unheated areas are shown in Table 18. The overall incidence of infestation by external parasites and disease in both the intake and discharge arms was very low at 0.6 and 0.3 percent, respectively. The proportion of externally infested fishes found in the intake and discharge arms was not compared statistically, because for most species the test results would, as a result of a large sample size and a low incidence of occurrence, have no biological importance. Inspection of the data indicated that the incidence of external infestation was similar in both heated and unheated areas for all species, except perhaps in the white crappie. A total of 50 white crappie from the discharge canal were examined, and 5 (14 percent) were infested, mostly with *Lymphocystis* disease. From the intake arm, 84 fish were examined and 2 (2.4 percent) were infested, suggesting that the heated water might have caused an

Table 18.—Species of fishes from the intake and discharge arms of Lake Sangchris infested with internal and/or external parasites or disease, including the number of fish examined and the percentage infested.

	External Parasites					
	Intake Arm			Discharge Arm		
Species	Number of Fish	Number Infested	Percentage Infested	Number of Fish	Number Infested	Percentage Infested
Carp	384	0	0.0	342	0	0.0
Channel catfish	362	12	3.3	513	6	1.2
White bass	107	0	0.0	297	4	1.4
Yellow bass	2,733	1	0.0	2,348	0	0.0
Bluegill	4,281	24	0.6	4,118	5	0.1
Largemouth bass	630	12	1.9	518	5	1.0
White crappie	84	2	2.4	50	7	14.0
Freshwater drum	21	0	0.0	115	0	0.0
Total or average infestation rate	*8,602*	*51*	*0.6*	*8,301*	*27*	*0.3*
	Internal Parasites					
Carp	234	0	0.0	266	0	0.0
Channel catfish	133	12	9.0	182	6	3.3
White bass	47	0	0.0	144	0	0.0
Yellow bass	237	0	0.0	301	7	2.3
Bluegill	430	397	92.3	439	376	85.7
Largemouth bass	197	79	40.1	308	131	42.5
White crappie	38	19	50.0	21	6	28.6
Freshwater drum	52	3	5.8	79	0	0.0
Total or average infestion rate	*1,368*	*510*	*37.3*	*1,740*	*526*	*30.2*

increased incidence of infestation in this species. A much larger sample size would be needed to confirm this relationship and to determine that it was biologically important to the white crappie population. The low total incidence of occurrence in each arm indicated that the fishes in this cooling lake were generally free of external parasites and disease and that such infestation was not a major cause for concern.

Fishes from Lake Sangchris were examined with special interest for external symptoms of gas-bubble disease, because it has been reported in fishes living in heated effluents of steam generating stations in North Carolina (DeMont & Miller 1971, Adair & Hains 1974, Miller 1974) and in Lake Michigan (Otto 1976). In thermal discharges this disease is caused by supersaturation of water with oxygen and/or nitrogen gases during the condenser cooling process. The external symptoms of this disease, "pop-eye" and gas embolism of fins or the body surface, were never observed in fishes from Lake Sangchris.

Since our objective was to compare the total incidence of infestation in heated and unheated areas, we made no attempt to identify intermediate forms of all internal parasites found in each fish. Two prevalent parasite species were identified, but infestation by other species undoubtedly occurred and were recorded in our data. A majority of the occurrences of internal parasitism were due to infestations of the visceral organs by metacercariae of the strigeid trematode, *Posthlodiplostomum minimum,* commonly known as the white liver grub. In the life cycle of this parasite, aquatic birds such as the great blue heron, *Ardea herodias,* serve as definitive hosts, while snails of the genus *Physa* serve as first intermediate hosts, and fishes serve as second intermediate hosts (Ferguson 1938 and Miller 1954). The bass tapeworm, *Proteocephalus ambloplitis,* was also found as a plerocercoid in the liver and gonads of the centrarchids examined. Largemouth bass were probably the only definitive hosts of this tapeworm in Lake Sangchris. They were the only species in which the adult was observed. First intermediate hosts of the bass tapeworm are free-swimming copepods. Plerocercoids develop in small fishes, which are the second intermediate hosts, and the adult worms develop only when the smaller fish are eaten by black bass (Hoffman 1967). Infestations of either adult or larval forms of *P. minimum* and/or *P. ambloplitis* have been reported by Hoffman (1967) to occur in all of the Lake Sangchris fish species which were infested with internal parasites.

In Lake Sangchris, the average internal infestation rate for the eight species examined from the intake and discharge arms was 37.3 and 30.2 percent, respectively (Table 18). Two examples from unheated reservoirs are included to keep these data in perspective. Hugghins (1959) examined fishes from 33 bodies of water in South Dakota and found an average infection rate of 76.3 percent, including both internal and external infestations. The incidence of infestation by plerocercoids of the bass tapeworm in Bull Shoals Reservoir was 88 percent for age I + largemouth bass and 92 percent for age I + bluegills (Holmes & Mullan 1965).

The incidence of internal parasitism in Lake Sangchris was greatest in three centrarchids, bluegills, largemouth bass, and white crappie. Infestation percentages for these species in the intake and discharge arms, respectively, were for bluegill 92.3 and 85.7 percent, for largemouth bass 40.1 and 42.5 percent, and for white crappie 50.0 and 28.6 percent. For the centrarchid species, the proportion of infested fishes from the intake and discharge arms was compared statistically by chi-square analysis in 2 x 2 contingency tables. The null hypothesis that location in heated or unheated water had no effect on the incidence of internal infestation was tested. Results of the test indicated there was no difference in the proportion of infected largemouth bass or white crappie from the two areas. However, a significantly greater ($P < 0.01$) number of bluegills from the intake arm were parasitized (chi-square = 9.185, 1 df), suggesting that perhaps bluegills living in the heated water were less susceptible to infestation by internal parasites or that the intermediate life stages of the parasites were somehow inhibited in heated areas. However, in another quantitative comparison, Hagele & Tranquilli (1979) reported that infestation by *P. minimum* was 100 percent in bluegills from heated and unheated areas of Lake Sangchris and 56 percent for fish from Lake Shelbyville. The percentages of infestation in the two lakes were related to basic differences in basin morphology and the resulting attractiveness of the habitat to the definitive host, the great blue heron.

Quantitative data regarding the intensity of parasitism were not recorded for any species in our study, but heavy infestations of *P. minimum* metacercariae were commonly observed in bluegills. A relationship between the size of bluegills and the incidence of infestation was also apparent, as found by Larimore (1957) in the warmouth. Usually only the smallest fish were free of internal parasites from this digenetic trematode. Although the high incidence of internal parasitism observed for bluegills from the intake and discharge arms was not unusual, the heavy infestations of *P. minimum* are reason for concern, because the growth of bluegills in Lake Sangchris is slow and they have a relatively low coefficient of condition. Smitherman (1968) evaluated the effect of various infection rates by *P. minimum* on growth and mortality of bluegills and found that high infestation rates (more than 353 metacercariae per fish) significantly reduced growth and caused significantly greater mortality than that of control fish. Thus, in addition to overabundance and direct intraspecific competition for food and space, the stunted condition of the Lake Sangchris bluegill population can perhaps also be related to a relatively heavy parasite load, especially of *P. minimum* metacercariae.

FISH KILLS

Substantial fish kills at power generating plants have been reported as a result of the inability of fish to acclimate rapidly to a sudden increase or decrease in water temperature. A number of such cases were documented by Edsall & Yocum (1972). From 1973 to 1977, several fish kills occurred at Lake Sangchris. Those fish kills were investigated to determine whether they were related to operations of the power plant and to determine if they were of sufficient magnitude to affect the fishery adversely.

METHODS

Fish kills were investigated immediately upon notification. The quantity of physical and chemical data recorded at the site and the number of water samples collected varied according to the particular situation. The numbers of fishes killed were estimated by counting individuals washed up along portions of the shoreline. The estimate was presented as a range, with the lower value representing the approximate number of fish counted. We assumed that 50 percent of the fish sank and doubled the approximate count to get the upper value of the range. At Commonwealth Edison Company's request, fishes that died during two of the fish kills and some control fishes captured live from the lake were frozen and sent to Industrial Bio-Test Laboratories, Northbrook, Illinois, and to the Warf Institute, Inc., Madison, Wisconsin, for physiological and/or chemical analyses.

RESULTS AND DISCUSSION

The first fish kill was reported in the vicinity of the dam (Station 3, Fig. 1) on 15 April 1974. Investigation revealed that most of the fishes had been dead for 1–5 days. Water quality parameters were measured in profile form from a large cove east of the dam, where many of the dead fishes had accumulated. All water quality parameters were normal at that time; water temperature (15.5°–16.2°C), dissolved oxygen (9.3–10.3 mg/l), and conductivity (309–329 μmho/cm). Ten species of fishes, including 621 individuals of all sizes, were counted in the immediate vicinity of the dam. A majority of the dead fish were gizzard shad. Subsequent (2–3 days later) travel around the lake indicated that a much larger number of fish had died at or about the same time in other portions of the intake arm. Dead fish were not observed in the discharge or control arms. All fish had been dead too long to determine the cause of death, but their distribution indicated that the kill was not related to operations of the generating station.

The second fish kill occurred on 4 May 1974 in the discharge canal area (Station 5, Fig. 1). We were so quickly notified of that fish kill that we were able to investigate while fish were still in distress. Water samples and water quality measurements were taken at six equidistant locations between the generating station and Station 4 (Fig. 1) and from the slag pond overflow. During the fish kill, Unit No. 2 (Kincaid Generating Station has two 616-megawatt units) was generating electricity and was being serviced by two of the four circulating water pumps (605.6 m^3/min capacity each). The first appearance of distressed fish observed by local fishermen and by the creel clerk was correlated with the time when a third circulating water pump was activated at the generating station. The utility had recently cleaned the condenser of Unit No. 1 by a mechanical process, which involved shooting plastic pellets through the condenser tubes under high air pressure to remove silt, slime, and algal deposits. According to the utility, no chemicals were used in the cleaning process. There was an obvious relationship between the appearance and distribution of plastic pellets and dead fish in the lake. Neither external examination of the dead fish nor water quality measurements (Table 19) taken while the fish kill was in progress gave any clue to its cause. From 5,000 to 10,000 fish were estimated to have been killed, including all species normally found in this area of the lake. The good physical condition of the fish indicated

Table 19.—Water quality measurements taken in the discharge canal and discharge arm of Lake Sangchris on 4 May 1974 while a fish kill was in progress. Relationships between locations of water sampling stations and distressed or dead fish at the time of the fish kill were: Station 1 was beyond the limit of the fish kill, since no dead or distressed fish were present; at stations 2–5 dead fish were present on the surface and others were in distress; and at Station 6 in the discharge canal (located above the point of entry of the slag pond outlet) few dead or distressed fish were present on the surface due to the swift current. Station 7 was located at the point where the slag pond outlet entered the discharge canal.

	Fish Kill Water Sampling Stations						
Parameter	1	2	3	4	5	6	7
Water temperature (°C)	23.5	24.0	22.0	22.5	22.0	22.5	...
Dissolved oxygen (mg/l)	8.6	9.0	9.2	9.1	9.2	9.3	...
Conductivity (μmho/cm)	390	402	385	390	392	392	...
Hydrogen ion (pH)	7.9	7.9	7.9	8.2	8.2	8.2	...
Hardness (mg/l as $CaCO_3$)	119	138	140	114	114	147	186
Ammonia (mg/l NH_3-N)	0.05	0.06	0.06	0.06	0.02	0.04	0.05
Nitrite (mg/l $NO_2 - N$)	0.10	0.06	0.10	0.07	0.06	0.09	0.09
Nitrate (mg/l $NO_3 - N$)	...	...	4.0	2.73	2.74	3.91	2.66
Soluble ortho–PO_4(mg/l $PO_4 - P$)	0.007	0.007	0.003	0.003	0.016	0.003	0.003
Sodium (mg/l)	14.0	15.5	13.75	9.75	10.25	14.75	17.25

they died quickly rather than by chronic exposure to a toxic substance.

On 28 May 1974 the third fish kill occurred in the discharge canal area under circumstances similar to those of the second. The generating station was in the same operational mode, with Unit No. 2 operating on two circulating water pumps. According to the utility, the third circulating water pump, servicing Unit No. 1, had been inactive for 24 days. When it was reactivated on 28 May, from 40,000 to 80,000 fish were estimated to have been killed. Water samples were not collected from the discharge canal during the third fish kill, because we were unable to investigate until the following day, by which time conditions had apparently returned to normal.

Additional mechanical cleaning of the condenser tubes of Unit No. 1 had not occurred during the interim period. However, on 28 May the utility was in the process of cleaning their boilers with hydroxyacetic and formic acids. These acids were neutralized with sodium hydroxide and flushed through the slag and water in the slag pond. An automatic water sampling device collected a composite water sample from the slag pond overflow, where it enters the approximate midpoint of the discharge canal. Analyses of this water sample revealed that alkalinity, total dissolved solids, EDTA hardness, turbidity, total phosphorus, soluble orthophosphate, nitrate, nitrite, ammonia, total iron, soluble iron, sulfate, and chloride concentrations were all normal and similar to values in the lake. Observations by witnesses indicated that the kill occurred in the canal between the slag pond overflow and the generating station, also indicating that the acid cleaning process probably was not responsible for the kill.

In the comparison of fish kill specimens from 4 May and 28 May with control samples, Industrial Bio-Test Laboratories (1974) concluded that there was no physiological evidence to reveal the cause of death. However, they did find hemorrhaging of the gills and the lateral line in one of four fish kill specimens they examined. Trace metal analyses performed on fish gills and internal organs by Industrial Bio-Test Laboratories indicated no unusual concentrations of copper, zinc, lead, or arsenic. Fish kill samples, analysed by the Warf Institute (1974) for the same four trace metals, showed slightly higher lead levels in muscle and liver tissues than those in control fish, but the consultant thought the concentration (<1.0–1.5 ppm) was tolerable to fish and unrelated to the kills. In gross pathological examinations of killed specimens, the

Warf Institute found massive hemorrhages behind the gills and/or along the backbone in the abdominal cavity in three of ten specimens they examined, but did not know the significance of this alteration.

Although the two fish kills which occurred in the discharge canal were undoubtedly related to operations of the generating station, little conclusive evidence has been found to suggest the causative factor. Possible explanations include the following: (1) temperature shock, (2) oxygen depletion, (3) concussion from the activation of an unprimed pump, and (4) toxic substances, especially chlorine.

The change in water temperature in the discharge canal when an additional circulating water pump is activated is approximately 2.2°C. During the 1974 fish kills, gizzard shad were probably the most abundant species in the canal. Edsall & Yocum (1972) reported that a temperature decrease of 13.89°C was needed to cause 50-percent mortality of gizzard shad acclimated at 25°C. It is therefore unlikely that the 2.2°C temperature drop was lethal to gizzard shad. In addition, from 1974 to 1977 in both midsummer and midwinter, changes in water temperature of much greater magnitudes were observed during start-up and emergency shutdowns of both units at the generating station, and no fish kills resulted.

During the first discharge-canal fish kill, biodegradable residues removed from the condenser tubes by mechanical cleaning could have temporarily depleted oxygen reserves. However, dissolved oxygen concentrations measured while the fish kill was occurring were all near saturation. Considering that (1) additional mechanical cleaning did not occur prior to the second discharge-canal fish kill, and (2) the same cleaning process has been used by the utility without incident since 1974, it is unlikely that the fish kills were related to residues discharged during the mechanical cleaning process.

No screens prevent fish from entering the 4.6-m diameter discharge pipe at Kincaid Generating Station. Cooling water from both units travels underground through a common pipe for a linear distance of more than 100 m before entering the head of the discharge canal. Thus, fishes could have entered the pipe within the generating station and found refuge from the high water velocities by passing the junction where water from Unit No. 2 was received. If fishes reached this potential refuge area (created only when Unit No. 1 was not in operation), they could have suffered concussion when the unprimed pumps were activated. This hypothesis was tested after the second discharge-canal fish kill. Access to the refuge area was gained through water boxes within the generating station, and the refuge was treated with a fish toxicant (rotenone). No fish were recovered in the test, indicating that fish probably were unable to enter the discharge pipe.

To prevent biological fouling of condenser tubes at the generating station, chlorine is injected several times a day by automatic pumps. The discharge-canal fish kills did not occur when chlorine was scheduled to be added. However, a malfunctioning valve may have allowed chlorine to leak into the system. If a valve was leaking, a reservoir of chlorine could have accumulated in Unit No. 1 and would have been discharged as a concentrated slug when the third pump was activated. This action could easily have caused the kind of fish kill that occurred in the discharge canal.

Information regarding the physiological damage to fishes caused by high chlorine concentrations was not found in a survey of the literature. Authors of a paper on the toxicity of chlorinated power plant condenser cooling waters to fish were contacted (Basch & Truchan 1976), and they indicated (personal communication, June 1978, Michigan Department of Natural Resources) that they had commonly observed bleeding of the gills and hemorrhage along the spinal column and lateral line as symptoms of fishes exposed to concentrations of chlorine. These symptoms were identical to those observed in some of the fish kill specimens of 4 and 28 May 1974 by the Warf Institute and Industrial Bio-Test Laboratories. On the basis of this evidence, we believe that the two fish kills that occurred in the Lake Sangchris discharge canal were very likely the result of accidental chlorination at the generating station.

Standing-crop data were used to assess the impact of the discharge-canal fish kills on the fishery. In six standing-crop surveys conducted at Lake Sangchris, an average of 11,331 fish and a maximum of 30,523 fish were found per hectare. During the spring, fish were concentrated in the discharge canal, and so the maximum standing crop value was used in the analyses. This value probably was a conservative estimate of the actual number of fish/ha present. The fish kill estimates of 10,000 and 80,000 fish on 4 and 28 May 1974 were thus equivalent to the standing crop of fish in 0.3 and 2.6 ha, respectively, of this 876-ha cooling lake. In the standing crop surveys, gizzard shad, an overabundant forage fish, constituted 73.3 percent of the total number of fish collected. If gizzard shad comprised a similar proportion of the fish in the two discharge-canal fish kills, the impact on the fish population would have been minimal. Additional evidence suggesting a minimal impact on the fishery came from a catch-per-unit-effort fish sample collected from the discharge canal (Station 5) on 31 May 1974, just 3 days after the largest fish kill occurred (Tables A3 and B3). No decrease in the catch (relative abundance or species composition) was apparent, indicating that only a small portion of the discharge canal was affected by the fish kill or that the area had become quickly repopulated.

SUMMARY

1.—Nine species of fishes constituted 97.4 percent of the total weight of the catch in Lake Sangchris. In order of decreasing abundance, they were carp (33.4 percent), gizzard shad (23.1 percent), largemouth bass (16.3 percent), bluegill (7.1 percent), yellow bass (5.3 percent), channel catfish (4.7 percent), white bass (4.6 percent), black bullhead (1.9 percent), and white crappie (1.0 percent).

2.—Lake Sangchris has not experienced the decline in production of largemouth bass commonly observed in unheated Illinois reservoirs as they age.

3.—Gizzard shad, blackstripe topminnow, and freshwater drum were significantly more abundant in heated than in unheated areas of the cooling lake, while black bullheads and white suckers were significantly more abundant in the unheated areas.

4.—Seasonal aggregations of white bass and channel catfish in heated areas were revealed in significant station-by-month interactions and related to important changes in the reproductive life histories of these species in cooling lakes. In the absence of major tributaries at Lake Sangchris, white bass made pronounced upstream spawning migrations into the discharge canal during early spring. In comparison with channel catfish reproduction in other large Illinois reservoirs, which have no major tributaries and relatively large game fish populations, channel catfish reproduction and recruitment was unusually successful in Lake Sangchris.

5.—Significant seasonal changes in relative abundance of fishes occurred between heated and unheated areas of Lake Sangchris. Gizzard shad, yellow bass, and largemouth bass were apparently attracted to the heated areas during cold months and repelled from them during warm months as a result of behavioral thermoregulation.

6.—Rotenone surveys revealed only minor differences in standing crops of fishes within coves between seasons or among coves located in heated and unheated areas of Lake Sangchris.

7.—The average standing crop of fishes in Lake Sangchris (360.9 kg/ha) was intermediate between those found in reservoirs of the mid-South and the Midwest.

8.—A comparison of the standing crop of fishes in Lake Sangchris determined by cove rotenone samples with Jenkins's (1977) regression model indicated that the production of fish biomass in the cooling lake was much the same as that in chemically similar unheated reservoirs with comparable total dissolved-solids concentrations.

9.—Elevated temperatures in heated areas of Lake Sangchris advanced the date of largemouth bass spawning by 1–3 weeks over that in unheated areas and consequently provided a head start in growth for young-of-the-year fish.

10.—In 1975, carp spawning apparently began at the same time in both heated and unheated areas, but in 1976 carp began to spawn approximately 1 month earlier in heated areas.

11.—A degenerate ovarian condition was found in approximately 20 percent of the female carp examined and may have partially accounted for the absence of successful reproduction by that species in Lake Sangchris. Results of chemical analyses indicated that mercury and pesticide contamination probably did not cause the degenerate ovarian condition.

12.—Length-frequency distributions showed that the Lake Sangchris carp population was composed almost entirely of large individuals, whereas the populations of bluegills and yellow bass consisted almost entirely of small fish.

13.—The growth of carp, gizzard shad, bluegills, and yellow bass in the cooling lake was slow in comparison with that of these species in other waters, while the growth of white bass, largemouth bass, channel catfish, and freshwater drum was greater than the average growth of these fishes in other waters.

14.—Weight-length relationships for eight species of fishes in Lake Sangchris were compared and found to be similar at heated and unheated stations. Significant differences in weight-length regressions were found among seasons for largemouth bass and bluegills.

15.—Body condition factors were examined and showed that (1) throughout the year, gizzard shad from unheated areas were in significantly better condition than those from heated areas, (2) bluegills from all areas of the lake were in significantly better condition in July than in November, and (3) in July, mean condition factors of bluegills were higher in heated than in unheated areas, while the opposite was true during November. These differences were related to the relative abundance and/or use of fish food resources in heated and unheated areas and to greater metabolic requirements of fishes inhabiting thermally affected zones.

16.—The overall incidence of infestation by external parasites and disease organisms in fishes from the intake and discharge arms of the lake was very low at 0.6 and 0.3 percent, respectively. No gas-bubble disease was ever observed on fishes from Lake Sangchris.

17.—The average internal infestation rate for the eight species of fishes examined was 37.3 percent for the intake arm and 30.2 percent for the discharge arm. The incidence of internal parasitism was greatest in bluegills, largemouth bass, and white crappies.

18.—Heavy parasitic infestations of bluegills by the white liver grub, *Posthlodiplostomum minimum,* may have contributed to the stunted condition of the bluegill population in the cooling lake.

19.—Three fish kills occurred at Lake Sangchris during 1974, and two were related to operations at the electrical generating station. Examination of dead fishes indicated that the two fish kills which occurred in the discharge canal were very likely the result of inadvertent chlorination at the power plant.

20.—The fish kills which occurred at Lake Sangchris had a minimal impact on the fishery.

REFERENCES CITED

ADAIR, W.D., AND J.J. HAINS. 1974. Saturation values of dissolved gases associated with the occurrence of gas-bubble disease in fish in a heated effluent. Pages 59–78 *in* J. W. Gibbons and R. R. Sharitz, eds., Thermal ecology. AEC Symposium Series (CONF-730505), Augusta, GA.

AHO, J.M., J.W. GIBBONS, and G.W. ESCH. 1976. Relationship between thermal loading and parasitism in the mosquitofish. Pages 213–218 *in* G.W. Esch and R.W. McFarlane, eds., Thermal ecology II. ERDA Symposium Series (CONF-750425), Augusta, GA.

ANDERSON, W.L., and K.E. SMITH. 1977. Dynamics of mercury at coal-fired power plant and adjacent cooling lake. Environmental Science and Technology 11 (1): 75–80.

BAGENAL, T.B., and E. BRAUM. 1971. Eggs and early life history. Pages 166–198 *in* W.E. Ricker, ed., Methods for assessment of fish production in fresh waters. I.B.P. Handbook No. 3, 2nd ed. Blackwell Scientific Publications, Oxford.

BARKLEY, S.W., and C. PERRIN. 1971. The effects of the Lake Catherine steam electric plant effluent on the distribution of fishes in the receiving embayment. Southeastern Association of Game and Fish Commissioners Proceedings for 1970, 25:384–392.

BARR, A.J., J.H. GOODNIGHT, J.P. SALL, and J.T. HELWIG. 1976. A user's guide to SAS 76. SAS Institute, Inc., Raleigh, NC. 329 p.

BASCH, R.E., and J.G. TRUCHAN. 1976. Toxicity of chlorinated power plant condenser cooling waters to fish. Publication 600/3-76-009. Environmental Protection Agency, Duluth, MN. 105 p.

BENDA, R.S., and M.A. PROFFITT. 1974. Effects of thermal effluents on fish and invertebrates. Pages 438–447 *in* J.W. Gibbons and R. R. Sharitz, eds., Thermal ecology. AEC Symposium Series (CONF-730505), Augusta, GA.

BENNETT, D.H. 1972. Length-weight relationships and condition factors of fishes from a South Carolina reservoir receiving thermal effluent. Progressive Fish Culturist 34(2):85–87.

______, and J.W. GIBBONS. 1974. Growth and condition of juvenile largemouth bass from a reservoir receiving thermal effluent. Pages 246–254 *in* J.W. Gibbons and R.R. Sharitz, eds., Thermal ecology. AEC Symposium Series (CONF-730505), Augusta, GA.

______, and ______. 1975. Reproductive cycles of largemouth bass *(Micropterus salmoides)* in a cooling reservoir. American Fisheries Society Transactions 104(1):77–82.

BENNETT, G.W. 1951. Experimental largemouth bass management in Illinois. American Fisheries Society Transactions 50:231–239.

______, and D.H. THOMPSON. 1939. Lake management reports. 3. Lincoln Lakes near Lincoln, Illinois. Illinois Natural History Survey Biological Notes 11. 24 p.

BONN, E.W. 1953. The food and growth of young white bass *(Morone chrysops)* in Lake Texoma. American Fisheries Society Transactions 82:213–221.

BOX, G.E.P., and D.R. COX. 1964. An analysis of transformations. Royal Statistical Society Journal, Series B, 26(2):211–243.

BRIGHAM, A.R. 1981. Water quality in a cooling water reservoir. Pages 290–319 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

CARLANDER, K.D. 1955. The standing crop of fish in lakes. Canada Fisheries Research Board Journal 12(4):543–570.

______. 1969. Handbook of freshwater fishery biology. Vol. I. Iowa State University Press, Ames. 752 p.

______. 1977. Handbook of freshwater fishery biology. Vol. II. Iowa State University Press, Ames. 431 p.

CHERRY, D.S., K.L. DICKSON, and J. CAIRNS, JR. 1974. The use of a mobile laboratory to study temperature response of fish. 29th Purdue Industrial Conference Proceedings. Purdue University, Lafayette, IN. 28 p.

COUTANT, C.C. 1974. Temperature selection by fish—a factor in power plant impact assessments. Symposium on the physical and biological effects on the environment of cooling systems and thermal discharges at nuclear power stations. IAEA-SM-187/11. 25 p.

COUTANT, L.W. 1979. Identifiable food organisms in gizzard shad from Lake Sangchris and Lake Shelbyville. Pages 12-1–12-14 *in* Evaluation of a cooling lake fishery. Vol. III. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

DEMONT, D.J., and R.W. MILLER. 1971. First reported incidence of gas-bubble disease in the heated effluent of a steam-electric generating station. Southeastern Association of Game and Fish Commissioners Proceedings for 1970, 25:392–399.

DREW, H.R., and J.E. TILTON. 1970. Thermal requirements to protect aquatic life in Texas reservoirs. Water Pollution Control Federation Journal 42(4):562–572.

DRYER, W., and N.G. BENSON. 1957. Observations on the influence of the New Johnsonville steam plant on fish and plankton populations. Southeastern Association of Game and Fish Commissioners Proceedings for 1956, 10:85–91.

EDSALL, T.A., and T.G. YOCUM. 1972. Review of recent technical information concerning the adverse effects of once-through cooling on Lake Michigan. Lake Michigan Enforcement Conference, Chicago. Great Lakes Fishery Laboratory, Ann Arbor, MI. 86 p.

EURE, H.E., and G.W. ESCH. 1974. Effects of thermal effluent on the population dynamics of Helminth parasites in largemouth bass. Pages 207–215 *in* J.W. Gibbons and R.R. Sharitz, eds., Thermal ecology. AEC Symposium Series (CONF-730505), Augusta, GA.

FERGUSON, M.S. 1938. Experimental studies on *Posthodiplostomum minimum* (MacCallum, 1921), a trematode from herons. Journal of Parasitology 24(6):31.

FERGUSON, R.G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. Canada Fisheries Research Board Journal 15(4):607–624.

GAMMON, J.R. 1973. The response of fish populations in the Wabash River to heated effluents. Pages 513–523 *in* D.J. Nelson, ed., Third national symposium on radioecology. USAEC Report CONF-710501-P1.

GIBBONS, J.W., and D.H. BENNETT. 1973. Abundance and local movement of largemouth bass *(Micropterus salmoides)* in a reservior receiving heated effluent from a reactor. Pages 524–527 *in* D.J. Nelson, ed., Third national symposium on radioecology. USAEC Report CONF-710501-P1.

______, ______, G.W. ESCH, and T.C. HAZEN. 1978. Effects of thermal effluent on body condition of largemouth bass. Nature 274(5670):470–471.

______, J.T. HOOK, and D.L. FORNEY. 1972. Winter responses of largemouth bass to heated effluent from a nuclear reactor. Progressive Fish Culturist 34(2):88–90.

GUPTA, S. 1975. The development of carp gonads in warmwater aquaria. Journal of Fishery Biology (7):775–782.

HAGELE, R.A., and J.A. TRANQUILLI. 1979. A comparison of monogenetic trematode (Subfamily Ancyrocephalinae) populations of bluegills from heated and ambient areas of Lake Sangchris and from Lake Shelbyville. Pages 14-1–14-19 *in* Evaluation of a cooling lake fishery. Vol. III. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

HAYNE, D.W., G.E. HALL, and H.M. NICHOLS. 1967. An evaluation of cove sampling of fish populations in Douglas Reservoir, Tennessee. Pages 244–297 *in* Reservoir Fishery Resources Symposium. University of Georgia, Athens.

HEIDINGER, R.C. 1975. Life history and biology of the largemouth bass. Pages 11–20 *in* R.H. Stroud and H. Clepper, eds., Black bass biology and management. Sport Fishing Institute, Washington, D.C.

HOFFMAN, G.L. 1967. Parasites of North American freshwater fishes. University of California Press, Berkeley and Los Angeles. 486 p.

HOLMES, P.D., and J.W. MULLAN. 1965. Infection incidence and intensity of bass tapeworm in black basses of Bull Shoals Reservoir. Progressive Fish Culturist 27(3):142–146.

HUCKABEE, J.W., and N.A. GRIFFITH. 1974. Toxicity of mercury and selenium to the eggs of carp *(Cyprinus carpio)*. American Fisheries Society Transactions 103(4):822–825.

HUGGHINS, E.J. 1959. Parasites of fishes in South Dakota. Agricultural Experiment Station Bulletin 484, South Dakota State College and South Dakota Department of Game, Fish and Parks. 73 p.

INDUSTRIAL BIO-TEST LABORATORIES, INC. 1974. Physiological and chemical examination of fish from Lake Sangchris. IBT No. 6430 5374. Report to Commonwealth Edison Company, Chicago, Illinois. 10 p. + 2 appendices.

JENKINS, R.M. 1967. The influence of some environmental factors on standing crop and harvest of fishes in U. S. reservoirs. Pages 298–321 *in* Reservoir Fishery Resources Symposium. University of Georgia, Athens.

______. 1975. Black bass crops and species associations in reservoirs. Pages 114–124 *in* R.H. Stroud and H. Clepper, eds., Black bass biology and management. Sport Fishing Institute, Washington, D.C.

______. 1977. Prediction of fish biomass, harvest, and prey-predator relations in reservoirs. Pages 282–293 *in* W. VanWinkle, ed., Proceedings of the Conference on Assessing the Effects of Power Plant Induced Mortality on Fish Populations. Pergamon Press, NY.

JESTER, D.B. 1974. Life history, ecology, and management of the carp, *Cyprinus carpio* Linnaeus, in Elephant Butte Lake. New Mexico State University Agricultural Experiment Station Research Report 273. 80 p.

JOY, T., and J.A. TRANQUILLI. 1979*a*. Annual growth of largemouth bass in Lake Sangchris, Lake Shelbyville, and other Midwestern waters. Pages 10-1–10-14 *in* Evaluation of a cooling lake fishery. Vol. III. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

______, and ______. 1979*b*. Growth of fishes in Lake Sangchris and Lake Shelbyville. Pages 11-1–11-36 *in* Evaluation of a cooling lake fishery. Vol. III. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

KRAMER, R.H., and L.L. SMITH, JR. 1962. Formation of year classes in largemouth bass. American Fisheries Society Transactions 91(1):29–41.

LARIMORE, R.W. 1957. Ecological life history of the warmouth (Centrarchidae). Illinois Natural History Survey Bulletin 27:1–83.

MARCY, B.C., JR. 1976. Fishes of the Lower Connecticut River and the effects of the Connecticut Yankee Plant. Pages 61–113 *in* D. Merriman and L.M. Thorpe, eds., The Connecticut River ecological study. Monograph 1. American Fisheries Society, Washington, D.C. 252 p.

MASSENGILL, R.R. 1973. Change in feeding and body condition of brown bullheads overwintering in the heated effluent of a power plant. Chesapeake Science 14(2):138–141.

MAUCK, P.E., and R.C. SUMMERFELT. 1971. Sex ratio, age of spawning fish, and duration of spawning in the carp, *Cyprinus carpio* (Linnaeus) in Lake Carl Blackwell, Oklahoma. Kansas Academy of Science Transactions 74(2):221–227.

McNeely, D.L., and W.D. Pearson. 1974. Distribution and condition of fishes in a small reservoir receiving heated waters. American Fisheries Society Transactions 103(3):518–530.

McNurney, J.M., and H. Dreier. 1981. Lake Sangchris creel survey, 1973–1975. Pages 594–614 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

Miller, J.H. 1954. Studies on the life history of *Posthodiplostomum minimum* (MacCallum, 1921). Journal of Parasitology 40 (3):255–270.

Miller, R.W. 1974. Incidence and cause of gas-bubble disease in a heated effluent. Pages 79–93 *in* J.W. Gibbons and R.R. Sharitz, eds., Thermal ecology. AEC Symposium Series (CONF-730505), Augusta, GA.

Mraz, D., and E.L. Cooper. 1957*a*. Natural reproduction and survival of carp in small ponds. Journal of Wildlife Management 21(1):66-69.

______, and ______. 1957*b*. Reproduction of carp, largemouth bass, bluegills, and black crappies in small rearing ponds. Journal of Wildlife Management 21(2):127–133.

Neill, W.H., and J.J. Magnuson. 1974. Distributional ecology and behavioral thermoregulation of fishes in relation to heated effluent from a power plant at Lake Monona, Wisconsin. American Fisheries Society Transactions 103(4):663–710.

Nikolsky, G.V. 1963. The ecology of fishes. Academic Press, London and New York. 352 p.

Otto, R.G. 1976. Thermal effluents, fish, and gas-bubble disease in southwestern Lake Michigan. Pages 121–129 *in* G.W. Esch and R.W. McFarlane, eds., Thermal ecology. Vol. II. ERDA Symposium Series (CONF-750425), Augusta, GA.

Pflieger, W.L. 1975. The fishes of Missouri. Missouri Department of Conservation. 343 p.

Rawson, M.V., and W.A. Rogers. 1972. The seasonal abundance of the Ancyrocephalinae (Monogenea) on largemouth bass in Walter F. George Reservoir. Helminthological Society of Washington Proceedings 39(2):159–162.

Rutledge, C.J. 1975. The fishes of Lake Arlington, Texas—a reservoir receiving a heated effluent. M.S. Thesis. University of Texas, Arlington. 71 p.

Ryder, R.A. 1965. A method for estimating the the potential fish production of north-temperate lakes. American Fisheries Society Transactions 94(3):214–218.

Satterthwaite, F.E. 1946. An approximate distribution of estimates of variance components. Biometrics 2(6):110–114.

Shields, J.T. 1957. Experimental control of carp reproduction through water drawdowns in Fort Randal Reservoir, South Dakota. American Fisheries Society Transactions 87:23–33.

Smith, P.W. 1979. The fishes of Illinois. University of Illinois Press, Urbana. 314 p.

Smith, S.F. 1971. Effects of a thermal effluent on aquatic life in an east Texas reservoir. Southeastern Association of Game and Fish Commissioners Proceedings for 1970, 25:374–384.

Smitherman, R.O. 1968. Effect of the strigeid trematode, *Posthodiplostomum minimum*, upon growth and mortality of bluegill, *Lepomis macrochirus*. FAO Fisheries Report 44, Vol. 5:IX/E-8:380–388.

Starrett, W.C., and A.W. Fritz. 1965. A biological investigation of the fishes of Lake Chautauqua, Illinois. Illinois Natural History Survey Bulletin 29(1):1–104.

Stauffer, J.R., Jr., K.L. Dickson, J. Cairns, Jr., and D.S. Cherry. 1976. The potential and realized influences of temperature on the distribution of fishes in the New River, Glen Lyn, Virginia. Wildlife Monographs 50. 40 p.

Sule, M.J. 1981. First-year growth and feeding of largemouth bass in a heated reservoir. Pages 520–535 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

______, J.M. McNurney, and D.R. Halffield, Jr. 1981. Food habits of some common fishes from heated and unheated areas of Lake Sangchris. Pages 500–519 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

______, ______, and J.A. Tranquilli. 1979. Fecundities of fishes from Lake Sangchris and Lake Shelbyville. Pages 7-1–7-36 *in* Evaluation of a cooling lake fishery. Vol. III. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

Swee, U.B., and H.R. McCrimmon. 1966. Reproductive biology of the carp, *Cyprinus carpio* L., in Lake St. Lawrence, Ontario. American Fisheries Society Transactions 95(4):372–380.

Tranquilli, J.A., T. Joy, and J.M. McNurney. 1979*a*. A comparison of fish standing crops in Lake Sangchris and Lake Shelbyville. Pages 2-1–2-7 *in* Evaluation of a cooling lake fishery. Vol. III. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

______, ______, ______, R. Kocher, and H. Bergmann. 1979*b*. Fish population dynamics in Lake Sangchris and Lake Shelbyville. Pages 1-1–1-34 *in* Evaluation of a cooling lake fishery. Vol. III. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

______, J.M. McNurney, and R. Kocher. 1979*c*. Growth, movements, and population estimates for fishes from Lake Sangchris determined by tagging studies. Pages 4-1–4-35 *in* Evaluation of a cooling lake fishery. Vol. III. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

______, D.W. Dufford, R.W. Larimore, R. Kocher, and J.M. McNurney. 1981*a* Radiotelemetry observations on the behavior of largemouth bass in a heated reservoir. Pages

559–584 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

———, J.M. MCNURNEY, AND R. KOCHER. 1981*b*. Results of a multiple-objective fish-tagging program in an artificially heated reservoir. Pages 536–558 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

WALKER, C.R., R.E. LENNON, and B.L. BERGER. 1964. Preliminary observation on the toxicity of antimycin A to fish and other aquatic animals. U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife Circular 186. 18 p.

WARF INSTITUTE, INC. 1974. Letter to Mr. Ed Juracek, environmental officer, Commonwealth Edison Company, including technical results of heavy metal analyses and gross pathological observations. Warf No. 4061386-1387; 4110704-0705. Warf Institute, Inc., Madison, WI. 7 p.

WEBB, J.F., and D.D. MOSS. 1968. Spawning behavior and age and growth of white bass in Center Hill Reservoir, Tennessee. Southeastern Association of Game and Fish Commissioners Proceedings for 1967, 22:343–357.

WHITAKER, J.O., and R.A. SCHLUETER. 1973. Effects of heated discharge on fish and invertebrates of White River at Petersburg, Indiana. Indiana University Water Resources Research Center. Report of Investigations 6. Bloomington, IN. 123 p.

WITT, A., JR., R.S. CAMPBELL, and J.D. WHITLEY. 1970. The evaluation of environmental alterations by thermal loading and acid pollution in the cooling reservoir of a steam-electric station. Missouri Water Resources Research Center, University of Missouri, Columbia. Project No. A-020-Mo. 99 p.

APPENDIX A
NUMBERS OF FISHES IN BIMONTHLY COLLECTIONS

Table A1.—Total number of fishes collected from Lake Sangchris during January 1974. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	21	38	30	42	163	21	315
Carp	19	27	5	30	12	7	100
Hornyhead chub	...	...	...	...	...	...	...
Golden shiner	4	20	1	2	2	16	45
Striped x golden shiner hybrid	...	...	...	...	...	...	...
Striped shiner	1	...	...	...	...	...	1
Bigmouth shiner	...	...	...	...	...	2	2
Red shiner	4	8	4	10	...	75	101
White sucker	...	2	1	...	...	...	3
Black bullhead	16	30	4	5	1	4	60
Yellow bullhead	1	...	...	1	4	...	6
Channel catfish	2	9	7	13	1	...	32
Flathead catfish	...	...	...	...	...	...	...
Blackstripe topminnow	...	...	...	...	...	...	...
White bass	...	...	9	18	7	...	34
Yellow bass	6	3	30	68	134	68	309
Green sunfish	1	3	...	2	32	5	43
Bluegill	23	81	2	64	84	294	548
Bluegill x green sunfish hybrid	...	...	...	...	...	...	...
Largemouth bass	...	10	1	12	27	...	50
White crappie	8	6	1	4	1	9	29
Freshwater drum	...	...	...	...	...	...	...
Total number	*130*	*237*	*95*	*271*	*468*	*517*	*1,678*
Total species	*12*	*12*	*12*	*13*	*12*	*10*	*16*

Table A2.—Total number of fishes collected from Lake Sangchris during March 1974. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	354	139	54	116	32	253	948
Carp	16	11	10	16	50	8	111
Hornyhead chub	...	...	...	...	...	...	...
Golden shiner	9	8	9	7	2	4	39
Striped x golden shiner hybrid	...	...	...	...	...	...	...
Striped shiner	...	...	...	...	...	...	...
Bigmouth shiner	...	...	...	...	1	...	1
Red shiner	8	37	5	1	7	39	97
White sucker	...	...	...	...	...	4	4
Black bullhead	107	118	93	32	26	66	442
Yellow bullhead	8	15	9	9	1	3	45
Channel catfish	18	101	51	74	42	21	307
Flathead catfish	...	...	...	...	...	...	...
Blackstripe topminnow	...	...	...	...	...	...	...
White bass	4	...	2	3	40	...	49
Yellow bass	334	100	292	262	400	481	1,869
Green sunfish	33	5	89	15	27	3	172
Bluegill	291	185	587	505	463	231	2,262
Bluegill x green sunfish hybrid	2	1	1	...	1	1	6
Largemouth bass	7	22	60	57	19	27	192
White crappie	5	7	3	7	3	3	28
Freshwater drum	...	...	1	...	7	...	8
Total number	*1,196*	*749*	*1,266*	*1,104*	*1,121*	*1,144*	*6,580*
Total species	*14*	*13*	*15*	*13*	*16*	*14*	*17*

Table A3.—Total number of fishes taken from Lake Sangchris during May 1974. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	165	536	598	442	726	609	3,076
Carp	20	38	11	23	28	8	128
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	5	12	. . .	5	14	3	39
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	. . .	16	7	8	. . .	34	65
White sucker	3	1	. . .	. . .	. . .	3	7
Black bullhead	35	5	13	6	54	17	130
Yellow bullhead	9	. . .	1	2	. . .	1	13
Channel catfish	12	10	20	31	6	37	116
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	. . .	. . .	. . .
White bass	8	6	34	2	11	3	64
Yellow bass	517	217	212	143	30	96	1,215
Green sunfish	32	2	2	4	13	5	58
Bluegill	446	52	154	240	156	162	1,210
Bluegill x green sunfish hybrid	. . .	. . .	. . .	. . .	1	. . .	1
Largemouth bass	31	43	30	30	6	17	157
White crappie	3	6	. . .	3	. . .	7	19
Freshwater drum	3	. . .	4	14	1	. . .	22
Total number	*1,289*	*944*	*1,086*	*953*	*1,046*	*1,002*	*6,320*
Total species	*14*	*13*	*12*	*14*	*12*	*14*	*16*

Table A4.—Total number of fishes taken from Lake Sangchris during July 1974. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	277	276	239	156	1,464	1,844	4,256
Carp	18	20	20	6	13	15	92
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	3	22	1	1	3	2	32
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	10	2	5	3	2	7	29
White sucker	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Black bullhead	52	6	1	. . .	29	3	91
Yellow bullhead	13	4	6	3	1	7	34
Channel catfish	10	28	28	67	12	39	184
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	1	. . .	1
White bass	4	11	37	17	3	16	88
Yellow bass	275	504	376	20	3	377	1,555
Green sunfish	20	5	14	1	26	2	68
Bluegill	384	669	342	524	101	211	2,231
Bluegill x green sunfish hybrid	. . .	2	. . .	. . .	. . .	. . .	2
Largemouth bass	40	62	35	9	9	56	211
White crappie	1	2	7	4	. . .	13	27
Freshwater drum	4	7	9	6	7	5	38
Total number	*1,111*	*1,620*	*1,120*	*817*	*1,674*	*2,597*	*8,939*
Total species	*14*	*15*	*14*	*13*	*14*	*14*	*16*

Table A5.—Total number of fishes taken from Lake Sangchris during September 1974. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	192	175	154	207	378	160	1,266
Carp	32	21	13	8	12	14	100
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	3	4	3	1	. . .	1	12
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	11	3	62	68	2	215	361
White sucker	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Black bullhead	27	5	9	4	2	4	51
Yellow bullhead	9	9	8	1	2	4	33
Channel catfish	58	42	39	46	57	37	279
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	3	2	. . .	5
White bass	6	20	20	18	68	8	140
Yellow bass	271	413	288	340	98	144	1,554
Green sunfish	28	9	56	6	9	13	121
Bluegill	456	609	572	577	255	301	2,770
Bluegill x green sunfish hybrid	. . .	. . .	1	1	. . .	. . .	2
Largemouth bass	50	45	67	47	19	72	300
White crappie	2	5	10	1	. . .	6	24
Freshwater drum	12	32	45	34	14	27	164
Total number	*1,157*	*1,392*	*1,347*	*1,362*	*918*	*1,006*	*7,182*
Total species	*14*	*14*	*15*	*16*	*13*	*14*	*16*

Table A6.—Total number of fishes taken from Lake Sangchris during November 1974. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	153	84	344	164	279	389	1,413
Carp	29	21	18	15	13	51	147
Hornyhead chub	1	. . .	. . .	. . .	. . .	. . .	1
Golden shiner	. . .	3	4	12	1	5	25
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	291	21	12	9	18	603	954
White sucker	6	1	. . .	. . .	. . .	7	14
Black bullhead	26	93	3	1	1	13	137
Yellow bullhead	5	13	7	7	3	4	39
Channel catfish	2	19	3	9	1	11	45
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	1	1	1	. . .	3
White bass	5	18	25	3	25	6	32
Yellow bass	392	669	34	65	312	552	2,024
Green sunfish	27	16	44	12	55	12	166
Bluegill	207	278	183	419	228	177	1,492
Bluegill x green sunfish hybrid	1	. . .	. . .	. . .	3	. . .	4
Largemouth bass	37	30	82	93	19	15	276
White crappie	1	9	6	10	2	2	30
Freshwater drum	1	4	2	1	13	1	22
Total number	*1,184*	*1,279*	*768*	*821*	*974*	*1,848*	*6,874*
Total species	*16*	*13*	*15*	*15*	*16*	*15*	*18*

Table A7.—Total number of fishes taken from Lake Sangchris during January 1975. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	9	. . .	. . .	5	1,185	2	1,201
Carp	. . .	. . .	. . .	20	8	3	31
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	. . .	. . .	. . .	. . .	1	1	2
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	8	84	55	2	17	45	211
White sucker	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Black bullhead	. . .	2	. . .	. . .	1	. . .	3
Yellow bullhead	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Channel catfish	. . .	. . .	1	1	2	. . .	4
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	. . .	. . .	. . .
White bass	. . .	. . .	2	2	15	. . .	19
Yellow bass	1	. . .	1	3	80	1	86
Green sunfish	. . .	. . .	. . .	2	7	. . .	9
Bluegill	1	1	. . .	22	23	. . .	47
Bluegill x green sunfish hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Largemouth bass	. . .	1	1	15	4	. . .	21
White crappie	. . .	17	. . .	. . .	. . .	1	18
Freshwater drum	. . .	. . .	. . .	. . .	7	. . .	7
Total number	*19*	*105*	*60*	*72*	*1,350*	*53*	*1,659*
Total species	*4*	*5*	*5*	*9*	*12*	*6*	*13*

Table A8.—Total number of fishes collected from Lake Sangchris during March 1975. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	458	13	72	149	731	95	1,518
Carp	25	33	31	19	19	8	135
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	1	. . .	3	4	29	6	43
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	6	69	6	. . .	. . .	63	144
White sucker	2	1	. . .	. . .	. . .	1	4
Black bullhead	4	8	5	2	6	1	26
Yellow bullhead	. . .	1	3	. . .	1	1	6
Channel catfish	. . .	3	21	36	1	4	65
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	1	. . .	. . .	. . .	1
White bass	. . .	2	. . .	. . .	54	1	57
Yellow bass	4	2	34	38	776	38	892
Green sunfish	2	3	5	1	10	. . .	21
Bluegill	8	24	74	150	147	28	431
Bluegill x green sunfish hybrid	. . .	. . .	. . .	1	2	. . .	3
Largemouth bass	3	10	34	34	20	31	132
White crappie	3	3	1	3	1	5	16
Freshwater drum	. . .	. . .	. . .	1	9	. . .	10
Total number	*516*	*172*	*290*	*438*	*1,806*	*282*	*3,504*
Total species	*11*	*13*	*13*	*12*	*14*	*13*	*17*

Table A9.—Total number of fishes collected from Lake Sangchris during May 1975. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	295	243	359	294	458	367	2,016
Carp	17	23	22	20	20	39	141
Hornyhead chub	...	...	...	...	3	...	3
Golden shiner	1	2	2	3	1	1	10
Striped x golden shiner hybrid	...	1	...	...	...	...	1
Striped shiner	...	...	...	...	...	...	...
Bigmouth shiner	...	...	...	...	...	...	...
Red shiner	...	2	44	22	1	1	70
White sucker	1	...	...	...	...	1	2
Black bullhead	15	24	6	3	20	19	87
Yellow bullhead	4	3	1	2	...	1	11
Channel catfish	8	11	27	34	59	59	198
Flathead catfish	...	...	...	...	...	...	...
Blackstripe topminnow	...	...	...	...	1	...	1
White bass	1	...	3	1	5	4	14
Yellow bass	6	18	34	19	20	7	104
Green sunfish	20	3	29	...	11	5	68
Bluegill	160	200	182	212	95	149	998
Bluegill x green sunfish hybrid	...	...	...	...	...	...	...
Largemouth bass	76	84	47	41	32	25	305
White crappie	1	2	7	3	4	2	19
Freshwater drum	5	4	2	45	36	6	98
Total number	*610*	*620*	*765*	*699*	*766*	*686*	*4,146*
Total species	*14*	*14*	*14*	*11*	*15*	*15*	*18*

Table A10.—Total number of fishes collected from Lake Sangchris during July 1975. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	327	364	720	203	137	583	2,334
Carp	4	10	16	8	2	10	50
Hornyhead chub	...	...	...	...	...	...	...
Golden shiner	1	4	1	1	...	...	7
Striped x golden shiner hybrid	...	...	...	...	...	...	...
Striped shiner	...	...	...	...	...	...	...
Bigmouth shiner	...	...	...	...	...	...	...
Red shiner	28	18	21	6	2	4	79
White sucker	...	...	...	...	...	...	...
Black bullhead	4	4	2	...	2	3	15
Yellow bullhead	...	1	1	...	...	...	2
Channel catfish	7	22	20	22	...	20	91
Flathead catfish	...	...	...	...	...	...	...
Blackstripe topminnow	...	...	...	...	14	...	14
White bass	5	17	25	4	1	6	58
Yellow bass	2	10	23	21	1	4	61
Green sunfish	13	5	3	5	40	3	69
Bluegill	164	477	120	194	256	216	1,427
Bluegill x green sunfish hybrid	1	...	...	1	...	...	2
Largemouth bass	37	42	16	12	13	44	164
White crappie	1	2	1	3	...	1	8
Freshwater drum	...	7	16	4	2	13	42
Total number	*594*	*983*	*985*	*484*	*470*	*907*	*4,423*
Total species	*13*	*14*	*14*	*13*	*11*	*12*	*16*

Table A11.—Total number of fishes taken from Lake Sangchris during September 1975. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	285	333	658	424	697	391	2,788
Carp	11	12	7	11	12	8	61
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	4	5	2	1	. . .	1	13
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	18	54	10	. . .	2	8	92
White sucker	1	1	. . .	. . .	. . .	. . .	2
Black bullhead	6	3	. . .	. . .	6	1	16
Yellow bullhead	1	. . .	3	2	. . .	. . .	6
Channel catfish	45	13	3	20	6	32	119
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	8	. . .	8
White bass	5	7	26	5	19	11	73
Yellow bass	20	5	8	5	4	10	52
Green sunfish	37	12	13	8	21	16	107
Bluegill	343	330	173	336	143	190	1,515
Bluegill x green sunfish hybrid	1	2	. . .	. . .	. . .	1	4
Largemouth bass	58	62	27	24	48	32	251
White crappie	2	. . .	2	1	. . .	2	7
Freshwater drum	4	7	15	3	7	12	48
Total number	*841*	*846*	*947*	*840*	*973*	*707*	*5,157*
Total species	*16*	*14*	*13*	*12*	*12*	*14*	*17*

Table A12.—Total number of fishes taken from Lake Sangchris during November 1975. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	243	254	311	340	2,678	100	3,926
Carp	9	39	13	9	1	27	98
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	2	4	8	4	2	1	21
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	1	1
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	22	. . .	83	. . .	4	20	129
White sucker	2	. . .	. . .	. . .	. . .	. . .	2
Black bullhead	. . .	9	1	1	5	. . .	16
Yellow bullhead	1	1	10	2	. . .	. . .	14
Channel catfish	7	4	4	7	2	5	29
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	6	. . .	4	1	11
White bass	8	8	14	6	45	3	84
Yellow bass	209	31	54	6	119	4	423
Green sunfish	26	35	36	8	42	16	163
Bluegill	95	143	256	225	255	26	1,000
Bluegill x green sunfish hybrid	. . .	. . .	. . .	. . .	. . .	1	1
Largemouth bass	12	45	71	46	36	42	252
White crappie	4	4	2	4	. . .	2	16
Freshwater drum	2	2	1	3	8	. . .	16
Total number	*642*	*579*	*870*	*661*	*3,201*	*249*	*6,202*
Total species	*14*	*13*	*15*	*13*	*13*	*14*	*17*

Table A13.—Total number of fishes taken from Lake Sangchris during January 1976. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	1	...	8	185	900	...	1,094
Carp	...	9	1	29	5	...	44
Hornyhead chub	...	...	...	...	...	...	...
Golden shiner	...	...	...	1	...	...	1
Striped x golden shiner hybrid	...	...	...	...	...	...	...
Striped shiner	...	...	...	...	...	...	...
Bigmouth shiner	...	...	...	...	...	...	...
Red shiner	2	...	1	...	5	...	8
White sucker	...	...	...	...	...	...	...
Black bullhead	...	3	...	...	1	...	4
Yellow bullhead	...	...	3	1	1	...	5
Channel catfish	...	...	1	1	...	...	2
Flathead catfish	...	...	...	...	...	...	...
Blackstripe topminnow	...	...	...	...	...	...	...
White bass	...	...	11	3	15	...	29
Yellow bass	...	5	4	28	760	...	797
Green sunfish	...	...	27	1	8	...	36
Bluegill	...	1	102	107	9	...	219
Bluegill x green sunfish hybrid	...	...	...	...	...	...	...
Largemouth bass	...	...	8	8	2	...	18
White crappie	...	1	1	1	...	...	3
Freshwater drum	...	...	...	...	1	...	1
Total number	*3*	*19*	*167*	*365*	*1,707*	*0*	*2,261*
Total species	*2*	*5*	*11*	*11*	*11*	*0*	*14*

Table A14.—Total number of fishes collected from Lake Sangchris during March 1976. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	36	52	37	137	543	17	822
Carp	25	33	26	33	23	26	166
Hornyhead chub	...	...	...	...	...	...	...
Golden shiner	2	...	6	5	26	4	43
Striped x golden shiner hybrid	...	...	...	...	...	...	...
Striped shiner	...	...	...	...	...	...	...
Bigmouth shiner	...	...	...	...	...	...	...
Red shiner	21	4	5	1	4	1	36
White sucker	...	...	...	...	...	...	...
Black bullhead	...	2	...	1	1	...	4
Yellow bullhead	...	...	3	...	...	...	3
Channel catfish	2	3	1	10	5	5	26
Flathead catfish	...	...	...	...	...	...	...
Blackstripe topminnow	...	...	4	...	1	...	5
White bass	8	2	3	4	106	...	123
Yellow bass	109	19	13	37	547	10	735
Green sunfish	9	...	15	5	32	7	68
Bluegill	44	16	136	245	242	65	748
Bluegill x green sunfish hybrid	...	...	2	1	...	...	3
Largemouth bass	10	11	10	77	34	9	151
White crappie	1	1	2	...	1	2	7
Freshwater drum	...	2	...	2	2	...	6
Total number	*267*	*145*	*263*	*558*	*1,567*	*146*	*2,946*
Total species	*11*	*11*	*14*	*13*	*14*	*10*	*16*

Table A15.—Total number of fishes collected from Lake Sangchris during May 1976. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	180	304	243	287	1.451	139	2,604
Carp	17	21	13	27	28	20	126
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	15	7	8	3	1	6	40
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	1	. . .	1
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	7	3	1	6	2	1	20
White sucker	7	1	. . .	. . .	. . .	. . .	8
Black bullhead	6	9	1	. . .	62	3	81
Yellow bullhead	1	2	2	1	. . .	1	7
Channel catfish	4	8	5	10	29	4	60
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	. . .	. . .	. . .
White bass	4	8	11	3	30	23	79
Yellow bass	356	280	409	100	320	217	1.682
Green sunfish	41	8	6	4	10	5	74
Bluegill	153	164	99	149	97	197	859
Bluegill x green sunfish hybrid	1	. . .	1	. . .	1	. . .	3
Largemouth bass	35	45	55	28	6	29	198
White crappie	4	. . .	7	3	. . .	. . .	14
Freshwater drum	2	. . .	. . .	7	18	. . .	27
Total number	*833*	*860*	*861*	*628*	*2,056*	*645*	*5,883*
Total species	*16*	*13*	*14*	*13*	*14*	*12*	*18*

Table A16.—Total number of fishes collected from Lake Sangchris during July 1976. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	369	689	411	346	583	300	2.698
Carp	15	12	9	5	7	17	65
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	1	1	5	. . .	. . .	. . .	7
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	. . .	4	. . .	59	28	10	101
White sucker	1	. . .	. . .	. . .	. . .	. . .	1
Black bullhead	7	. . .	. . .	. . .	. . .	1	8
Yellow bullhead	. . .	. . .	8	. . .	. . .	. . .	8
Channel catfish	9	6	2	11	1	8	37
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	2	. . .	20	. . .	22
White bass	5	23	17	13	2	9	69
Yellow bass	23	7	2	19	. . .	23	74
Green sunfish	4	. . .	32	2	23	7	68
Bluegill	88	174	286	252	121	395	1.316
Bluegill x green sunfish hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Largemouth bass	19	25	24	13	11	49	141
White crappie	3	1	2	7	6	2	21
Freshwater drum	6	11	5	2	8	3	35
Total number	*550*	*953*	*805*	*729*	*810*	*824*	*4,671*
Total species	*13*	*11*	*13*	*11*	*11*	*12*	*16*

Table A17.—Total number of fishes collected from Lake Sangchris during September 1976. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	271	242	309	538	717	535	2,612
Carp	7	32	9	15	12	8	83
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	15	12	4	2	1	8	42
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	1	. . .	. . .	. . .	. . .	. . .	1
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	18	29	3	193	4	135	382
White sucker	1	. . .	. . .	. . .	. . .	. . .	1
Black bullhead	. . .	4	4	. . .	. . .	4	12
Yellow bullhead	. . .	1	35	1	2	. . .	39
Channel catfish	3	7	8	3	5	5	31
Flathead catfish	. . .	. . .	. . .	1	. . .	. . .	1
Blackstripe topminnow	. . .	. . .	22	. . .	5	. . .	27
White bass	25	25	67	6	19	7	149
Yellow bass	28	9	15	3	1,015	1	1,071
Green sunfish	83	8	83	9	33	19	235
Bluegill	314	399	242	229	244	330	1,758
Bluegill x green sunfish hybrid	. . .	. . .	3	. . .	. . .	. . .	3
Largemouth bass	69	82	39	26	79	111	406
White crappie	5	16	3	1	10	10	45
Freshwater drum	. . .	3	2	4	10	1	20
Total number	*840*	*869*	*848*	*1,031*	*2,156*	*1,174*	*6,918*
Total species	*13*	*14*	*16*	*14*	*14*	*13*	*19*

Table A18.—Total number of fishes collected from Lake Sangchris during November 1976. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	160	24	24	235	422	168	1,033
Carp	17	29	20	23	7	36	132
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	. . .	. . .	4	2	. . .	. . .	6
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	1	. . .	. . .	1
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	3	9	1	1	1	2	17
White sucker	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Black bullhead	. . .	7	1	1	. . .	2	11
Yellow bullhead	. . .	. . .	. . .	1	. . .	. . .	1
Channel catfish	. . .	. . .	3	5	1	. . .	9
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstipe topminnow	. . .	. . .	7	. . .	. . .	. . .	7
White bass	1	11	1	5	6	3	27
Yellow bass	160	28	7	7	297	39	538
Green sunfish	4	7	2	6	11	4	34
Bluegill	21	55	44	21	101	113	355
Bluegill x green sunfish hybrid	. . .	. . .	. . .	. . .	3	. . .	3
Largemouth bass	5	5	7	23	14	16	70
White crappie	2	7	2	28	3	16	58
Freshwater drum	. . .	. . .	. . .	2	3	. . .	5
Total number	*373*	*182*	*123*	*361*	*869*	*399*	*2,307*
Total species	*9*	*10*	*13*	*15*	*12*	*10*	*17*

APPENDIX B

BIOMASS OF FISHES IN BIMONTHLY COLLECTIONS

Table B1.—Total biomass in kilograms of fishes collected from Lake Sangchris during January 1974. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station 1	2	3	4	5	7	Total
Gizzard shad	1.4740	1.7250	1.8120	0.7430	12.1410	0.6920	18.5870
Carp	33.2800	38.6250	3.4320	42.3930	17.4450	13.9450	149.1200
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	0.0704	0.2450	0.0190	0.0950	0.0360	0.1890	0.6544
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	0.0030	. . .	. . .	. . .	. . .	. . .	0.0030
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	0.1030	0.1030
Red shiner	0.0152	0.0304	0.1380	0.0137	. . .	0.2850	0.4823
White sucker	. . .	1.1050	0.8650	. . .	. . .	. . .	1.9700
Black bullhead	1.4180	3.1320	0.5980	0.7270	0.1420	0.3280	6.3450
Yellow bullhead	0.0850	. . .	. . .	0.1540	0.1030	. . .	0.3420
Channel catfish	0.4860	2.1800	0.6090	3.5100	0.2410	. . .	7.0260
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	. . .	. . .	. . .
White bass	. . .	. . .	2.7070	6.6350	2.9190	. . .	12.2610
Yellow bass	0.1450	0.2940	2.2730	1.5610	5.7790	1.6290	11.6810
Green sunfish	0.0140	0.0980	. . .	0.0230	0.6210	0.0700	0.8260
Bluegill	0.8384	3.5390	0.1050	0.6615	1.9291	3.7940	10.8670
Bluegill x green sunfish hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Largemouth bass	. . .	0.6990	0.3240	3.6370	22.8420	. . .	27.5020
White crappie	0.5125	0.8780	0.1550	0.5030	0.1980	0.8410	3.0875
Freshwater drum	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Total	*38.3415*	*52.5504*	*13.0370*	*60.6562*	*64.3961*	*21.8760*	*250.8572*
Mean temperature (°C)	*5.8*	*6.5*	*6.3*	*8.0*	*14.7*	*3.7*	

Table B2.—Total biomass in kilograms of fishes collected from Lake Sangchris during March 1974. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station 1	2	3	4	5	7	Total
Gizzard shad	6.2241	7.9790	3.9180	8.9970	1.8100	6.6590	35.5871
Carp	21.6300	13.2530	15.7550	13.7650	78.0430	9.6670	152.1130
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	0.1890	0.1040	0.2380	0.1730	0.0460	0.1280	0.8780
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	0.0020	. . .	0.0020
Red shiner	0.0057	0.0220	0.0032	0.0020	0.0028	0.0214	0.0571
White sucker	. . .	. . .	. . .	. . .	. . .	1.1250	1.1250
Black bullhead	10.4790	20.2800	10.9010	3.7150	2.0620	7.7560	55.1930
Yellow bullhead	0.6410	1.1930	0.9130	1.1680	0.0340	0.3490	4.2980
Channel catfish	2.6120	15.3920	2.8560	14.3610	21.1260	1.3590	57.7060
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	. . .	. . .	. . .
White bass	1.4680	. . .	0.5710	0.8610	14.8220	. . .	17.7220
Yellow bass	4.7374	2.3060	5.5480	3.3500	11.0570	6.6070	33.6054
Green sunfish	1.2020	0.2320	2.3220	0.4740	0.8500	0.0315	5.1115
Bluegill	13.4963	5.2255	14.9850	11.3410	17.8920	6.6060	69.5458
Bluegill x green sunfish hybrid	0.1580	0.0520	0.0360	. . .	0.0780	0.0260	0.3500
Largemouth bass	0.7510	7.5630	27.3470	24.5350	13.0890	7.1120	80.3970
White crappie	0.3880	0.5690	0.2530	1.1300	1.4810	0.2200	4.0410
Freshwater drum	. . .	. . .	0.1020	. . .	0.3770	. . .	0.4790
Total	*63.9815*	*74.1705*	*85.7482*	*83.8720*	*162.7718*	*47.6669*	*518.2109*
Mean temperature (°C)	*9.3*	*10.7*	*10.6*	*15.3*	*18.6*	*9.2*	

Table B3.—Total biomass of fishes (kilograms) collected from Lake Sangchris during May 1974. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station 1	2	3	4	5	7	Total
Gizzard shad	9.9810	27.8560	27.2800	21.0555	29.8470	27.6090	143.6285
Carp	20.0450	40.4700	11.1650	21.8850	32.0450	7.8750	133.4850
Hornyhead chub	...	...	...	...	...	...	...
Golden shiner	0.1630	0.3720	...	0.1230	0.3860	0.0130	1.0570
Striped x golden shiner hybrid	...	...	...	...	...	...	...
Striped shiner	...	...	...	...	...	...	...
Bigmouth shiner	...	...	...	...	...	...	...
Red shiner	...	0.0200	0.3090	0.0200	...	0.0160	0.3650
White sucker	1.6900	0.4060	...	...	...	3.4050	5.5010
Black bullhead	4.1640	0.4250	1.6220	0.6760	2.4360	1.9670	11.2900
Yellow bullhead	0.7000	...	0.0560	0.2450	...	0.0550	1.0560
Channel catfish	1.2500	3.5930	1.7120	9.4170	8.4700	1.4910	25.9330
Flathead catfish	...	...	...	...	...	...	...
Blackstripe topminnow	...	...	...	...	...	...	...
White bass	2.4040	1.8100	11.5400	0.2770	4.1050	0.8210	20.9570
Yellow bass	7.3350	7.4810	6.4580	3.7410	0.6990	2.0590	27.7730
Green sunfish	1.6040	0.0780	0.0950	0.2180	0.3550	0.1860	2.5360
Bluegill	14.7940	1.7460	3.4030	5.8730	5.7610	3.6700	35.1570
Bluegill x green sunfish hybrid	...	...	...	...	0.0400	...	0.0400
Largemouth bass	20.2560	23.6970	19.4200	15.5770	3.8690	4.8840	87.7030
White crappie	0.0880	0.8120	...	0.5750	...	1.4130	2.8880
Freshwater drum	0.2550	...	0.2680	1.0290	0.1300	...	1.6820
Total	*84.7290*	*108.7660*	*83.3280*	*80.7115*	*88.0530*	*55.4640*	*501.0515*
Mean temperature (°C)	*23.0*	*19.1*	*23.5*	*21.1*	*27.6*	*21.8*	

Table B4.—Total biomass of fishes (kilograms) collected from Lake Sangchris during July 1974. The sampling effort at each station conisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station						Total
	1	2	3	4	5	7	
Gizzard shad	11.0030	16.8070	14.7440	5.8583	5.6290	18.7560	72.7973
Carp	22.0200	20.3000	15.4200	3.2760	10.9660	11.2320	83.2040
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	0.0800	0.1500	0.0400	0.0230	0.0190	0.0510	0.3630
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	0.0050	0.0030	0.0210	0.0075	0.0100	0.0063	0.0528
White sucker	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Black bullhead	5.2710	0.5850	0.1540	. . .	0.8690	0.2680	7.1470
Yellow bullhead	1.0140	0.3030	0.3400	0.3763	0.0200	0.7040	2.7573
Channel catfish	1.4150	1.5465	3.2490	5.9015	0.6260	5.6330	18.3710
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	0.0010	. . .	0.0010
White bass	0.5080	0.4925	8.8610	3.2744	0.0120	2.3630	15.5109
Yellow bass	4.1410	8.6550	7.8900	0.2520	0.0350	5.3300	19.9730
Green sunfish	0.7700	0.2223	1.4140	0.0080	0.7410	0.0440	3.1993
Bluegill	7.3370	9.3439	7.7980	12.9755	2.5770	4.4123	43.4437
Bluegill x green sunfish hybrid	. . .	0.0960	. . .	. . .	. . .	. . .	0.0960
Largemouth bass	13.7230	5.8553	5.6490	0.9163	2.3180	16.0668	44.5284
White crappie	0.4680	0.6330	0.9030	0.9670	. . .	1.8120	4.7830
Freshwater drum	0.6510	0.8950	1.2490	0.6330	0.7890	0.2630	4.4800
Total	*68.4060*	*65.8875*	*65.7220*	*34.4688*	*24.6120*	*66.9414*	*321.2747*
Mean temperature (°C)	*29.0*	*31.3*	*30.5*	*35.9*	*37.3*	*29.9*	

Table B5.—Total biomass of fishes (kilograms) collected from Lake Sangchris during September 1974. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station 1	Station 2	Station 3	Station 4	Station 5	Station 7	Total
Gizzard shad	11.0830	10.1490	6.8915	11.3857	13.0700	7.5660	60.1452
Carp	35.8300	23.7750	14.4250	5.9850	13.2700	17.1100	110.3950
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	0.0470	0.0633	0.0438	0.0070	. . .	0.0260	0.1871
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	0.0130	0.0003	0.0386	0.0397	0.0017	0.1057	0.1990
White sucker	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Black bullhead	2.6800	0.5150	1.1690	0.6260	0.0650	0.4310	5.4860
Yellow bullhead	0.7070	0.9360	0.5670	0.1130	0.0160	0.4240	2.7630
Channel catfish	4.8820	2.5870	3.3520	5.2980	3.6790	5.6410	25.4390
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	0.0049	0.0023	. . .	0.0072
White bass	0.4210	4.5770	4.1580	1.1330	2.1310	1.2014	13.6214
Yellow bass	3.7700	7.2510	4.0890	5.8910	2.2510	2.3060	25.5580
Green sunfish	0.7500	0.2257	1.6050	0.1445	0.2600	0.2453	3.2305
Bluegill	7.1225	11.5679	9.1504	5.6738	5.3354	5.5656	43.4156
Bluegill x green sunfish hybrid	. . .	. . .	0.0230	0.0420	. . .	. . .	0.0650
Largemouth bass	22.7135	11.6678	13.7431	7.1524	2.1589	20.1405	77.5762
White crappie	0.2160	0.8140	1.7190	0.0630	. . .	1.3400	4.1520
Freshwater drum	1.4360	1.1580	1.5870	1.4410	0.6930	0.5950	6.9100
Total	*91.6710*	*75.2870*	*62.5614*	*45.0000*	*42.9333*	*61.6975*	*379.1502*
Mean temperature (°C)	*23.8*	*24.0*	*24.5*	*27.2*	*27.9*	*24.3*	

Table B6.—Total biomass of fishes (kilograms) collected from Lake Sangchris during November 1974. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	5.8780	4.3700	16.3520	12.5810	11.0750	16.6630	66.9190
Carp	41.8000	27.6150	25.2100	23.7750	18.7200	38.6650	175.7850
Hornyhead chub	0.0230	. . .	. . .	. . .	. . .	. . .	0.0230
Golden shiner	. . .	0.1190	0.2410	0.5300	0.0170	0.0280	0.9350
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	0.1110	0.0309	0.0036	0.0265	0.0425	0.2600	0.4745
White sucker	3.5460	0.6600	. . .	. . .	. . .	3.3880	7.5940
Black bullhead	2.2560	8.1030	0.2430	0.0880	0.0280	1.7410	12.4590
Yellow bullhead	0.6780	1.1690	0.5070	1.1450	0.0360	0.3300	3.8650
Channel catfish	0.5500	0.6100	0.7880	1.1900	0.2420	1.2920	4.6720
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	0.0013	0.0020	0.0008	. . .	0.0041
White bass	0.0930	3.3350	7.4650	0.9390	1.2690	0.3380	13.4390
Yellow bass	9.0390	8.6390	1.4490	1.9680	9.8920	8.2020	39.1890
Green sunfish	0.8530	0.5210	0.9430	0.3210	1.7336	0.2941	4.6657
Bluegill	8.0600	16.0030	2.3879	9.3400	3.6566	3.7688	43.2163
Bluegill x green sunfish hybrid	0.0140	. . .	. . .	. . .	0.0790	. . .	0.0930
Largemouth bass	3.0980	4.1830	23.2392	49.0940	6.2260	1.8910	87.7312
White crappie	0.1010	1.5910	1.3520	2.8660	0.4780	0.4620	7.8500
Freshwater drum	0.1580	0.2900	0.3720	0.0380	1.8810	0.1720	2.9110
Total	*76.2580*	*77.2389*	*80.5540*	*103.9035*	*55.3765*	*77.4949*	*470.8258*
Mean temperature (°C)	*10.4*	*11.2*	*11.7*	*14.2*	*15.0*	*9.2*	

Table B7 —Total biomass of fishes (kilograms) collected from Lake Sangchris during January 1975. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station						Total
	1	2	3	4	5	7	
Gizzard shad	0.9330	. . .	. . .	0.4850	54.3660	0.0060	55.7900
Carp	. . .	. . .	. . .	19.7200	11.0500	3.1650	33.9350
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	. . .	. . .	. . .	. . .	0.0110	0.0040	0.0150
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	0.0040	0.0880	0.0147	0.0013	0.0150	0.0178	0.1408
White sucker	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Black bullhead	. . .	0.1530	. . .	. . .	0.0580	. . .	0.2110
Yellow bullhead	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Channel catfish	. . .	. . .	0.2620	0.2840	0.2520	. . .	0.7980
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	. . .	. . .	. . .
White bass	. . .	. . .	0.6380	0.4900	2.5870	. . .	3.7150
Yellow bass	0.0450	. . .	0.1370	0.2650	2.0240	0.0100	2.4810
Green sunfish	. . .	. . .	. . .	0.0840	0.1780	. . .	0.2620
Bluegill	0.0670	0.0680	. . .	0.1965	0.3630	. . .	0.6945
Bluegill x green sunfish hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Largemouth bass	. . .	0.0320	0.0770	1.0050	0.0850	. . .	1.1990
White crappie	. . .	2.8450	. . .	. . .	. . .	0.1280	2.9730
Freshwater drum	. . .	. . .	. . .	. . .	1.2480	. . .	1.2480
Total	*1.0490*	*3.1860*	*1.1287*	*22.5308*	*72.2370*	*3.3308*	*103.4623*
Mean temperature (°C)	*3.2*	*3.3*	*3.9*	*8.8*	*9.8*	*3.3*	

Table B8.—Total biomass of fishes (kilograms) collected from Lake Sangchris during March 1975. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station 1	2	3	4	5	7	Total
Gizzard shad	9.1750	0.6700	3.3220	6.8830	28.3590	3.6950	52.1040
Carp	39.6800	52.2900	40.4200	21.7050	23.7700	9.1250	186.9900
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	0.0130	. . .	0.0816	0.0440	0.7470	0.1990	1.0846
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	0.0052	0.0453	0.0088	. . .	. . .	0.0353	0.0946
White sucker	0.9080	0.2380	. . .	. . .	. . .	0.6500	1.7960
Black bullhead	0.3280	0.6900	0.5430	0.2110	0.6080	0.1160	2.4960
Yellow bullhead	. . .	0.0760	0.2370	. . .	0.0150	0.0680	0.3960
Channel catfish	. . .	1.8840	1.7860	8.4300	0.1710	0.5240	12.7950
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	0.0002	. . .	. . .	. . .	0.0002
White bass	. . .	1.0700	. . .	. . .	14.7010	0.1330	15.9040
Yellow bass	0.1210	0.0660	0.7690	1.0740	21.7350	1.2670	25.0320
Green sunfish	0.0300	0.2090	0.1280	0.0830	0.3480	. . .	0.7980
Bluegill	0.3590	1.4350	2.4690	3.5320	4.5075	1.1520	13.4545
Bluegill x green sunfish hybrid	. . .	. . .	. . .	0.0520	0.0870	. . .	0.1390
Largemouth bass	0.0780	5.1495	19.1480	14.7440	11.4360	6.0990	56.6545
White crappie	0.7820	0.4730	0.3370	0.5830	0.2540	1.1450	3.5740
Freshwater drum	. . .	. . .	. . .	0.1190	1.7140	. . .	1.8330
Total	*51.4792*	*64.2958*	*69.2496*	*57.4600*	*108.4525*	*24.2083*	*375.1454*
Mean temperature (°C)	*9.2*	*9.0*	*9.3*	*13.2*	*13.0*	*7.2*	

Table B9.—Total biomass of fishes (kilograms) collected from Lake Sangchris during May 1975. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station 1	2	3	4	5	7	Total
Gizzard shad	18.5860	14.5380	20.6290	14.1680	17.7610	22.3650	108.0470
Carp	19.4800	22.1550	19.3600	15.8950	16.1060	27.2100	120.2060
Hornyhead chub	. . .	. . .	. . .	. . .	0.0103	. . .	0.0103
Golden shiner	0.0310	0.0970	0.0209	0.0410	0.0130	0.0420	0.2449
Striped x golden shiner hybrid	. . .	0.0011	. . .	. . .	. . .	. . .	0.0011
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	. . .	0.0020	0.0625	0.0355	0.0025	0.0015	0.1040
White sucker	0.5000	. . .	. . .	. . .	. . .	0.5400	1.0400
Black bullhead	2.2020	2.4980	0.9370	0.3220	0.9520	2.4670	9.3780
Yellow bullhead	0.4490	0.3100	0.2440	0.2860	. . .	0.1250	1.4140
Channel catfish	4.7990	1.5210	2.3000	5.6920	18.1450	3.7900	36.2470
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	0.0019	. . .	0.0019
White bass	0.3790	. . .	0.7840	0.0820	1.9700	0.1230	3.3380
Yellow bass	0.9820	0.7860	0.9745	0.6370	0.4980	0.1650	4.0425
Green sunfish	0.7530	0.1740	0.6170	. . .	0.3520	0.1569	2.0529
Bluegill	4.1670	6.9630	4.1860	5.8395	2.9285	4.9305	29.0145
Bluegill x green sunfish hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Largemouth bass	15.0930	13.2592	4.8585	19.6878	9.6646	19.7806	32.3437
White crappie	0.1040	0.2690	1.2340	0.9850	0.8240	0.3510	3.7670
Freshwater drum	0.9550	0.2932	0.2370	3.2110	5.4640	0.3250	10.4902
Total	*68.4800*	*62.8715*	*56.4444*	*66.8818*	*74.6928*	*82.3725*	*411.7430*
Mean temperature (°C)	*25.2*	*24.9*	*26.0*	*27.3*	*27.9*	*23.7*	

Table B10.—Total biomass of fishes (kilograms) collected from Lake Sangchris during July 1975. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station						Total
	1	2	3	4	5	7	
Gizzard shad	20.6670	20.7220	33.8060	11.5792	4.7538	33.5351	125.0631
Carp	4.9200	11.6910	17.3700	7.3950	2.8640	9.7150	53.9550
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	0.0390	0.1268	0.0430	0.0065	. . .	. . .	0.2153
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	0.0385	0.0192	0.0418	0.0080	0.0013	0.0101	0.1189
White sucker	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Black bullhead	0.3840	0.4520	0.3620	. . .	0.1850	0.4060	1.7890
Yellow bullhead	. . .	0.1010	0.1790	. . .	. . .	. . .	0.2800
Channel catfish	2.7150	6.0400	3.8750	5.3110	. . .	4.5030	22.4440
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	0.0215	. . .	0.0215
White bass	0.5195	3.3950	5.5200	0.4930	0.1390	1.8020	11.8685
Yellow bass	0.0960	0.5700	0.7770	0.4070	0.0110	0.1990	2.0600
Green sunfish	0.5018	0.1604	0.1020	0.2340	0.7210	0.0802	1.7994
Bluegill	3.5110	4.9048	2.4024	3.4210	1.7308	4.4961	20.4661
Bluegill x green sunfish hybrid	0.0200	. . .	. . .	0.0300	. . .	. . .	0.0500
Largemouth bass	11.7793	3.4394	2.1620	2.6802	0.0805	9.2624	29.4038
White crappie	0.0690	0.2790	0.1660	0.5440	. . .	0.1440	1.2020
Freshwater drum	. . .	0.7570	1.8150	0.3430	0.1230	1.9860	5.0240
Total	*45.2601*	*52.6576*	*68.6212*	*32.4519*	*10.6309*	*66.1389*	*275.7606*
Mean temperature (°C)	*30.0*	*29.8*	*30.0*	*35.1*	*37.2*	*27.7*	

Table B11.—Total biomass of fishes (kilograms) collected from Lake Sangchris during September 1975. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station 1	2	3	4	5	7	Total
Gizzard shad	13.6920	17.1450	27.2350	17.5470	14.7450	2.4360	93.8000
Carp	10.8610	13.5830	6.8450	11.2090	12.0900	6.4350	61.0230
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	0.0930	0.1700	0.0480	0.0010	. . .	0.0700	0.3820
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	0.0140	0.0550	0.0385	. . .	0.0015	0.0065	0.1155
White sucker	0.5100	0.5000	. . .	. . .	. . .	. . .	1.0100
Black bullhead	0.5690	0.2900	. . .	. . .	0.1280	0.3080	1.2950
Yellow bullhead	0.1120	. . .	0.1280	0.1060	. . .	. . .	0.3460
Channel catfish	7.1080	3.2770	1.7800	9.5800	1.1000	3.6320	26.4770
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	0.0100	. . .	0.0100
White bass	0.4580	2.4190	6.1190	1.5760	1.6060	2.1320	14.3100
Yellow bass	0.8710	0.1750	0.2690	0.1400	0.0750	0.3020	1.8320
Green sunfish	0.9900	0.6410	0.4980	0.2000	0.3720	0.2890	2.9900
Bluegill	5.5280	4.1630	2.4440	6.2220	3.4950	3.2740	25.1260
Bluegill x green sunfish hybrid	0.0220	0.1060	. . .	. . .	. . .	0.0480	0.1760
Largemouth bass	10.5250	19.2460	0.2100	4.2720	3.6860	5.2375	43.1765
White crappie	0.2390	. . .	0.1230	0.0359	. . .	0.0150	0.4129
Freshwater drum	0.7950	0.3000	1.2000	0.3130	0.6500	1.5330	4.7910
Total	*52.3870*	*62.0700*	*46.9375*	*51.2019*	*37.9585*	*26.7180*	*277.2729*
Mean temperature (°C)	*26.6*	*26.2*	*29.5*	*29.8*	*31.5*	*28.8*	

Table B12.—Total biomass of fishes (kilograms) collected from Lake Sangchris during November 1975. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station						Total
	1	2	3	4	5	7	
Gizzard shad	9.3170	13.7460	16.9700	18.0170	41.1640	5.0210	104.2350
Carp	15.9650	44.7250	16.8450	6.9750	0.6310	35.2850	120.4260
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	0.0520	0.1530	0.2800	0.1060	0.0590	0.0390	0.6890
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	0.0015	0.0015
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	0.0050	. . .	0.1040	. . .	0.0035	0.0215	0.1340
White sucker	0.7960	. . .	. . .	. . .	. . .	. . .	0.7960
Black bullhead	. . .	0.8190	0.1220	0.1160	0.1320	. . .	1.1890
Yellow bullhead	0.1040	0.0720	0.6970	0.2430	. . .	. . .	1.1160
Channel catfish	2.4300	4.7420	1.5540	2.5000	0.0890	0.7670	12.0820
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	0.0035	. . .	0.0040	0.0003	0.0078
White bass	0.9430	2.5820	4.8100	2.3900	6.5300	0.0350	17.2900
Yellow bass	5.7840	1.3110	1.1550	0.2010	3.3270	0.0600	11.8380
Green sunfish	0.5430	0.2853	0.6135	0.1630	0.6750	0.0713	2.3511
Bluegill	1.0853	3.6033	3.0275	2.7580	2.8720	0.5630	13.9091
Bluegill x green sunfish hybrid	. . .	. . .	. . .	. . .	. . .	0.0160	0.0160
Largemouth bass	1.4890	19.8885	10.8440	19.2140	8.7810	1.3670	61.5835
White crappie	0.7280	0.6790	0.4480	0.7580	. . .	0.1880	2.8010
Freshwater drum	0.2530	0.3320	0.1500	0.7180	1.3370	. . .	2.7900
Total	*39.4943*	*92.9381*	*57.6235*	*54.1590*	*65.6045*	*43.4356*	*353.2550*
Mean temperature (°C)	*12.8*	*12.7*	*16.0*	*18.3*	*20.6*	*10.5*	

Table B13.—Total biomass of fishes (kilograms) collected from Lake Sangchris during January 1976. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station						Total
	1	2	3	4	5	7	
Gizzard shad	0.0110	. . .	0.8820	9.3860	38.6300	. . .	48.9090
Carp	. . .	12.3200	1.9850	43.2850	6.7500	. . .	64.3400
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	. . .	. . .	. . .	0.0440	. . .	. . .	0.0440
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	0.0015	. . .	0.0010	. . .	0.0105	. . .	0.0130
White sucker	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Black bullhead	. . .	0.2830	. . .	. . .	0.0240	. . .	0.3070
Yellow bullhead	. . .	. . .	0.1290	0.1570	0.0070	. . .	0.2930
Channel catfish	. . .	. . .	0.2500	0.0640	. . .	. . .	0.3140
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	. . .	. . .	. . .
White bass	. . .	. . .	6.7750	1.1510	0.6230	. . .	8.5490
Yellow bass	. . .	0.0780	0.2850	0.9370	20.6310	. . .	21.9310
Green sunfish	. . .	. . .	0.5590	0.0035	0.2220	. . .	0.7845
Bluegill	. . .	0.0530	0.7100	1.7400	0.1690	. . .	2.6720
Bluegill x green sunfish hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Largemouth bass	. . .	. . .	5.5520	2.5920	0.0300	. . .	8.1740
White crappie	. . .	0.3200	0.2800	0.0800	. . .	. . .	0.6800
Freshwater drum	. . .	. . .	. . .	. . .	0.2310	. . .	0.2310
Total	*0.0125*	*13.0540*	*17.4080*	*59.4395*	*67.3275*	*0*	*157.2415*
Mean temperature (°C)	*2.1*	*3.0*	*3.6*	*7.3*	*11.3*	*0*	

Table B14.—Total biomass of fishes (kilograms) collected from Lake Sangchris during March 1976. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station						Total
	1	2	3	4	5	7	
Gizzard shad	0.7595	6.5190	4.1090	12.8450	19.1680	1.7180	45.1185
Carp	36.4430	49.1100	32.0950	46.4700	21.3450	33.6400	219.1030
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	0.0150	. . .	0.1220	0.1370	1.1350	0.0870	1.4960
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	0.0390	0.0060	0.0070	0.0010	0.0040	0.0020	0.0590
White sucker	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Black bullhead	. . .	0.1650	. . .	0.1640	0.0620	. . .	0.3910
Yellow bullhead	. . .	. . .	0.1550	. . .	. . .	. . .	0.1550
Channel catfish	0.4650	1.9170	0.3290	4.2930	1.2720	1.7330	10.0090
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	0.0040	. . .	0.0020	. . .	0.0060
White bass	6.8130	0.7220	0.9300	1.0450	30.5510	. . .	49.0610
Yellow bass	2.8100	0.7930	0.4020	0.8740	10.7580	0.2750	15.9120
Green sunfish	0.2520	. . .	0.2610	0.2300	0.8330	0.1800	1.7560
Bluegill	2.2130	0.7700	3.4840	6.1130	5.2660	1.2880	18.1340
Bluegill x green sunfish hybrid	. . .	. . .	0.0590	0.0250	. . .	. . .	0.0840
Largemouth bass	2.2155	7.3140	9.5150	46.2850	20.6080	6.2130	92.1505
White crappie	0.0420	0.1130	0.4930	. . .	0.1380	0.3240	1.1100
Freshwater drum	. . .	0.2810	. . .	0.8020	0.2340	. . .	1.3170
Total	*52.0670*	*67.7100*	*51.9650*	*118.2840*	*120.3760*	*45.4600*	*455.8620*
Mean temperature (°C)	*10.1*	*10.1*	*11.0*	*12.9*	*13.5*	*9.7*	

Table B15.—Total biomass of fishes (kilograms) collected from Lake Sangchris during May 1976. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station 1	Station 2	Station 3	Station 4	Station 5	Station 7	Total
Gizzard shad	8.3890	15.7180	15.4250	13.9900	25.0180	7.5970	113.1320
Carp	25.8400	26.8680	15.7800	30.4500	24.2650	26.0100	149.2130
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	0.5810	0.1720	0.4720	0.0840	0.0670	0.3060	1.6820
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	. . .	0.0780	. . .	0.0780
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	0.0030	0.0150	0.0040	0.0090	0.0010	0.0010	0.0330
White sucker	5.0750	0.5650	. . .	. . .	. . .	. . .	5.6400
Black bullhead	0.6180	1.0140	0.1350	. . .	1.9850	0.3850	4.1370
Yellow bullhead	0.0930	0.2900	0.2350	0.1880	. . .	0.0800	0.8860
Channel catfish	0.6650	1.6900	2.1050	3.1980	13.8210	0.5580	22.0370
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	. . .	. . .	. . .	. . .	. . .
White bass	1.2020	2.1100	3.5220	0.8900	9.5390	6.6400	23.9030
Yellow bass	9.9320	8.2950	11.9640	2.6750	6.4700	5.9870	45.3230
Green sunfish	1.5410	0.4350	0.1890	0.2550	0.2990	0.1630	2.8820
Bluegill	5.8850	4.5520	2.6070	5.4640	3.6640	5.3660	27.5380
Bluegill x green sunfish hybrid	0.1310	. . .	0.0250	. . .	0.0310	. . .	0.1870
Largemouth bass	17.1340	36.6180	43.0120	21.5650	0.8880	14.7050	133.9220
White crappie	0.7250	. . .	2.2500	0.6490	. . .	. . .	3.6240
Freshwater drum	0.2750	. . .	. . .	0.9500	2.5660	. . .	3.7910
Total	*78.0890*	*98.3420*	*97.7250*	*80.3670*	*115.6870*	*67.7980*	*538.0080*
Mean temperature (°C)	*19.0*	*19.6*	*20.3*	*23.0*	*25.9*	*20.2*	

Table B16.—Total biomass of fishes (kilograms) collected from Lake Sangchris during July 1976. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

Species	Station						Total
	1	2	3	4	5	7	
Gizzard shad	27.2160	40.9900	22.3000	15.8370	16.6170	20.4550	143.4150
Carp	12.9900	10.9450	5.5550	5.8200	5.2200	20.1150	60.6450
Hornyhead chub	...	...	...	...	...	...	...
Golden shiner	0.0420	0.0330	0.3080	...	...	...	0.3830
Striped x golden shiner hybrid	...	...	...	...	...	...	...
Striped shiner	...	...	...	...	...	...	...
Bigmouth shiner	...	...	...	...	...	...	...
Red shiner	...	0.0050	...	0.0720	0.0310	0.0200	0.1280
White sucker	0.1100	...	...	...	...	...	0.1100
Black bullhead	0.8360	...	...	...	...	0.1450	0.9810
Yellow bullhead	...	...	0.5550	...	...	...	0.5550
Channel catfish	1.4290	1.1810	0.6900	2.3500	0.0660	1.1450	6.8610
Flathead catfish	...	...	...	...	...	...	...
Blackstripe topminnow	...	...	0.0010	...	0.0140	...	0.0150
White bass	1.6860	6.1440	4.6450	3.0520	0.2040	2.8500	18.5810
Yellow bass	0.7150	0.3200	0.0400	0.2870	...	0.5600	1.9220
Green sunfish	0.2470	...	0.9850	0.1150	0.5040	0.1330	1.9840
Bluegill	2.7801	2.2500	4.5970	4.1170	1.5445	2.4950	17.7836
Bluegill x green sunfish hybrid	...	...	...	...	...	...	...
Largemouth bass	6.5950	6.6565	3.6350	1.6200	1.9540	15.1780	35.6385
White crappie	0.8370	0.3250	0.0460	0.5470	0.3690	0.1650	2.2890
Freshwater drum	1.0680	1.3290	0.6020	0.2600	0.8620	0.5600	4.6810
Total	*56.5511*	*70.1785*	*43.9590*	*34.0770*	*27.3855*	*63.8210*	*295.9721*
Mean temperature (°C)	*27.3*	*27.8*	*29.1*	*32.3*	*34.9*	*28.3*	

Table B17.—Total biomass of fishes (kilograms) collected from Lake Sangchris during September 1976. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.[a]

Species	Station						Total
	1	2	3	4	5	7	
Gizzard shad	16.4440	16.8950	19.3520	31.1480	24.5110	31.6940	140.0440
Carp	12.3750	38.8780	9.8650	16.3600	16.5550	10.9450	104.9780
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	0.1410	0.3440	0.0910	0.1220	0.0430	0.1600	0.9010
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	0.0470	. . .	. . .	. . .	. . .	. . .	0.0470
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	0.0170	0.0610	0.0010	0.1310	0.0010	0.1810	0.3920
White sucker	0.7350	. . .	. . .	. . .	. . .	. . .	0.7350
Black bullhead	. . .	0.3420	0.3200	. . .	. . .	0.4650	1.1270
Yellow bullhead	. . .	0.0570	1.8850	0.0980	0.0140	. . .	2.0540
Channel catfish	0.3700	1.0930	1.5400	0.3180	1.2440	1.2510	5.8160
Flathead catfish	. . .	. . .	. . .	1.7600	. . .	. . .	1.7600
Blackstripe topminnow	. . .	. . .	0.0160	. . .	0.0040	. . .	0.0200
White bass	6.0010	7.5190	18.0270	1.4020	1.9090	1.6630	36.5210
Yellow bass	1.1050	0.3670	0.5170	0.0800	21.2000	0.1330	23.4020
Green sunfish	2.3400	0.1900	2.1770	0.3320	1.0830	0.5440	7.6660
Bluegill	5.2630	4.0410	4.8210	5.1340	3.9400	5.7940	28.9930
Bluegill x green sunfish hybrid	. . .	. . .	0.1120	. . .	. . .	. . .	0.1120
Largemouth bass	11.6890	22.1450	9.9440	4.7120	9.7940	17.9840	67.2680
White crappie	0.4370	0.9970	0.3730	0.4150	0.9120	0.9350	4.0690
Freshwater drum	. . .	0.4850	0.3450	0.6060	1.4470	0.1390	3.0330
Total	*56.9640*	*93.4140*	*69.3970*	*62.6180*	*82.6570*	*71.8880*	*436.9380*
Mean temperature (°C)	*19.4*	*19.1*	*19.7*	*18.3*	*22.7*	*19.6*	

[a] No thermal discharge occurred during September 1976 as Kincaid Generating Station was not in operation.

Table B18.—Total biomass of fishes (kilograms) collected from Lake Sangchris during November 1976. The sampling effort at each station consisted of 1 hour of alternating-current electrofishing, one (24-hour) experimental gill net set, and four seine hauls.

	Station						
Species	1	2	3	4	5	7	Total
Gizzard shad	9.9000	2.0540	1.9900	17.6250	13.2780	5.7550	50.6020
Carp	29.0000	41.5100	30.8900	26.6770	9.5900	14.1990	151.8660
Hornyhead chub	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Golden shiner	. . .	. . .	0.1180	0.0620	. . .	. . .	0.1800
Striped x golden shiner hybrid	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Striped shiner	. . .	. . .	. . .	0.0550	. . .	. . .	0.0550
Bigmouth shiner	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Red shiner	0.0020	0.0095	0.0005	0.0005	0.0005	0.0015	0.0145
White sucker	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Black bullhead	. . .	0.6230	0.0940	0.1130	. . .	0.2970	1.1270
Yellow bullhead	. . .	. . .	. . .	0.0530	. . .	. . .	0.0530
Channel catfish	. . .	. . .	0.2300	1.1700	0.5050	. . .	1.9050
Flathead catfish	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blackstripe topminnow	. . .	. . .	0.0020	. . .	. . .	. . .	0.0020
White bass	0.0200	3.1020	0.0260	1.9230	0.0720	0.0960	5.2390
Yellow bass	5.2940	1.4690	0.3040	0.2470	7.0550	1.8880	16.2570
Green sunfish	0.1320	0.0970	0.0560	0.1210	0.2040	0.0610	0.6710
Bluegill	1.1050	2.1180	1.7020	0.5810	1.1850	4.7195	11.4105
Bluegill x green sunfish hybrid	. . .	. . .	. . .	. . .	0.0960	. . .	0.0960
Largemouth bass	0.0340	1.3360	4.4550	10.7100	0.2570	0.6800	17.4720
White crappie	0.3120	0.4970	0.1620	5.5900	0.3480	2.6500	9.5590
Freshwater drum	. . .	. . .	. . .	0.3730	0.6610	. . .	1.0340
Total	*45.7990*	*52.8155*	*40.0295*	*65.3005*	*33.2515*	*30.3470*	*267.5430*
Mean temperature (°C)	*6.5*	*6.0*	*4.7*	*8.3*	*12.2*	*4.3*	

Food Habits of Some Common Fishes from Heated and Unheated Areas of Lake Sangchris

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ABSTRACT

The food habits of largemouth bass, bluegill, channel catfish, yellow bass, and freshwater drum were studied during various periods from 1974 through 1976 to determine the typical foods used and seasonal shifts in feeding in a power plant cooling lake. Diets changed with season and fish size, but they generally followed similar patterns of change in the two thermally dissimilar areas and depended primarily on food resource availability.

Through some part of their growth history each species used aquatic insects and zooplankton as food. Largemouth bass and channel catfish were best adapted to the resource structure of the lake because of morphological or physiological features that allowed them to consume underutilized food resources. No peculiar feeding relationships were found among the fishes of Lake Sangchris. Ingestion rates relative to food resource production rates were not measured.

INTRODUCTION

Knowledge of the types and quantities of food consumed by a species is necessary for a basic understanding of the interactions within most ecosystems. In an aquatic ecosystem, the interrelationships of various key consumers within the food web are usually of great interest to lake managers and fishermen but are often complex and difficult to quantify. In addition to determining these relationships, researchers studying an artificially heated lake need to identify any deviations from normal fish feeding which are attributable to the various water temperatures of the lake. This study was initiated to determine the typical foods for fish of different lengths (ages) during different seasons and to ascertain any changes in food habits as a result of power plant operation. Of primary interest were the food habits of fish inhabiting the intake and discharge arms of Lake Sangchris and their diet changes relative to water temperatures. Diets of all major fish species of Lake Sangchris except carp were examined. Results of stomach analyses are presented for largemouth bass, *Micropterus salmoides* (Lacepede); channel catfish, *Ictalurus punctatus* (Rafinesque); freshwater drum, *Aplodinotus grunniens* Rafinesque; yellow bass, *Morone mississippiensis* Jordan & Eigenmann; and bluegill, *Lepomis macrochirus* Rafinesque.

Largemouth bass was the primary game fish for most anglers at Lake Sangchris during the study period (McNurney & Dreier 1981). Although its popularity as a game fish was adequate qualification for food-habits investigations, other characteristics of this species in Lake Sangchris necessitated its inclusion in any comprehensive study of the lake.

Largemouth bass in Lake Sangchris have exhibited exceptional growth and good population levels longer than in most newly constructed reservoirs (Tranquilli et al. 1981). Therefore, basic information was needed concerning the food

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resources used in such favorable bass production. Even more important was the influence this species has upon the entire lake ecosystem. Largemouth bass are typically piscivorous and could play a major role in the population dynamics of the various forage fishes in the system. Considering this role of the largemouth bass and our increasing demand for electrical energy production, knowledge gained about the relationships between largemouth bass and heated water can only better equip us to meet our future energy and recreational needs more wisely.

The food habits of channel catfish in the intake and discharge arms of Lake Sangchris were of particular interest to biologists studying the lake because of the unusual reproductive success channel catfish achieved in Lake Sangchris, a lake not expected to be conducive to channel catfish production (Tranquilli et al. 1981). Only by knowing food habits and other life history information can one isolate the factors responsible for such unexpected reproduction. The channel catfish was also a prime game fish for Lake Sangchris anglers (McNurney & Dreier 1981). This reason alone has justifiably dictated most of the past fisheries research regarding fish food habits. Additionally, channel catfish could potentially suppress growth or reproduction of other fishes in Lake Sangchris through competition for limited foods. For example, channel catfish competition with bluegill and redear sunfish apparently reduced sunfish growth, condition, and reproduction and consequently limited bass growth in Alabama farm ponds (Brown 1965). Competition of this type as well as direct predation could be extremely important in the dynamics of a cooling lake fishery. Fourthly, since channel catfish are often opportunistic omnivores (Bailey & Harrison 1948), their diet may indicate the general condition of the fish food base of the lake.

Freshwater drum were not known to occur in Lake Sangchris until they were collected in substantial numbers during March 1974. At that time, concern mounted regarding the potential problems and possible promise associated with this species, and it was included among species to be examined for diet. Freshwater drum represented an expanding fish population that had the potential to provide an important future sport fishery to the area. We also thought that the free-floating eggs of the drum might be highly vulnerable to mechanically induced mortality from power plant entrainment. Freshwater drum might also act as a natural control for populations of the Asiatic clam, *Corbicula fluminea*, that can foul power plant condenser tubes. Consequently, diets of freshwater drum were monitored during the establishment of the species to understand better its relationships in a heated reservoir and to provide basic information for management.

Since the yellow bass was one of the six most abundant fish (by weight) in Lake Sangchris, it was included in the food-habits investigations. The yellow bass population in Lake Sangchris was stunted, with only a few individuals larger than 200 mm (Tranquilli et al. 1981). A possible cause for a stunted population is an inadequate food base, and we studied the food habits of yellow bass to determine their food source and its adequacy.

Bluegills were also commonly collected in Lake Sangchris but were not an important species in the creel (McNurney & Dreier 1981). Bluegills can be an important sport fish for anglers in some lakes; however, in Lake Sangchris they were stunted (Tranquilli et al. 1981). Consequently, bluegill diets were examined for comparison with those of bluegills in other areas and to determine if any deviations observed were power-plant induced.

DESCRIPTION OF THE STUDY AREA

Lake Sangchris is an 876-ha power plant cooling lake situated in central Illinois approximately 24 km southeast of Springfield. The lake, described in detail by Larimore & Tranquilli (1981), consists of three arms, two of which form a cooling loop for the Commonwealth Edison Kincaid Generating Station. The middle arm of the lake (discharge arm) receives cooling water with waste heat from the power plant and usually has temperatures 7°–9°C higher than water temperatures in the west (intake) arm. Water travels around the cooling loop and dissipates waste heat before being reused by the power plant. Study sites selected for comparison of fish food habits in the lake's two temperature regimes (intake and discharge arms) were the same described by Tranquilli et al. (1981) for fish population comparisons.

METHODS

During 1974 fish collections were made bimonthly in the intake (stations 1 and 2) and discharge (stations 4 and 5) arms of Lake Sangchris for each of the five previously mentioned species. In 1975 collections were made at approximately 3-week intervals during the spring at stations 1.5 (intake arm) and 4.5 (discharge arm) in addition to those taken during the regular bimonthly fish collections continued from the previous year. Samples from outside the cooling loop were not included because of limitations of manpower and time. No channel catfish were collected for stomach analysis in 1975. Channel catfish and freshwater drum are the only fish discussed in this study that were collected for stomach analysis during 1976. During 1976 fish were collected at approximately 3-week intervals (May–October 1976) from the intake (stations 1, 1.5, and 2) and discharge (stations 4, 4.5, and 5) arms of the lake.

All fish analyzed for stomach contents were collected by electrofishing along the shoreline with a boat-mounted shocker, which employed a 230-volt, three-phase AC generator as the power source. Collections were made at night during 1974 and during daylight hours in subsequent years.

The stomachs of large fish and whole small fish were preserved in 10-percent formalin for later examination. Stomachs were individually opened, and their contents were identified to the lowest possible taxon under a dissecting microscope. The proportion of the meal represented by each food item was determined by weight (wet blotted) and recorded as a percentage of the total weight of food and matter per stomach. The average of these percentages was used to indicate the portion of the diet represented by each kind of food. Only stomachs that contained measurable (≤ 0.1 mg) amounts of food were used in calculating average weight percentages. Analyses of this type give equal importance to stomach contents from small and large fish and to stomachs in different stages of digestion or degrees of fullness, as discussed by Larimore (1957).

RESULTS AND DISCUSSION

LARGEMOUTH BASS

Largemouth bass collected for stomach analysis in the intake and discharge arms of Lake Sangchris totaled 792 specimens (54–754 mm total length). Fish collected in the discharge arm of the lake constituted 57 percent of the total and were collected in equal proportion during 1974 and 1975. Fifty-eight percent of the bass from the intake arm were collected during 1974. Most bass were captured during March, May, and September, the 3 months in which collections from the 2 years coincided. Over the 2-year period, bass were captured for stomach analysis during all calendar months except June, August, October, and December. Although during both years bass from the discharge arm averaged greater total lengths than those from the intake arm, mean lengths were not significantly different (5-percent level), and bass collectively averaged 253 mm in total length.

The predominant food item of bass in both arms of the lake during 1974 and 1975 was fish, chiefly gizzard shad, *Dorosoma cepedianum* (Lesueur). Fish constituted 61 percent and 44 percent of the diet of bass in the intake arm in 1974 and 1975, respectively, and averaged 54 percent for that area overall. The diet of bass in the discharge arm consisted of 80 percent and 65 percent fish in those years and averaged 72 percent.

Insects were the only other food that contributed substantially to bass diets. Insects constituted a larger proportion of the food of bass from the intake arm of the lake than they constituted of food of bass from the discharge arm. Collectively, insects provided averages of 18 percent and 32 percent of the food that bass consumed in the intake arm during 1974 and 1975, respectively, and averaged 24 percent of the diet for all bass from the intake arm. Insects provided only 8 percent of the bass diet in the discharge arm. Chironomids, ephemeropterans, zygopterans, and terrestrial or aerial insects were the major components of the insect portion of the bass diet.

Many specimens were needed to evaluate the effects of heated water on the food habits of largemouth bass. Factors such as time of collection and specimen size are two important variables which limit conclusions drawn from small samples collected over several years. Another complicating factor is the number of empty stomachs encountered when examining largemouth bass. Bass stomachs from the intake arm were empty 31 percent of the time (33 percent in 1974, 27 percent in 1975), while 38 percent of those from the discharge arm were empty (41 percent in 1974, 35 percent in 1975). These figures are smaller than the average of 56 percent reported by Zweiacker & Summerfelt (1974) in Oklahoma and indicate that good bass feeding conditions generally prevailed in Lake Sangchris.

Although average percentages of certain foods over entire years are adequate for an overview of a fish's diet, the effects upon the diet of fish size and season of collection are matters which need detailed examination before any evaluation can be made regarding the effects of an extraneous influence, such as heated water.

Probably the most important influence to keep in mind when comparing fish diets from different areas is the sizes of fish that are being compared. Bass diets in Lake Sangchris changed according to the lengths of the fish examined. Zooplankton was more important as a food source to small (60–100 mm) bass than to larger ones in both study areas of the lake (Fig. 1). Although zooplankton was never the major food of these bass, it formed a substantial portion of their diet and showed a marked decrease in importance in larger fish. The fact that zooplankton never represented the major food for Lake Sangchris bass reflected the rather large size of the smallest bass examined.

Bass smaller than 140 mm from both arms of the lake preyed primarily on insects. Insects were still consumed by bass 140–250 mm long but in greatly reduced proportions. In general, bass from the intake arm ate more insects than did those from the discharge arm (Fig. 1). Comparatively lower benthic biomass in the discharge channel (Webb 1981) was probably responsible for the difference in insect consumption observed.

Beyond 140 mm, bass ate virtually nothing but fish. Bass between 80 and 140 mm consumed some fish but were still mainly insectivorous. Among bass in the transition stage between insectivorous size and piscivorous size, those in the discharge arm typically ate more fish than those in the intake arm. Fish consumption by largemouth bass larger than 140 mm was nearly identical in the two arms of Lake Sangchris (Fig 1). Cyprinidae and *Lepomis* species were important to small piscivorous bass, while larger bass primarily ate gizzard shad and secondarily ate *Lepomis* species.

These results were not unlike those obtained by Sule (1981) for food habits of young-of-the-year bass in Lake Sangchris during 1975. It was learned in that study that most zooplankton was consumed by largemouth bass shorter than 50 mm and in lesser amounts by bass beyond that size. Insect consumption, in that study, was also associated with bass of the size

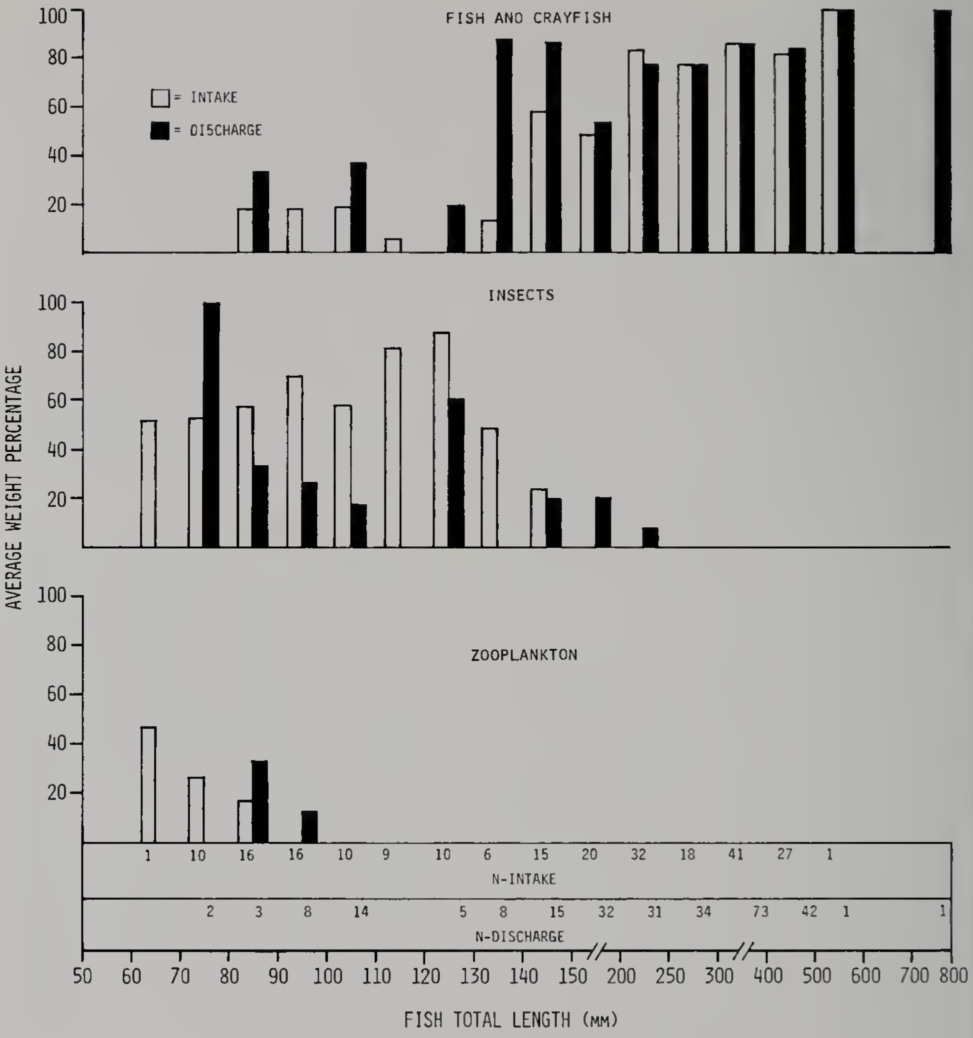

Fig. 1.—Average weight percentages of major foods found in largemouth bass of different lengths from the intake and discharge arms of Lake Sangchris during 1974 and 1975.

found here to be mainly insectivorous. Young-of-the-year bass were reported not to have preyed upon fish consistently until they reached a total length of 90–100 mm. The data presented here indicated that for largemouth bass in Lake Sangchris the complete shift from insectivore to piscivore may occur at around 140 mm.

According to size, bass from both arms of Lake Sangchris showed about the same food habits. Those in the intake arm ate more insects and less fish than those in the discharge arm until the complete shift in food habits occurred. From fish of that size to the largest bass examined, reliance upon fish as forage was equally great in both the intake and discharge arms of the lake. These trends were evident during both 1974 and 1975.

For the best analysis of feeding seasonality, it is essential that comparisons of similar-sized fish be made at frequent intervals throughout the year. As in most analyses, the effort required for such comparisons proved too great, and conclusions had to be based upon smaller samples. In general, though, consumption of fish by bass in both arms of the lake was high during each collection.

Crayfish consumption occurred mainly during the spring. Occurrence of other foods, such as zooplankton or insects, was primarily correlated to the size of fish examined.

The food habits of largemouth bass have been extensively investigated (Carlander 1977). Although contingent upon prey available in each particular body of water, young bass generally begin to feed upon zooplankton and as size increases, progressively depend more upon larger arthropods (mainly aquatic insects). As bass grow, their diets eventually shift to include larger organisms, such as fish and crayfish. Bass ordinarily continue to feed upon the most efficient foods available, which generally means the largest fish that bass can easily catch and swallow. Opportunities undoubtedly arise, however, when the abundance of undersized prey compensate for the inefficiency involved in their capture. Consequently, there are times when many small fish or numerous terrestrial insects, for example, become conspicuous in the diet of large bass that generally prey on larger foods. There is also the possibility that in some circumstances prey of the proper size are simply unavailable. What appears important for good bass growth and reproduction is adequate food of the proper quality (size) obtainable when it is required by the bass.

Sule (1981) found a normal shift of bass foods from zooplankton to aquatic insects and then to forage fish for young-of-the-year largemouth bass in both arms of Lake Sangchris during 1975. Feeding habits of older bass, however, were not examined as part of that study. Our study also revealed the shift in bass diets from zooplankton to insects and then to fish and crayfish as bass increase in size. Additionally, it indicated that bass prey did not grow so rapidly because of the elevated temperatures that they became undesirable or unavailable to adult bass, and thus an adequate prey resource for adult bass was sustained.

Overall trends in bass feeding were similar in both arms of Lake Sangchris and also were similar to those reported by Carlander (1977). Although food consumption rates were not compared, analyses of stomachs of largemouth bass from the intake and discharge arms of Lake Sangchris indicated that the types of foods that made up the diet, and the relative proportions that each type contributed, were basically similar for the two thermally different areas. Minor differences existed, but identical shifts in feeding that accompanied changes in fish length in the two lake arms suggested that little disruption of the normal feeding chronology occurred. Fish predation by adult bass continued throughout the seasons and by all sizes of bass examined, indicating that excellent forage conditions existed for bass in Lake Sangchris. Good forage, coupled with the artificially prolonged growing season, has probably led to the excellent growth of largemouth bass observed at Lake Sangchris.

CHANNEL CATFISH

A total of 399 channel catfish (79–643 mm) from Lake Sangchris were examined for stomach contents. Seventy-five percent of the fish examined were collected during 1974 and the rest in 1976. Samples were evenly divided between the two sampling areas (intake and discharge) of the lake during the entire study. February and December were the only months not represented by samples, but most channel catfish were captured for stomach analysis during March, May, July, and September. Average lengths of channel catfish from the intake (262 mm) and discharge (268 mm) arms of the lake during 1976 were significantly (5-percent level) greater than those from their respective areas in 1974 (intake 177 mm, discharge 230 mm). During 1974 average lengths of catfish from the two arms were significantly (5-percent level) different. The frequency of empty stomachs was 7.5 percent in the intake arm and 13.6 percent in the discharge arm.

Predominant food items for catfish included insects, plants, and fish. During 1974 the diets of channel catfish in both arms of Lake Sangchris were dominated by insects. Stomach contents averaged 47 percent insects for catfish from the intake arm and 34 percent for those from the discharge arm. In both cases, chironomids represented over 90 percent of the insect biomass consumed. Fish matter and plant matter each contributed approximately 9 percent to the diet of catfish in the intake arm during 1974. These latter foods constituted 12 percent and 18 percent, respectively, of the catfish diet in the discharge arm.

Catfish captured during 1976, however, fed mainly on plants. Plant matter, consisting mostly of filamentous algae, averaged 68 percent of the diet of catfish in the intake arm and 49 percent in the discharge arm. Insects were less important to catfish than during 1974 and averaged 19 and 7 percent of the diet in the intake and discharge arms, respectively. The 2.7-fold difference in insect consumption between the two arms during 1976 was mainly due to increased consumption of *Hexagenia* mayflies in the intake arm. Swadener & Buckler (1979) found that the intake arm of Lake Sangchris typically had greater *Hexagenia* populations than did the discharge arm. Fish collections may also have inadvertently corresponded to periods of emergence of these burrowing invertebrates, times when they would have been readily available and vulnerable as prey. Crayfish were a relatively unimportant food resource for channel catfish overall, but during 1976 represented a greater portion of the catfish diet than did fish.

Shira (1917), Boesel (1938), Hoopes (1960), and Ware (1967) all found that insect larvae, mostly Chironomidae and Ephemeroptera, were most important to channel catfish and that plant matter was used little as a food resource. However, Dill (1944) found that aquatic and higher plants were of chief importance to channel catfish in the Colorado River. McCormick (1940) also found that filamentous algae were important to channel catfish from Reelfoot Lake, and Menzel (1943) found that channel catfish from a river in Virginia fed primarily on filamentous algae during August. The omnivorous habits of the channel catfish indicate that variations in the diets of catfish from different areas are largely dependent upon food availability. Bailey & Harrison (1948) attributed the small quantity of filamentous algae, microcrustaceans, crayfish, and mollusks in catfish stomachs to the low abundance of these foods in the Des Moines River. But they also found that channel catfish were omnivorous; the young fed almost exclusively on aquatic insect larvae, and larger catfish progressively used larger insects and elm seeds.

The differences between channel catfish diets in the two arms of Lake Sangchris were trivial compared to the observed differences between years and to the results offered by various investigators. Observed differences, however, may have resulted from a factor commonly overlooked. Diets of channel catfish changed in Lake Sangchris according to size of the fish examined, and fish examined during the 2 separate years were of different sizes.

Channel catfish between 100 and 200 mm total length fed heavily on insects (Fig. 2), especially chironomids. As catfish lengths exceeded 200 mm, the portion of the diet that consisted of insects decreased until no insects were consumed by catfish larger than 400 mm. Plant matter, mostly filamentous algae, was eaten by channel catfish as small as 135 mm but became most prominent in fish between 200 and 500 mm. Fish and crayfish did not form a consistent part of the diet until channel catfish exceeded a total length of 260 mm.

The shift in food from insects to plants and then to fish or crayfish, as channel catfish increased in size, was evident in both the intake and discharge arms of Lake Sangchris. This trend was exhibited best by fish captured during 1974 because fish sizes during that year ranged from 79 mm to 492 mm. During 1976 the catfish examined were generally larger, and none shorter than 178 mm were analyzed. Specimens collected during 1976 indicated diets similar to those of channel catfish of equal size captured in 1974.

Analyses of seasonal feeding indicated

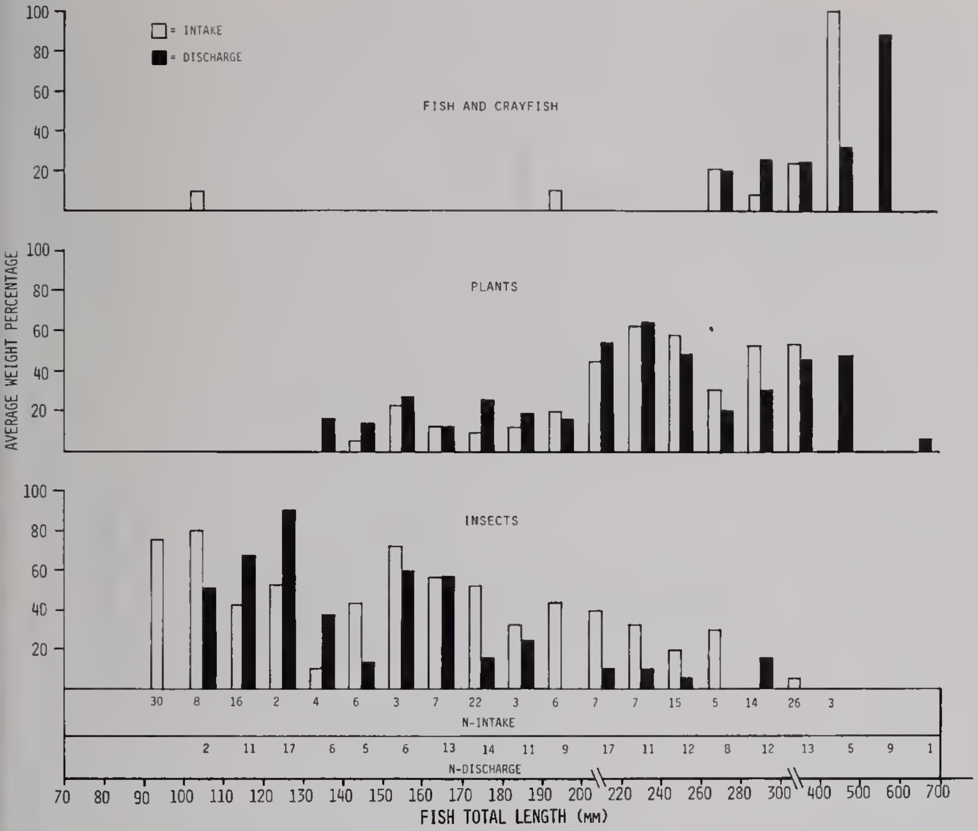

Fig. 2.—Average weight percentages of major foods found in channel catfish of different lengths from the intake and discharge arms of Lake Sangchris during 1974 and 1976.

that consumption of plants was greatest from April to June. Insects generally contributed more to the catfish diet during the rest of the year. Seasonal comparisons were believed not very accurate, because they were highly influenced by the number of fish sampled and their sizes.

Channel catfish from the intake and discharge arms of Lake Sangchris ate similar foods. Diets depended more on the size of the specimen than its particular location in the lake or the season of its capture. Results showed that plant or animal matter could provide a substantial part of the diet for a reproducing population of channel catfish and that a shift from one type of food to another normally accompanied growth. Small channel catfish consumed insects and therefore, competed with all other fishes in Lake Sangchris that possessed an insectivorous phase in their life histories. Competition with other fishes for forage fish or crayfish appeared limited to large channel catfish. Plants, therefore, were one main food upon which channel catfish could subsist during the change of diet from primarily insects to fish and crayfish. The only difference observed in food habits of channel catfish from the two arms of Lake Sangchris was a greater consumption of insects in the intake arm of the lake, attributed to greater insect availability.

FRESHWATER DRUM

Of the 259 freshwater drum collected for stomach analysis from May 1974 through October 1976, 39 percent (101) were from the intake arm, while 61 percent (158) were from the discharge arm. They ranged in total length from 105 to 372 mm (mean, 191 mm) in the intake arm and from 52 to 349 mm (mean, 178 mm) in the discharge arm. During the

2½-year study period, samples were taken from the discharge arm in every month except August from March through November and in the intake arm from May through November, except in October.

Fig. 3 shows relative quantities of selected food items eaten by freshwater drum in the intake and discharge arms in 1974, 1975, and 1976. Chironomids were the most important food item at all times except in the intake arm in 1976 and in the summer of 1974, when Ephemeroptera (primarily *Hexagenia* spp.) were the predominant food item. Overall, the percentages of empty stomachs were 8.9 from the discharge arm and 3.3 from the intake arm. The percentage of empty stomachs was consistently higher in the discharge arm in all 3 years of the study; however, empty stomachs always represented less than 10 percent of the total.

Freshwater drum displayed similar food habits in the intake and discharge arms during 1974 and 1975, when Chironomidae predominated over all other food items, each of which averaged less than 10 percent of the weight of all food. In 1976 Chironomidae were still very important as food of freshwater drum in both arms. However, substantial increases occurred in the consumption of Mollusca, especially in the discharge arm (26 percent), and of Ephemeroptera in the intake arm (66 percent). The Ephemeroptera consisted almost entirely of a *Hexagenia* species, large burrowing mayflies, while the Mollusca were primarily *Corbicula fluminea.* The mean length of freshwater drum sampled was 35 percent greater in 1976 than in 1974, and thus, the diet change observed in 1976 reflected the increase in the size of freshwater drum. *Corbicula* populations were denser in the discharge arm (Dreier & Tranquilli 1981), possibly explaining the higher comsumption of *Corbicula* there. Ephemeropteran populations were substantially higher in the intake arm than they were in the discharge arm during the summer of 1976 (Swadener & Buckler 1979). Since a majority of the freshwater drum examined were collected in the summer in 1976, the high consumption of ephemeropterans in the intake arm by freshwater drum was a reflection of ephemeropteran abundance during a period when freshwater drum were intensively collected.

	1974			1975			1976		
	SAMPLE	EMPTIES	MEAN SIZE	SAMPLE	EMPTIES	MEAN SIZE	SAMPLE	EMPTIES	MEAN SIZE
INTAKE	51	2	159	12	0	217	38	1	227
DISCHARGE	90	9	167	29	2	180	39	3	215

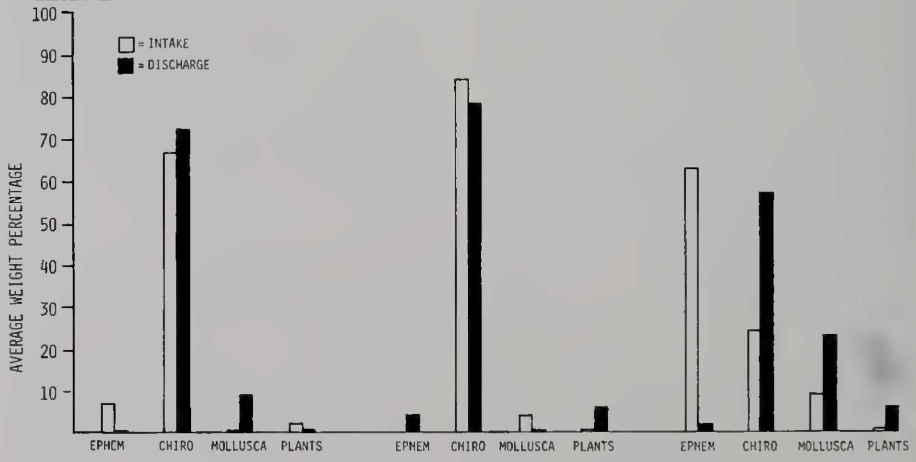

Fig. 3.—Average weight percentages of major foods found in freshwater drum from the intake and discharge arms of Lake Sangchris during 1974, 1975, and 1976.

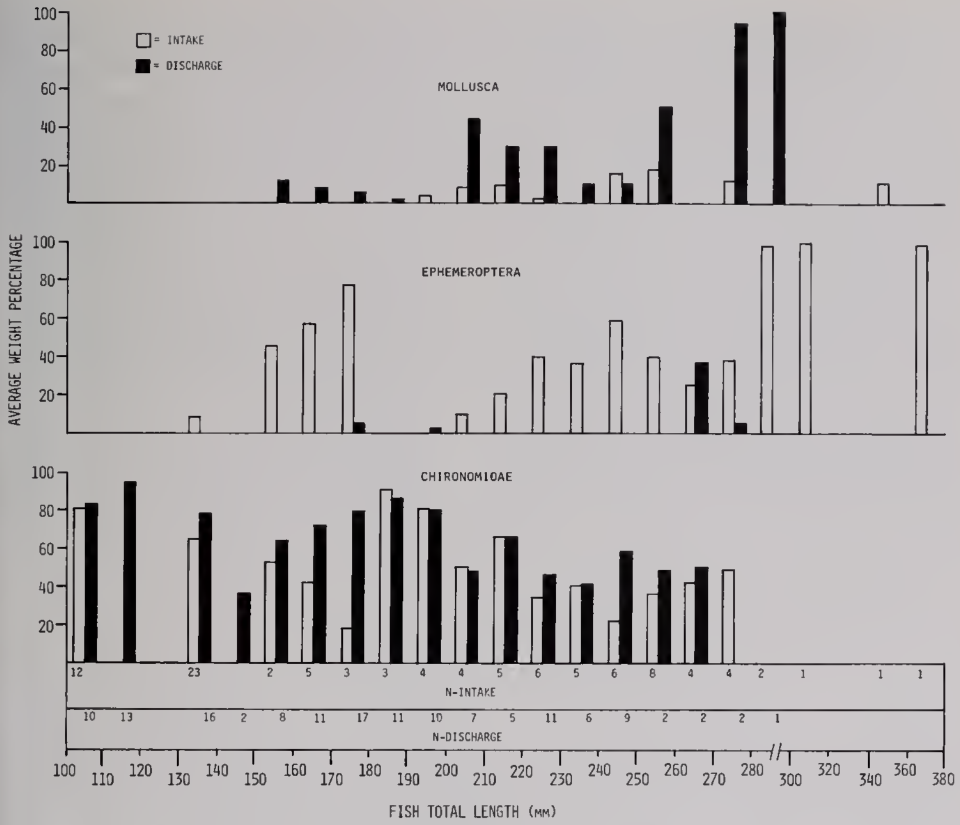

Fig. 4.—Average weight percentages of major foods found in freshwater drum of different lengths from the intake and discharge arms of Lake Sangchris, 1974–1976.

Freshwater drum were divided into 10-mm size groups to study food-habit trends relative to changes in fish size (Fig. 4). The main shift observed was that of increasing consumption of Mollusca and Ephemeroptera and a decrease in the use of Chironomidae as freshwater drum sizes increased. Feeding on *Corbicula* by freshwater drum was of particular importance in Lake Sangchris, since *Corbicula* had been identified as a nuisance species in the lake because of its habit of colonizing the condenser tubes of the power plant. Increased consumption of *Corbicula* would be expected as the relatively young population of freshwater drum in Lake Sangchris matures and more specimens reach larger sizes.

To determine seasonal trends, food habits were examined by month by combining all sizes of freshwater drum; however, no feeding trends were observed in connection with any of the major food items. The food habits of freshwater drum in Lake Sangchris were similar to those reported in the literature. High consumption of invertebrates, such as Chironomidae and Ephemeroptera, and low consumption of fish and Mollusca were reportedly typical for small freshwater drum in a lake ecosystem (Scott & Crossman 1973). A shift to larger food items, such as fish, crayfish, and Mollusca, as drum increased in length has been reported by several authors (Daiber 1952, Dendy 1946, Forbes 1888, and Moen 1955).

YELLOW BASS

A total of 691 yellow bass was collected in Lake Sangchris for stomach analysis during 1974 and 1975. Of these, 56 percent were from the discharge arm with the remainder from the intake arm.

Yellow bass ranged in size from 67 to 247 mm with 96 percent being between 80 and 180 mm. The mean total length was 130 mm in the intake arm and 122 mm in the discharge arm. Yellow bass were collected in March, April, May, July, September, and November in both arms and additionally in January and February in the discharge arm.

Zooplankton and Chironomidae were the predominant food items of yellow bass in both arms of Lake Sangchris in both years. Chaoboridae, Ephemeroptera, and plant material were also eaten but were minor food items relative to zooplankton and Chironomidae. During 1974 these food items were eaten in similar amounts in both arms; however, in 1975 zooplankton heavily predominated in the diet of yellow bass from the discharge arm. The reason for this predominance was unclear. In the discharge arm zooplankton was consumed during all months to a greater degree than in the intake arm and by all sizes of yellow bass except the 90–100 mm group. Therefore, sampling bias due to fish size or seasonality was not indicated. Zooplankton populations were similar in both areas of the lake during this period (Brigham et al. 1975). Chironomidae populations were known to be low in the discharge canal (Webb 1981); however, even if fish collected from the discharge canal were excluded from the sample, zooplankton predominated among the food items

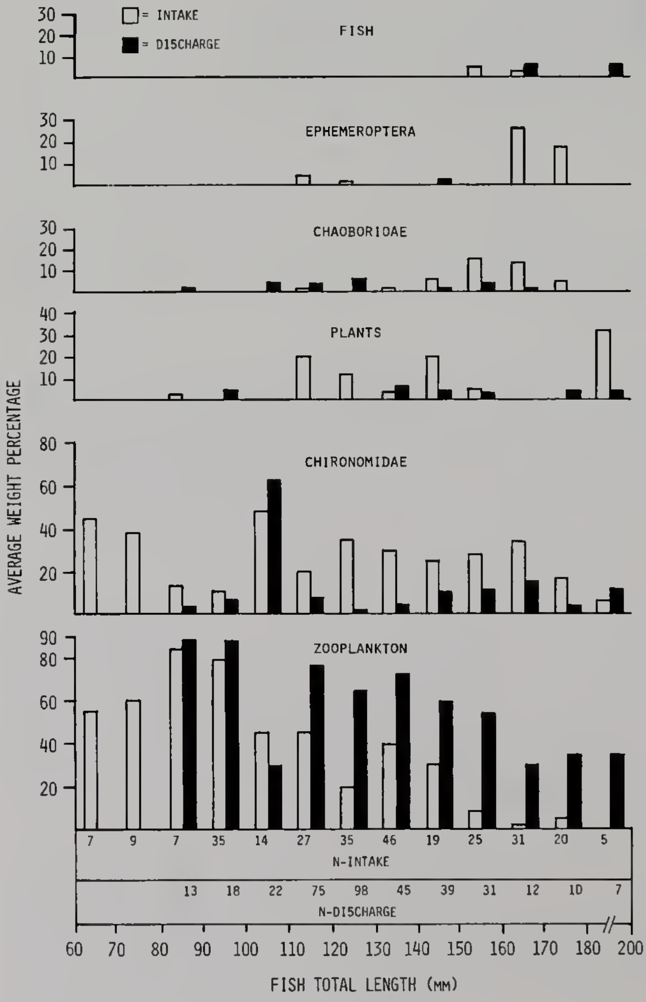

Fig. 5.—Average weight percentages of major foods found in yellow bass of different lengths from the intake and discharge arms of Lake Sangchris during 1974 and 1975.

eaten by yellow bass in the rest of the discharge arm. Yellow bass were of similar mean sizes in both arms in 1975, 134 mm and 129 mm for the intake and discharge arms, respectively. The proportions of empty stomachs were 6.6 percent in the intake arm and 4.9 percent in the discharge arm.

Yellow bass were divided into 10-mm size groups in order to examine shifts in feeding associated with fish size (Fig. 5). Zooplankton consumption declined with increasing size, while consumption of Chaoboridae, Ephemeroptera, and fish increased with increasing yellow bass size. This shift to larger prey items at the larger fish sizes, which was similar to that found for stunted populations of yellow bass in Iowa (Kutkuhn 1954, Collier 1959, Ridenhour 1960, Kraus 1963, and Welker 1963), occurred in both arms but was most pronounced in the intake arm. In the discharge arm, although yellow bass consumption of zooplankton declined as yellow bass grew, zooplankton still dominated the food base of even large

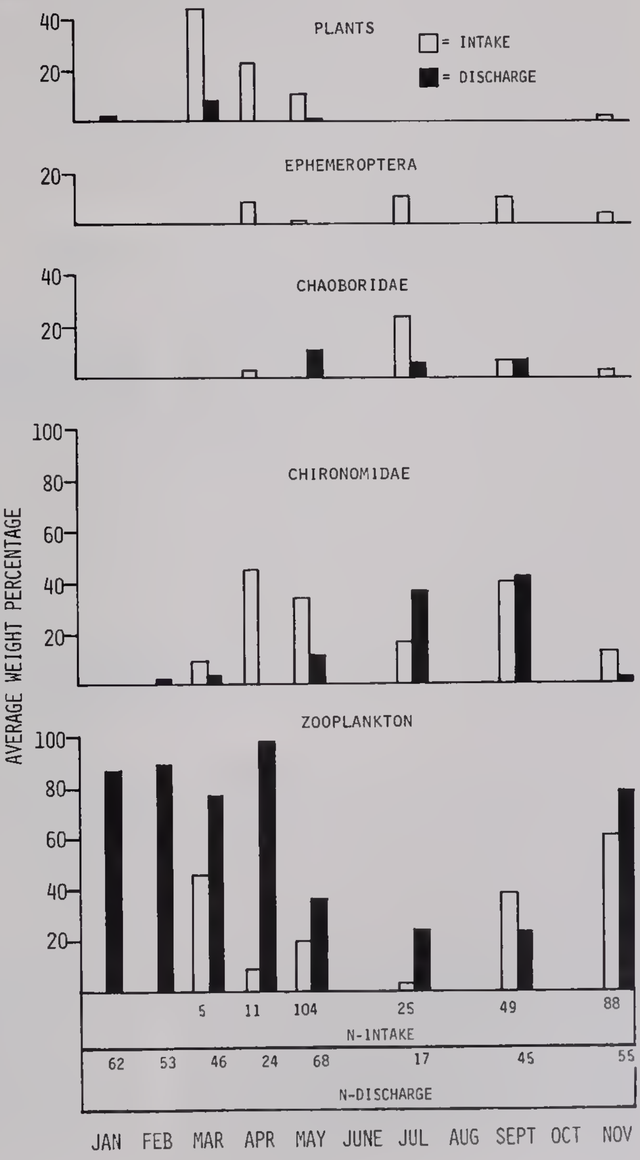

Fig. 6.—Average weight percentages of major foods found in yellow bass from the intake and discharge arms of Lake Sangchris during different months of 1974 and 1975.

size classes. Chironomidae, plant material, Ephemeroptera, and Chaoboridae were eaten by most sizes of yellow bass to a greater degree in the intake arm than in the discharge arm. These general trends were observed in both years of the study.

Weighted monthly averages of samples taken over the 2-year study period were compiled to determine possible seasonal trends of yellow bass feeding (Fig. 6). Consumption of zooplankton was greatest in winter, early spring, and late autumn and least in midsummer and early autumn in both arms. Yellow bass consumption of Chironomidae in the discharge arm followed a reverse trend to that of zooplankton consumption in that it was high in midsummer and early autumn and low at other times of the year. Consumption of chironomids in the intake arm was less in the summer and greater in the spring and autumn. Chaoboridae were the dominant food of yellow bass in the intake arm in midsummer, when their use of Chironomidae and zooplankton was low. While these same trends were identified during 1974, insufficient data made seasonal trends during 1975 difficult to discern. Thus, in the discharge arm yellow bass shifted their feeding from zooplankton to Chironomidae in the summer and early fall, while in the intake arm the shift was from zooplankton and plant material in the winter to Chironomidae in spring to Chaoboridae and Ephemeroptera in summer and to zooplankton and Chironomidae in fall.

Virtually all previous investigations of yellow bass food habits have been done in the summer in North Twin Lake and Clear Lake, Iowa (Collier 1959, Kraus 1963, Kutkuhn 1954, Ridenhour 1960, and Welker 1963). In these lakes it was found that young-of-the-year yellow bass fed heavily on zooplankton and dipteran larvae with increasing ingestion of dipteran larvae as the fish grew larger. Other aquatic insects became more important as fish increased in size until forage fish predominated in the diet of large yellow bass. Nonstunted populations began feeding on fish earlier (130–150 mm) than did stunted populations, where almost no fish were eaten by yellow bass of less than 200 mm in total length.

The stunted population of yellow bass in Lake Sangchris appeared to be forced to eat primarily zooplankton through an extensive portion of their growth history. Since zooplankters were abandoned as forage early in the growth histories of other fish species, zooplankton represented an acceptable forage item that was under less competitive pressure than were the large aquatic insects. This niche segregation subsequently suppressed further growth of yellow bass, since zooplankton represent an inefficient source of nutrition for large yellow bass and thus limit their choice of alternate foods by limiting yellow bass growth.

BLUEGILL

Approximately half of the 1,341 bluegills examined during the food-habits study were collected during each of the 2 study years, 1974 and 1975. Beginning in January of 1974, approximately 100 fish were captured during each of twelve 2-month periods. Half of each bimonthly collection came from the heated (discharge) arm of the lake, while the other half came from the intake arm. Size distributions of the collected bluegill were very similar in the heated and unheated arms although some small seasonal variations in length frequency distributions were apparent.

The food habits of bluegills in Lake Sangchris during 1974 and 1975 were influenced by competition for food, availability of food resources, and temperature. The effects of both intraspecific and interspecific food competition were evident among bluegills in the discharge and intake arms. The effects of the power plant in the discharge arm influenced bluegill food habits indirectly by reducing benthic biomass in the discharge channel and directly by apparently increasing their feeding rate.

Food items used by bluegills in Lake Sangchris were generally similar to the

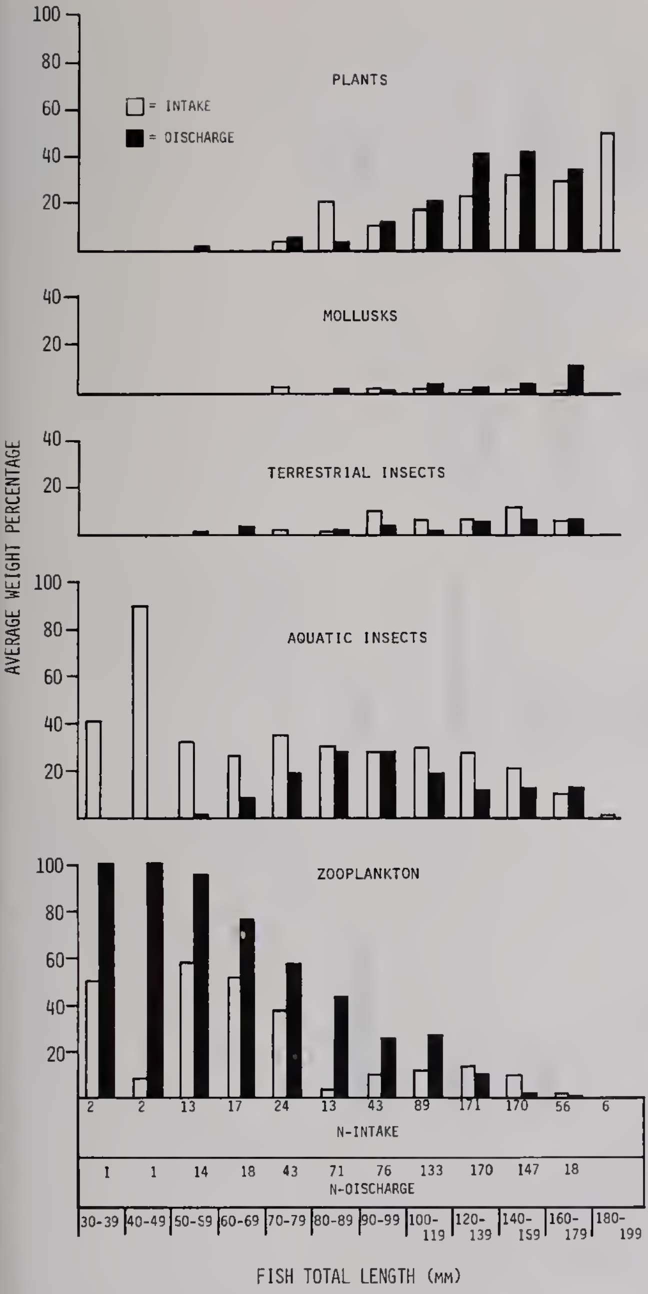

Fig. 7.—Average weight percentages of major foods found in bluegill of different lengths from the intake and discharge arms of Lake Sangchris during 1974 and 1975.

items reported for other bluegill populations. Aquatic insects, mainly Chironomidae, were an important food item for bluegills of all sizes (Fig. 7), as reported by other researchers (Gerking 1962, Keast & Webb 1966, and Seaburg & Moyle 1964). Peak use of aquatic insects at Lake Sangchris occurred in September and October (Fig. 8). In contrast, this was a period of low use of aquatic insects by bluegills in two Wisconsin lakes (Seaburg & Moyle 1964) and in Lake Opinicon, Ontario (Keast 1978). Zooplankton consumption by bluegills in Lake Sangchris was similar to that reported for other waters.

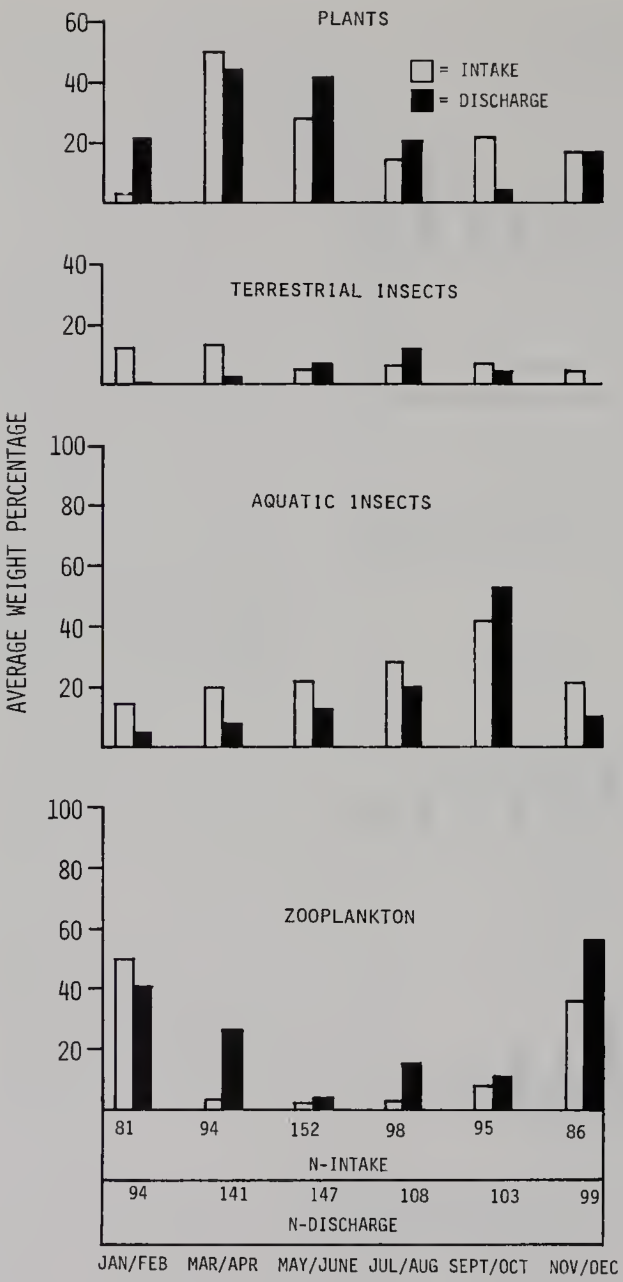

Fig. 8.—Average weight percentages of major foods found in bluegill from the intake and discharge arms of Lake Sangchris during different seasons of 1974 and 1975.

Zooplankton formed a major portion of the diet of all bluegills during the winter (Fig. 8), as also reported by Goodson (1965) and Moffett & Hunt (1943), and it was consistently eaten by small bluegills in all seasons (Fig. 7), as reported by Keast (1978). Aquatic plants and terrestrial insects were also major components of the diets of bluegills in Lake Sangchris. These were reported as variably important food items by Keast & Webb (1966) and Gerking (1962).

Seasonal transitions were apparent in the diets of bluegills from both the discharge and intake arms of Lake Sangchris (Fig. 8). The cycles in both areas were similar. As had been the case for yellow bass, the most important food item for bluegills in the winter months was zooplankton. Aquatic plant use peaked in the spring and then declined as more aquatic and terrestrial insects were consumed until a peak in aquatic insect consumption occurred in the September-October period. Since bluegills smaller than 120 mm predominated the samples as well as in the population, their food habits considerably influenced any population-wide study. Seasonal trends for large, 140–159 mm, bluegill (Fig. 9)

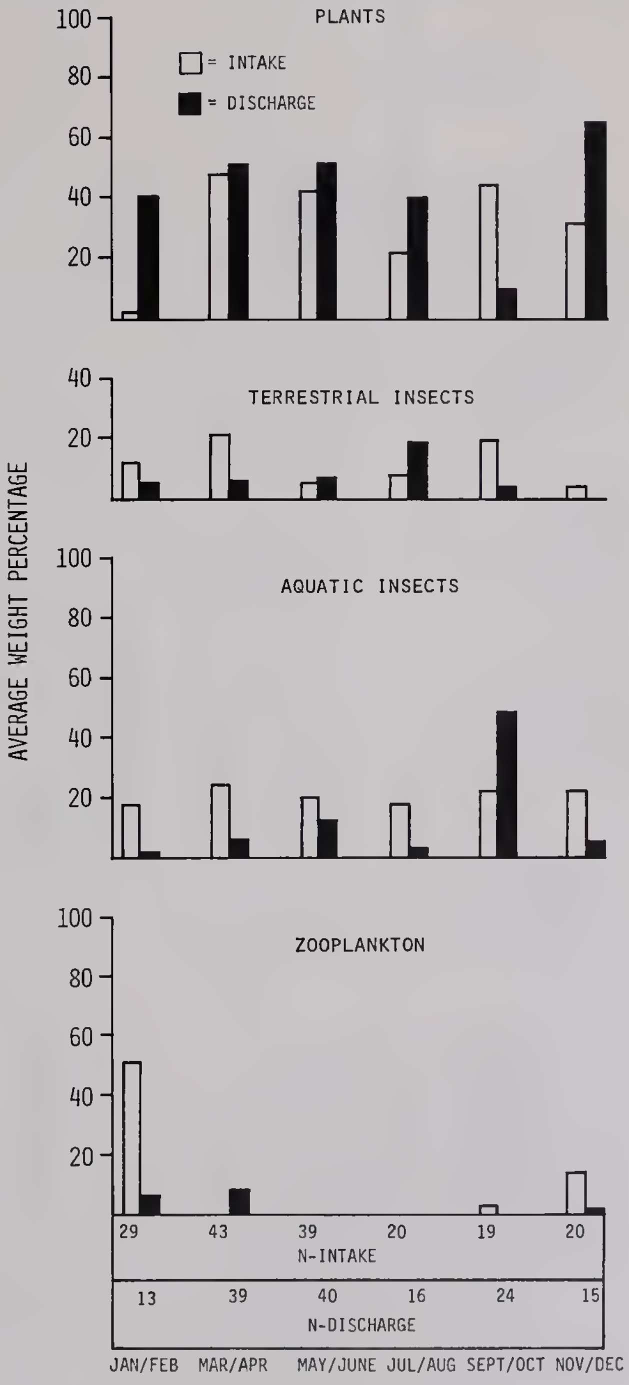

Fig. 9.—Average weight percentages of major foods found in large bluegill (140–159 mm) from the intake and discharge arms of Lake Sangchris during different seasons of 1974 and 1975.

were compared with those of smaller fish of 100–119 mm (Fig. 10). While seasonal trends typical of the total population were found for the small fish, only minor seasonal variations were noted in the diet of the larger bluegills. The larger fish, with a competitive size advantage, were able to feed on selected food items throughout the year. Smaller bluegills were probably forced, by competition with larger bluegills and other species, to use whatever food resources were available.

The food items consumed by bluegills

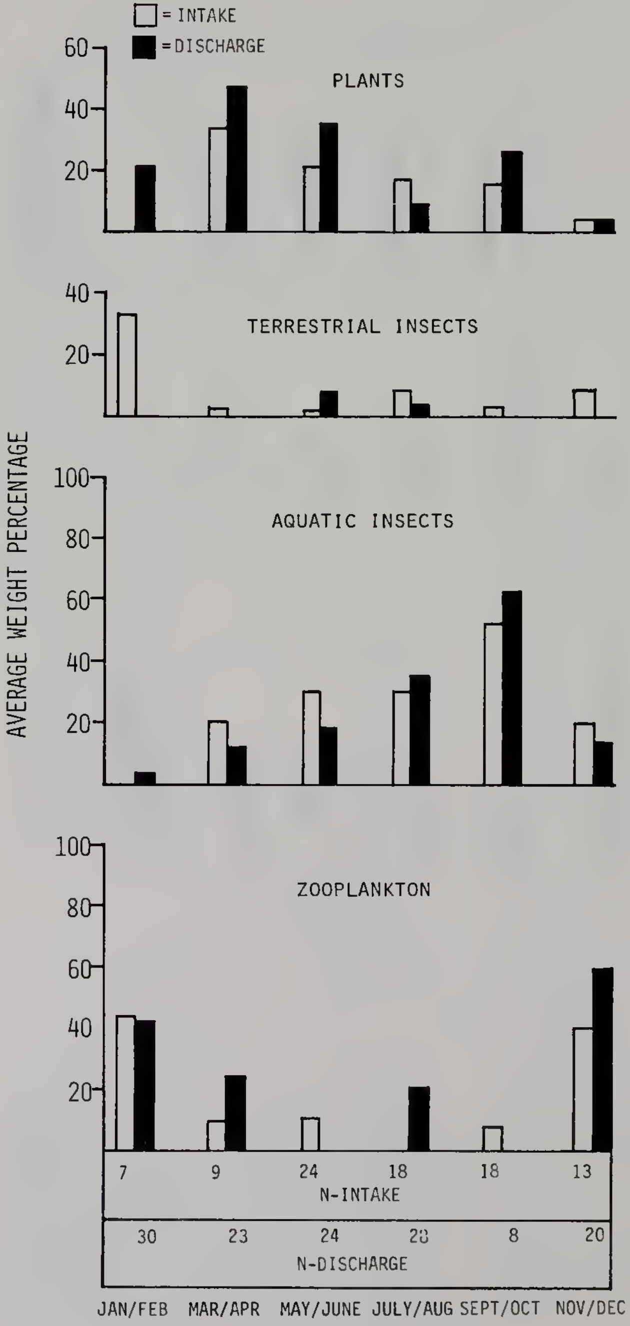

Fig. 10.—Average weight percentages of major foods found in small bluegill (100–119 mm) from the intake and discharge arms of Lake Sangchris during different seasons of 1974 and 1975.

Table 1.—Frequency of occurrence of empty stomachs in bluegills during the 1974–1975 food-habits study.

Month	Intake Arm		Discharge Arm	
	Number Examined	Percent Empty	Number Examined	Percent Empty
January–February	97	16.5	96	2.1
March–April	98	4.1	137	0.0
May–June	154	1.3	152	0.7
July–August	102	3.9	109	0.9
September–October	98	3.1	105	1.9
November–December	89	3.4	104	4.8
Total	*638*	*5.0*	*703*	*1.6*

varied considerably with fish size (Fig. 7). Small bluegills, because of their small mouths, were required to eat small aquatic insects and zooplankters (Keast & Webb 1966). Larger items were added to the diets of larger-sized fish. These larger items, including terrestrial insects, plant parts, and mollusks, assumed a dominant role in the bluegill diet principally because of their larger individual size rather than the frequency with which they were ingested. As with most other fish species examined, bluegills used aquatic insects more extensively in the intake arm than in the discharge arm. On the other hand, bluegills in the discharge arm (like yellow bass) used zooplankton more frequently than did those in the intake arm. These differences in types of foods consumed were probably due to a low benthic biomass in the discharge channel (Webb 1981). Zooplankton densities were similar in both arms (Waite 1981). However, some zooplankters may have been damaged by passage through the power plant and therefore, may have become more vulnerable to predation.

Throughout most of the year there were fewer empty stomachs in samples of bluegills from the discharge arm than occurred in bluegills from the intake arm (Table 1). These data indicated more frequent feeding by bluegills in the heated arm, especially during periods of low air and water temperatures. Similar data were recorded by Sarker (1977) in two cooling lakes in Texas. The elevated water temperatures of the discharge arm probably induced higher metabolic rates in bluegills in that area, causing more frequent food ingestion.

SUMMARY AND CONCLUSIONS

1.—Analyses of stomach contents of five fish species common to Lake Sangchris indicated a food web based on the dominant component of the benthos (chironomids) for the majority of species, possibly because of necessity rather than preference.

2.—Sudden changes in stomach contents revealed the dietary plasticity of most species in the lake and the immediate use of any food (such as ephemeropterans) which periodically became abundant.

3.—Apparently there was extensive competition for the aquatic insect prey by large populations of fishes, which contributed to the generally small size of the individuals in the bluegill and yellow bass populations.

4.—Additional evidence of the pressure exerted on the available animal food base was the extensive quantity of plant matter consumed by channel catfish and the seasonally important contribution of plants to the diets of bluegills.

5.—Dietary changes relative to fish size were well defined for each species, presumably natural reactions toward efficient resource use and feeding strategies.

6.—Fish species that appeared best adapted to use the most readily available food resources were channel catfish, because of their successful use of plant foods, and largemouth bass, because of their mostly piscivorous habits.

7.—Fish diets were typical of those of fish in other lakes and were generally similar in both the heated and unheated arms of Lake Sangchris, indicating little direct impact from the elevated water temperatures.

8.—Because we found no direct evidence of the alteration of typical food-habit patterns for the fishes studied, future research in this area should pursue the relationship between food resource production and use.

REFERENCES CITED

Bailey, R. M., and H. M. Harrison, Jr.1948. Food habits of the southern channel catfish (*Ictalurus lacustris punctatus)* in the Des Moines River, Iowa. American Fisheries Society Transactions 75:110–138.

Boesel, M. W. 1938. The food of nine species of fish from the western end of Lake Erie. American Fisheries Society Transactions 67:215–223.

Brigham, A. R., R. L. Moran, and S. R. Gnilka. 1975. Plankton investigations at Lake Sangchris 4 September 1974 through 12 August 1975. Pages 2.1–2.68 *in* Annual report for fiscal year 1975, Lake Sangchris project. Illinois Natural History Survey, Urbana.

Brown, B. E. 1965. Two-year study of a bass, sunfish, channel catfish population exposed to flooding and angling. Southeastern Association of Game and Fish Commissioners Proceedings 17:367–372.

Carlander, K. D. 1977. Handbook of freshwater fishery biology. Vol. II. Iowa State University Press, Ames. 431 p.

Collier, J. E. 1959. Changes in fish populations and food habits of yellow bass in North Twin Lake, 1956–1958. Iowa Academy of Science Proceedings 66:518–522.

Daiber, F. C. 1952. The food and feeding relationships of the freshwater drum, *Aplodinotus grunniens* Rafinesque, in western Lake Erie. Ohio Journal of Science 52:35–46.

Dendy, J. S. 1946. Food of several species of fish, Norris Reservoir, Tennessee. Tennessee Academy of Science Journal 21(1): 105–127.

Dill, W. A. 1944. The fishery of thelower Colorado River. Colorado Fish and Game 30:109–211.

Dreier, H., and J. A. Tranquilli. 1981. Reproduction, growth, distribution, and abundance of *Corbicula* in an Illinois cooling lake. Pages 378–393 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

Forbes, S. A. 1888. Studies of the food of freshwater fishes. Illinois State Laboratory of Natural History Bulletin 2:433–473.

Gerking, S. D. 1962. Production and food utilization in a population of bluegill sunfish. Ecological Monographs 32:31–78.

Goodson, L. F., Jr. 1965. Diets of four warmwater game fishes in a fluctuating, steep-sided, California reservoir. California Fish and Game 51:259–269.

Hoopes, D. T. 1960. Utilization of mayflies and caddis flies by some Mississippi River fishes. American Fisheries Society Transactions 89:32–34.

Keast, A. 1978. Feeding interrelations between age-groups of pumpkinseed (*Lepomis gibbosus*) and comparisons with bluegill *(L. macrochirus).* Canada Fisheries Research Board Journal 35:12–27.

———, and D. Webb. 1966. Mouth and body form relative to feeding ecology in the fish fauna of a small lake. Lake Opinicon, Ontario, Canada Fisheries Research Board Journal, 23:1845–1874.

Kraus, R. 1963. Food habits of the yellow bass, *Roccus mississippiensis*, Clear Lake, Iowa, summer 1962. Iowa Academy of Science Proceedings 70:209–215.

Kutkuhn, J. H. 1954. Mid-summer fishing at North Twin. Iowa Conservationist 13:41–44.

Larimore, R. W. 1957. Ecological life history of the warmouth (Centrarchidae). Illinois Natural History Survey Bulletin 27:1–83.

——— and J. A. Tranquilli. 1981. The Lake Sangchris Project. Pages 279–289 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

McCormick, E. M. 1940. A study of the food of some Reelfoot Lake fishes. Reelfoot Lake Biological Station Report 4:64–75.

McNurney, J. M., and H. Dreier. 1981. Lake Sangchris Creel Survey: 1973-1975. Pages 594–614 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

Menzel, R. W. 1945. The catfish fishery of Virginia. American Fisheries Society Transactions 73:364–372.

Moen, T. 1955. Food of the freshwater drum, *Aplodinotis grunniens* Rafinesque, in four Dickinson County, Iowa, lakes. Iowa Academy of Science Proceedings 62:589–598.

Moffett, J. W. and B. P. Hunt. 1945. Winter feeding habits of bluegills, *Lepomis macrochirus* Rafinesque, and yellow perch, *Perca flavescens* (Mitchill), in Cedar Lake, Washtenaw County, Michigan. American Fisheries Society Transactions 73:231–242.

Ridenhour, R. L. 1960. Abundance, growth and food of young game fish in Clear Lake, Iowa, 1949 to 1957. Iowa State Journal of Science 35:1–23.

SARKER, A. L. 1977. Feeding ecology of the bluegill, *Lepomis macrochirus,* in two heated reservoirs of Texas. III. Time of day and patterns of feeding. American Fisheries Society Transactions 106:596-601.

SCOTT, W. B., AND E. J. CROSSMAN. 1973. Freshwater fishes of Canada. Canada Fisheries Research Board Bulletin 184. 966 p.

SEABURG, K. G., AND J. B. MOYLE. 1964. Feeding habits, digestive rates, and growth of some Minnesota warmwater fishes. American Fisheries Society Transactions 93:269-285.

SHIRA, A. F. 1917. Notes on the rearing, growth, and food of the channel catfish, *Ictalurus punctatus.* American Fisheries Society Transactions 46:77-88.

SULE, M. J. 1981. First-year growth and feeding habits of largemouth bass in a heated reservoir. Pages 520-535 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

SWADENER, S. O., AND J. BUCKLER. 1979. Benthic communities of Lake Sangchris and Lake Shelbyville. Pages 1-1-1-54 *in* Evaluation of a cooling lake fishery. Vol. 4. Fish food resources studies. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

TRANQUILLI, J.A., R. KOCHER, and J. M. McNURNEY. 1981. Population dynamics of the Lake Sangchris fishery. Pages 413-499 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

WAITE, S. W. 1981. effects of cooling lake perturbations upon the zooplankton dynamics of Lake Sangchris. Pages 342-357 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

WARE, F. J. 1967. The food habits of channel catfish in south Florida. Southeastern Association of Game and Fish Commissioners Proceedings 20:283-287.

WEBB, D. W. 1981. The benthic macroinvertebrates from the cooling lake of a coal-fired electric generating station. Pages 358-377 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

WELKER, B. D. 1963. Summer food habits of yellow bass and black bullheads in Clear Lake. Iowa Academy of Science Proceedings 69:286-295.

ZWEIACKER, P. L., and R. C. SUMMERFELT. 1974. Seasonal variation in food and diet periodicity in feeding of northern largemouth bass, *Micropterus s. salmoides* (Lacepede), in an Oklahoma reservoir. Southeastern Association of Game and Fish Commissioners Proceedings 27:579-591.

First-Year Growth and Feeding of Largemouth Bass in a Heated Reservoir

Michael Jay Sule

ABSTRACT

Juvenile largemouth bass were sampled 10 times during 1975 and two times during 1976 from the intake (cool) and discharge (warm) arms of Lake Sangchris, Illinois. Bass grew larger in the discharge arm, where the growing season had been lengthened artificially. Although bass from the intake arm had higher coefficients of condition than those from the discharge arm, none was in poor condition. Stomach analyses generally indicated similar feeding in the two study areas and that feeding habits depended strongly on the size of the bass examined. The extended growing season in the discharge arm allowed juvenile largemouth bass to make major length and weight gains, and become predominantly piscivorous during their first growing season.

INTRODUCTION

The growth of a fish species during its first growing season may affect the survival rate and, hence, the year class strength of that species. Consequently, first-year growth can strongly influence a species' future growth and catch as well as that of other fishes, and in the case of largemouth bass, *Micropterus salmoides,* perhaps affect the population dynamics for the entire fishery. Additionally, growth and food habits data are valuable for fishery models, as well as for comparative evaluations of fish communities. For these reasons, describing the effects of a thermal discharge on the first-year growth of largemouth bass was an essential part of a comprehensive study of the fishery of Lake Sangchris, a heated lake whose principal game and main predatory fish is the largemouth bass.

Many factors have been reported to influence growth of bass, including sex, population density, abundance of other fishes, turbidity, oxygen concentration, genetic characteristics, and parasites. The influence of temperature and length of growing season on bass growth is known to be especially important and has been shown to vary considerably from year to year and between fish from different areas (Bennett 1937, Stroud 1948, Kramer & Smith 1960, Mraz et al. 1961, Strawn 1961, and Clugston 1964). Equally important to temperature and growing season length are the food resources upon which fish growth depends. This study was developed to examine the first-year growth and feeding habits of largemouth bass in two areas of Lake Sangchris in an attempt to isolate any alterations in growth and feeding attributed directly to the thermal loading of the lake.

DESCRIPTION OF THE STUDY AREA

Lake Sangchris in central Illinois provides condenser cooling water for the Kincaid Electric Generating Station. The 876-ha lake (described in detail by Larimore & Tranquilli 1981) consists of three narrow arms oriented approximately in a north-south direction with the power plant between the upper ends of the middle and western arms. Warm water from the power plant is discharged into a canal and then circulates in a cooling loop through the middle arm (discharge arm) and the west arm (intake arm) to the plant intake canal. Water increases in temperature by 7°–9°C as it passes through the power plant but is back to ambient temperatures by the time it has traveled about halfway around

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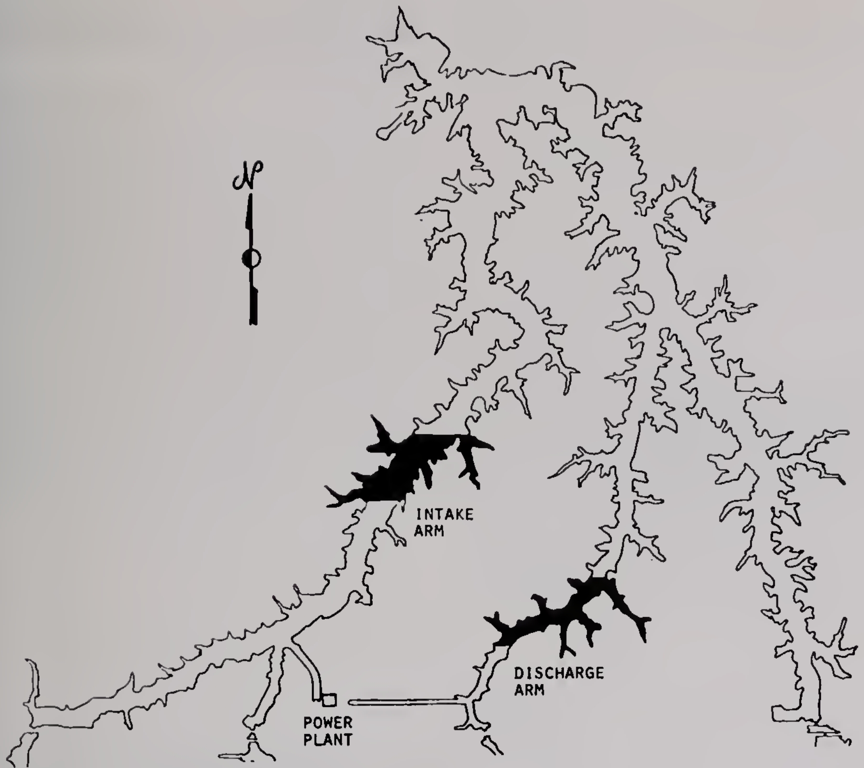

Fig. 1.—Sampling areas (shaded) for juvenile bass in the intake and discharge arms of Lake Sangchris, Illinois.

the 16-km cooling loop. This design provides an ideal situation for comparing biotic communities inhabiting areas that differ primarily in temperature. Consequently, collection locations were established in the intake and discharge arms of the lake to examine growth and feeding of young-of-the-year bass populations in the lake's two extreme temperature regimes (Fig. 1).

METHODS

Young-of-the-year largemouth bass were collected at approximately 3-week intervals from 29 May to 11 December 1975 from the intake and discharge arms of Lake Sangchris. Two additional collections of young bass were taken in the summer and fall of 1976 for comparison of bass growth between 1976 and 1975. Water temperatures were monitored in both arms of the lake throughout the study period. From 29 May to 29 September 1975, seven collections were made by seining along the shoreline. In the first two collections a 6.1 x 1.2-m bag seine with 4-mm square mesh was used. The subsequent five collections were made with a 6.1 x 1.2-m bag seine with 6-mm square mesh. All collections were made between 0900 and 1300 hours.

There was no significant difference between the mean length of fish collected by seining and those collected by electrofishing during the 3 September 1975 collection, so this collection and the two subsequent samples included specimens obtained by both techniques. From 17 October to 11 December 1975, three additional collections were made by electrofishing along the shoreline. The 17 October 1975 collection was supplemented by fish collected from a cove treated with rotenone within the sampling area in the discharge arm. On 14 July and 26 September 1976, samples were collected by seining and electrofishing in both the intake and discharge arms of the lake.

Fish were placed on ice until accurate measurements were made in the laboratory. Each fish was measured to the nearest millimeter total length and weighed to the nearest 0.1 g. Fish stomachs were preserved for analysis in a solution of 10-percent formalin.

Growth of young-of-the-year bass was analyzed by the length-frequency method. Absolute growth was determined from the mean total length of fish captured on each sampling date. The absolute growth in weight was also determined, as were length-frequency distributions and length-weight relationships. The coefficient of condition, K(TL), (Carlander 1969) was computed for each fish using formula (1):

$$K(TL) = \frac{W \times 10^5}{L^3}$$

where, W is the weight of the fish in grams, and L is the total length in millimeters.

Fish from both sampling sites were separated into 5-mm size groups. For each date, stomachs of five fish from each size group were analyzed for food content. If one of those fish was found to have an empty stomach, another fish from that size group was examined, when possible, to insure a relatively large sample of fish that contained food. Stomachs were removed from fish by severing the disgestive tract at the anterior end of the esophagus and at the posterior end of the stomach. Stomachs were then rinsed with alcohol and placed on a clean petri dish where they were dissected and examined. Food items were identified to the lowest possible taxon and the proportion of each food item was determined by weight and recorded as a percentage of the total food matter (wet weight) in each stomach. Although empty stomachs were found, all average weight percentage calculations were based only on stomachs that contained food matter. All statistical comparisons were made at the 5-percent probability level.

RESULTS AND DISCUSSION

GROWTH

Surface waters in the discharge arm were warmer than in the intake arm throughout most of the study period (Fig. 2). Water temperatures in the discharge arm of Lake Sangchris in the hottest part of the year rose above temperatures considered preferred by bass. Since young bass were captured throughout the year in the discharge arm, springs, coves, and sheltered weedy areas were probably used by bass at times as cooler refuge areas. Surface water temperatures were recorded at the sampling site, but isolated temperature anomalies within the sampling areas may have existed.

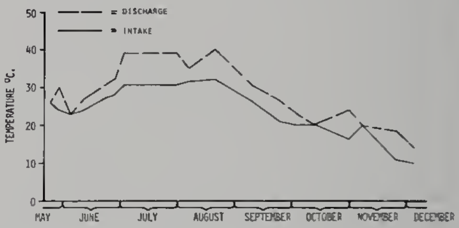

Fig. 2.—Surface water temperatures (°C) in the intake and discharge arms of Lake Sangchris from May to December 1975.

Measurements were taken from 415 largemouth bass collected from the discharge arm and 705 from the intake arm. Since accurate weights were not obtained for fish from the two collections in 1976 or the first two collections in 1975, no K(TL) calculations or growth-in-weight data for those dates were possible. Length-frequency distributions were plotted in 5-mm size groups for fish collected from 29 May to 13 August 1975 (Fig. 3), and in 10-mm size groups for fish collected from 3 September to 11 December 1975 (Fig. 4). Length-frequency distributions showed that two distinct populations of different sized young-of-the-year bass were always present in Lake Sangchris, and that bass from the discharge arm were larger than those from the intake arm.

Mean total lengths and weights were calculated for fish from both arms of the lake (Table 1). Absolute growth curves

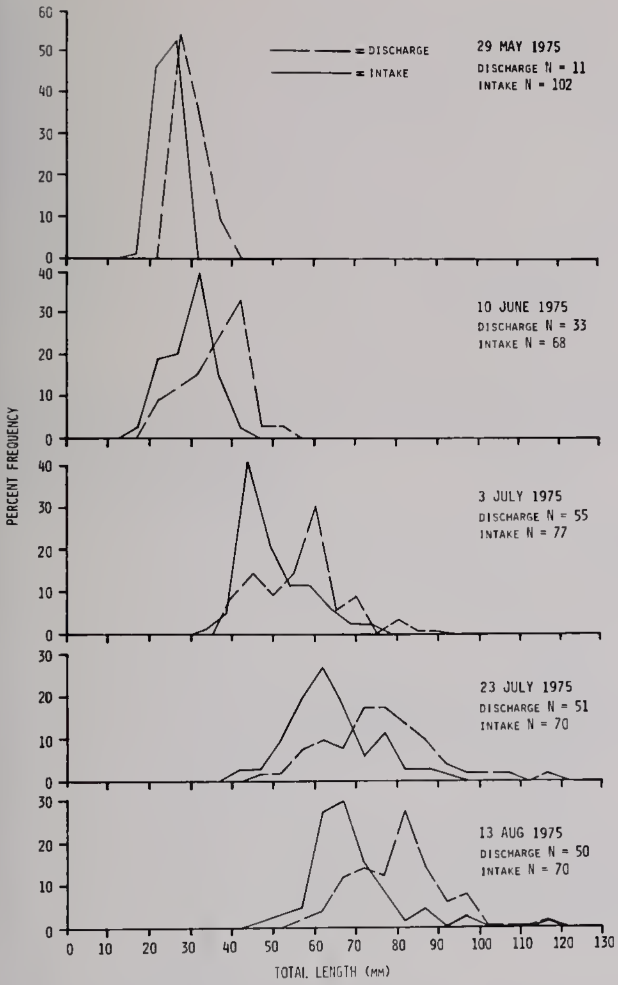

Fig. 3.—Length-frequency distributions for juvenile bass (5-mm length groups) in Lake Sangchris from 29 May to 13 August 1975.

were drawn from the mean lengths of fish collected from each arm (Fig. 5). By 11 December 1975, the lengths attained by bass from the discharge arm were clearly greater than those from the intake arm. On each collection date, fish from the discharge arm were significantly larger than those from the intake arm. The rate of growth in the first half of the growing season was not different, however, for fish from the two arms. Although admittedly less extensive, the 1976 data indicated that the 1975 growth trend had been repeated the following year. During both years, fish from the discharge arm were significantly larger than those from the intake arm. In general, bass collected in 1976 were smaller than bass from the same areas in 1975; however, those size differences were only significant for September from the intake arm. This annual difference may reflect the reduced thermal loading experienced at Lake Sangchris during 1976 (Larimore & Tranquilli 1981).

Total lengths of bass at the end of the 1975 growing season averaged about 100 mm and 140 mm from the intake and discharge arms, respectively. Although Carlander (1977) cited 134 mm as the average total length attained by largemouth bass in Illinois by October–December of their first growing season, the mean total length for bass from central Illinois probably is somewhat less. Carlander's estimate was based on several

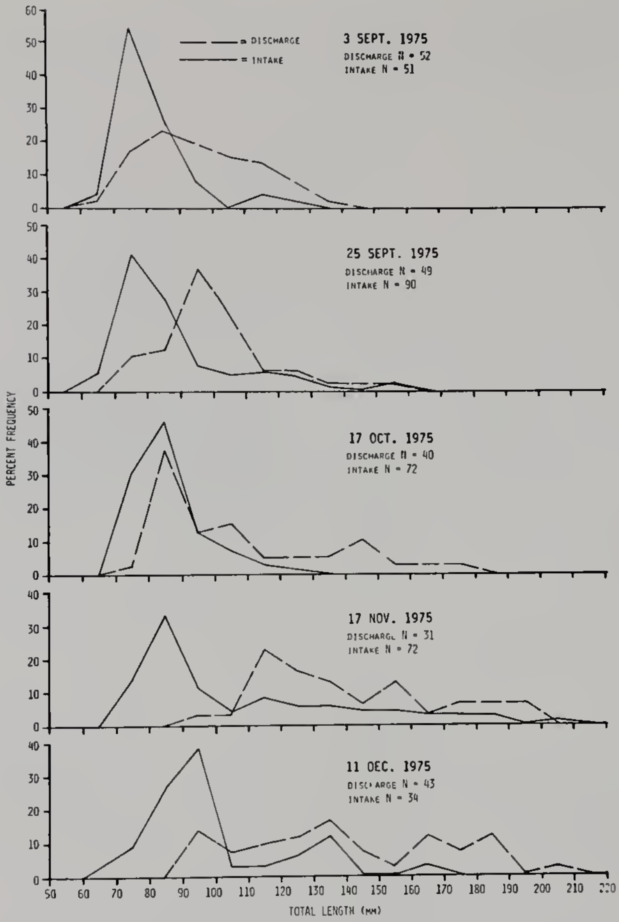

Fig. 4.—Length-frequency distributions for juvenile bass (10-mm length groups) in Lake Sangchris from 3 September to 11 December 1975.

studies of fish populations in ponds and small lakes actively managed for superior production, which probably raised the average size of bass examined. For this reason, a more conservative estimate of first-year growth for Illinois largemouth bass may be more representative.

The combined average (110 mm) for age 0 largemouth bass from Iowa, Illinois, Indiana, and Ohio offered by Carlander (1977) may more accurately typify first-year growth of largemouth bass in most Illinois waters. In any case, the most applicable datum for comparison with growth of bass from Lake Sangchris is that offered by Joy (1976). He found that bass attained a total length of 100 mm during the 1975 growing season in Lake Shelbyville, a thermally unaltered reservoir about 80 km east of Lake Sangchris. That final length was attained by bass from the intake arm of Lake Sangchris in 1975; however, it was considerably less than the growth achieved by bass in the discharge arm. Thus, growth of bass in the discharge arm was above average for Illinois lakes, while growth of bass in the intake arm was normal.

Weights of bass from the two study areas were also different, with bass from the discharge arm having significantly greater average weights on each collection date (Fig. 6). There was also a great increase in fish weight near the end of the study period.

The average coefficient of condition for fish from each date was calculated to determine the difference between fish from the intake and discharge arms (Table 2). On five of the eight dates for

Table 1.—Mean total lengths (mm) and mean weights (g) of largemouth bass collected from the intake and discharge arms of Lake Sangchris from 29 May 1975 to 11 December 1975 and two dates in 1976.

	1975										1976	
	5/29	6/10	7/03	7/23	8/13	9/03	9/25	10/17	11/17	12/11	7/14	9/26
Total Length						Intake Arm						
Sample Size	102	68	77	70	70	51	90	72	71	34	13	69
Average	24.3	29.6	50.1	63.8	68.7	80.9	87.0	85.5	105.9	99.6	52.2	76.8
SD	2.23	5.73	8.37	10.34	11.02	11.89	18.52	10.16	31.73	20.92	8.98	15.44
Weight												
Sample Size	102	68	77	70	70	51	90	72	71	34	...	...
Average	...	...	1.42	3.15	4.92	6.52	9.14	7.53	19.53	12.63	...	...
SD	...	...	0.767	1.581	2.886	3.551	7.603	2.668	21.576	10.429	...	...
Total Length						Discharge Arm						
Sample Size	11	33	55	51	50	52	49	40	31	43	6	69
Average	29.7	35.9	57.2	75.5	79.5	95.1	100.0	106.4	140.0	138.2	63.3	100.8
SD	3.80	7.47	11.07	13.86	9.66	16.69	17.86	26.26	27.84	30.50	13.33	23.50
Weight												
Sample Size	11	33	55	51	50	52	49	40	31	43	...	...
Average	...	...	2.64	5.48	6.49	10.21	13.22	15.49	35.61	36.06	...	...
SD	...	...	1.741	3.769	2.228	5.601	9.494	12.050	23.651	26.332	...	...

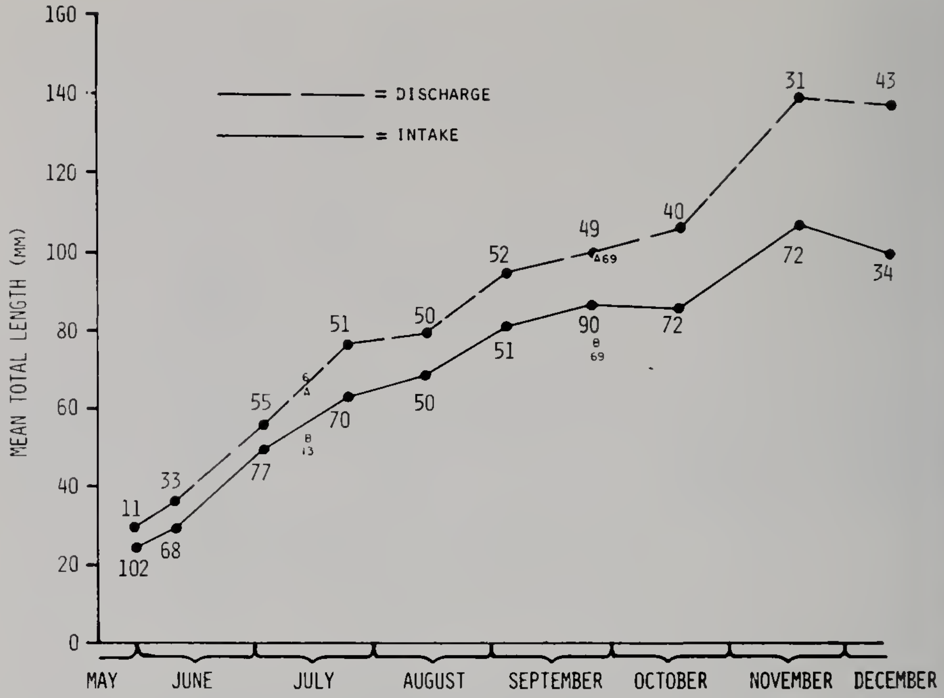

Fig. 5.—Absolute growth in length of juvenile largemouth bass in Lake Sangchris from 29 May to 11 December 1975. Mean lengths of bass on 14 July 1976 and 26 September 1976 are indicated by letters A (discharge arm) and B (intake arm). Numbers indicate sample size.

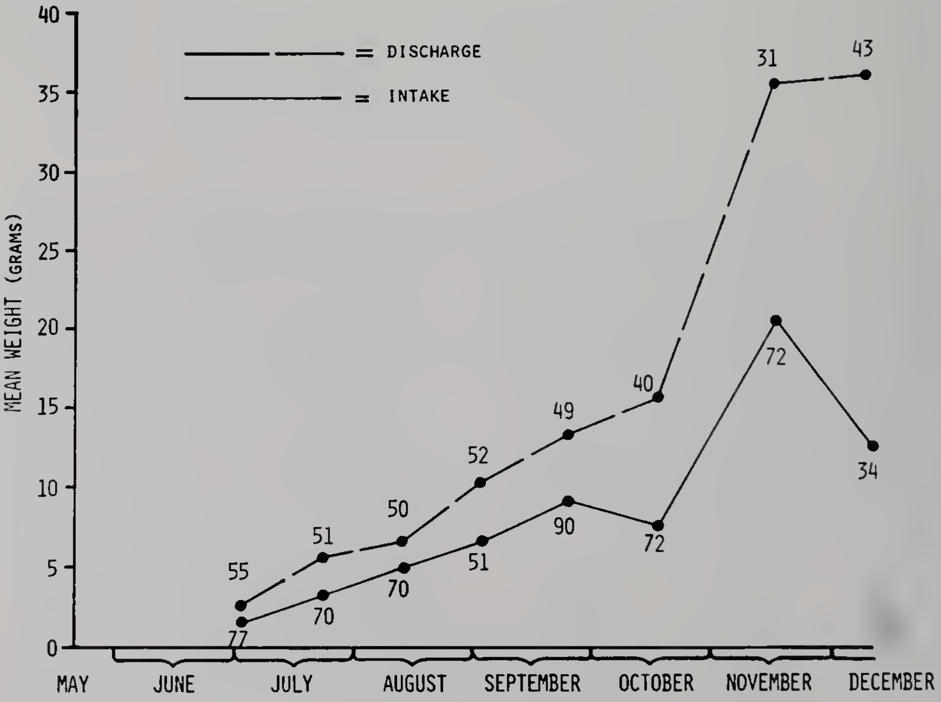

Fig. 6.—Absolute growth in weight of juvenile largemouth bass in Lake Sangchris from 3 July to 11 December 1975. Numbers indicate sample size.

Table 2.—Average coefficients of conditions [K(TL)] for young-of-the-year largemouth bass collected from the intake and discharge arms of Lake Sangchris. Figures marked with an asterisk (*) are significantly (5 percent) greater than the corresponding value for that date by *t* test.

	Intake Arm			Discharge Arm	
1975 Date	Mean K(TL)	N	$P > T$	Mean K(TL)	N
5/29	. . .	0		. . .	0
6/10	. . .	0		. . .	0
7/03	1.05	77	0.0001	1.25*	55
7/23	1.14	70	0.7846	1.13	51
8/13	1.44*	70	0.0001	1.25	50
9/03	1.17*	51	0.0001	1.08	52
9/25	1.23*	90	0.0080	1.18	49
10/17	1.17*	72	0.0427	1.13	40
11/17	1.25*	71	0.0001	1.14	31
12/11	1.11	34	0.4147	1.13	43
Yearly Average	*1.20*	*535*		*1.16*	*371*

which coefficients of conditions could accurately be determined, fish from the intake arm were in significantly better condition than those from the discharge arm. When analyzed by length, five of the 29 size groups (5 mm) showed a significant difference in condition between the two study areas, with four groups indicating better condition in the intake arm (Table 3). The grand average coefficient of condition for bass from all dates and all length groups combined was similar for the intake (1.20) and discharge (1.16 arms of the lake. Conversely, analysis of covariance on the length-weight relationships (formulas 2 and 3) showed significantly greater adjusted means for fish from the intake area, indicating better fish condition in the cooler water. Condition factor may be inversely related to a fish's metabolic rate and therefore lower for those inhabiting the warmer water. Bass from neither study area appeared malnourished or emaciated at any time.

Intake Arm:

$$\log Wt = 3.05345057 \log Lt - 5.0245776 \tag{2}$$

$$R^2 = 0.978$$

$$N = 535$$

Discharge Arm:

$$\log Wt = 2.95053540 \log Lt - 4.8399136 \tag{3}$$

$$R^2 = 0.986$$

$$N = 371$$

$$F = 10.839 \text{ (d.f. } 1{,}903)$$

Since bass from the discharge arm were always larger than those from the intake arm and since they continued to grow later in the season in the discharge arm, it was determined that bass in that area were experiencing a growing season similar to that of a more southerly latitude. In Lake Sanchris, water temperatures warmed earlier and remained warm longer in the discharge arm than in the intake arm. The warmth allowed adult bass in the discharge arm to spawn earlier than those in the intake area and consequently establish the size difference in juvenile bass revealed in the first collection. Additional evidence of an earlier bass spawn in the discharge arm was found in the gonosomatic indices of adult largemouth bass collected during 1975 from Lake Sangchris (Tranquilli et al. 1981). Similar growth rates in both areas maintained the size difference established earlier in the year until the advent of falling autumn water temperatures slowed growth for bass in the intake arm. At that time, rapid growth by bass in the discharge arm continued and further extended the size difference between juvenile bass from the two areas.

Bennett & Gibbons (1974) found that juvenile largemouth bass in the artificially heated portion of a South Carolina reservoir were larger than those in the unheated portion, but attributed the greater size to an accelerated growth rate.

Table 3.—Average coefficients of condition [K(TL)] for young-of-the-year bass within 5 mm size groups collected from Lake Sangchris, 1975. Figures marked with an asterisk (*) are significantly (5 percent) greater than the corresponding value for that size group by *t*-test.

	Intake Arm			Discharge Arm	
Length (mm)	Mean K(TL)	N	$P>T$	Mean K(TL)	N
35– 39	0.93	3	0.1233	1.35	1
40– 44	1.06	23	0.0039	1.28*	6
45– 49	1.10	24	0.7961	1.08	9
50– 54	1.17	19	0.2659	1.24	9
55– 59	1.17	26	0.0563	1.27	13
60– 64	1.26	45	0.4167	1.21	27
65– 69	1.31*	42	0.0152	1.21	13
70– 74	1.25*	48	0.0024	1.17	22
75– 79	1.24*	82	0.0006	1.14	28
80– 84	1.21	65	0.9297	1.21	41
85– 89	1.19	48	0.4815	1.17	28
90– 94	1.11	21	0.2621	1.15	22
95– 99	1.13	23	0.7749	1.12	28
100–104	1.07	8	0.1708	1.14	15
105–109	1.10	5	0.7875	1.14	16
110–114	1.29	8	0.1295	1.07	10
115–119	1.18	9	0.2286	1.08	14
120–124	1.06	6	0.2382	1.10	11
125–129	1.12	6	0.1062	1.17	8
130–134	1.12	5	0.4652	1.09	8
135–139	1.32*	4	0.0426	1.12	7
140–144	1.13	1	0.5586	1.08	8
145–149	1.23	2	0.6265	1.29	2
150–154	1.27	1	0.5840	1.17	3
155–159	1.26	4	0.6096	1.21	4
160–164	1.41	1	0.1833	1.14	5
165–169	1.33	2	0.2731	1.21	2
170–174	1.26	1	0.2900	1.20	3
175–179	0.0	0	. . .	1.17	3
180–184	1.46	2	0.1249	1.30	4
185–189	0.0	0	. . .	1.23	3
190–194	0.0	0	. . .	0.0	0
195–199	0.0	0	. . .	1.22	2
200–204	1.32	1	. . .	1.33	1
All Sizes	*1.20*	*535*		*1.16*	*371*

They also reported condition factors similar for both areas except in May, June, and July when bass from the heated area had higher condition factors. Trembly (1965) reported that fish inhabiting areas of streams receiving thermal effluents generally were larger than those in the unheated areas. Although he found that heated areas did not produce more fish or higher growth rates, fish in the heated areas apparently extended their growing season by continuing to feed throughout the winter months. Busacker (1971) also reported larger largemouth bass in the thermally loaded area of a Missouri reservoir that he attributed to longer growing seasons but did not report any difference in condition factors between the two areas.

FOOD HABITS

Investigations into the food habits of a species are fundamental in determining the basis for alteration in growth which might be observed in a thermally enriched environment. The primary interests in such cases are the types and amounts of foods eaten in the thermally different areas. Consequently, the stomachs of 326 young-of-the-year largemouth bass from the intake arm and 352 from the discharge arm of Lake Sangchris were examined for food content. The fish ranged in size from 18 mm to 200 mm total length. A total of 35 (10.7 percent) stomachs of fish from the intake arm were empty, while 59 (16.8 percent) of those from the discharge arm were empty. Food items found in juvenile largemouth bass stomachs are listed in Table 4.

Food habits were quite varied, and utilization of food organisms differed with respect to size of the fish examined and date of collection (Tables 5 and 6). Bass from both arms of the lake, however, fed essentially on the same food items, aquatic insects, fishes, and zooplankton.

In both areas, aquatic insects were the most important food resource. An average of 47.7 percent and 38.3 percent of the stomach contents (wet weight) of bass from the intake and discharge arms, respectively, consisted of aquatic insects. Composition of the aquatic insects consumed by bass in the intake arm consisted mainly of ephemeropterans (40.5 percent) and zygopeterans (37.3 percent), while chironomids comprised a relatively small (11.5 percent) portion of the total aquatic insects ingested. In the discharge arm, aquatic insect consumption was divided among zygopterans (25.6 percent), ephemeropterans (20.0 percent), corixids (20.2 percent), chironomids (16.6 percent), and anisopterans (9.9 percent).

All zygopterans indentified were *Enallagma* spp. Most Ephemeroptera found were *Callibaetis* spp., along with a few *Hexagenia* spp. and *Caenis* spp. *Cricotopus* spp. and *Xenochironomus* spp. were the most frequently ingested chironomids. No single anisopteran was

Table 4—Common food items of young-of-the-year largemouth bass in Lake Sangchris during 1975.

- Aquatic Insects
  - Ephemeroptera
    - *Callibaetis* spp.
    - *Caenis* spp.
    - *Hexagenia* spp.
  - Zygoptera
    - *Enallagma* spp.
  - Anisoptera
    - *Libellula semifasciata*
    - *Erythemis simplicicollis*
    - *Tramea carolina*
  - Hemiptera
    - Mesoveliidae
      - *Mesovelia* spp.
    - Gerridae
      - *Trepobates* spp.
    - Corixidae
      - *Sigara alternata*
      - *Trichocorixa kanza*
      - *T. calva*
      - *Palmacorixa* spp.
  - Coleoptera
    - *Tropisternus* spp.
  - Diptera
    - Ceratopogonidae
      - *Palpomyia* complex
    - Culicidae
      - *Culiseta inornata*
    - Chironomidae (larvae and pupae)
      - *Procladius* prob. *P. bellus*
      - *Chironomus* prob. *C. attenuatus*
      - *Glyptotendipes* prob. *G. lobiferus*
      - *Dicrotendipes* prob. *D. modestus*
      - *Tanytarsus* spp.
      - *Polypedilum* spp.
      - *Cricotopus* spp.
      - *Orthocladius* spp.
      - *Xenochironomus* spp.
- Terrestrial or Aerial Insects
  - Zygoptera
    - *Enallagma* spp.
  - Trichoptera
    - *Hydroptila* spp.
  - Hymenoptera
    - Formicidae
    - Apidae
  - Coleoptera
  - Mecoptera
- Zooplankton
  - Cladocera
    - *Bosmina longirostris*
    - *Chydorus sphaericus*
    - *Pleuroxus denticulatus*
    - *Scapholeberis kingi*
    - *Simocephalus vetulus*
    - *S. serrulatus*
    - *Daphnia parvula*
    - *Sida crystallina*
    - *Diaphanosoma leuchtenbergianum*
  - Copepoda
    - Cyclopoida
      - *Cyclops vernalis*
      - *Eucyclops agilis*
      - *E. speratus*
      - *Macrocyclops albidus*
      - *Mesocyclops edax*
    - Calanoida
      - *Diaptomus siciloides*
  - Ostracoda
    - Podocopa
  - Other Crustacea
    - *Hyallela azteca*
- Fishes
  - *Lepomis macrochirus*
  - *Micropterus salmoides*
  - *Dorosoma cepedianum*
  - *Notropis lutrensis*
  - *Notemigonus crysoleucas*
- Nematoda
- Plant Matter
- Inorganic
- Unidentified

Table 5.—Average weight percentages of major food items of young-of-the-year bass from the intake arm of Lake Sangchris in 1975.

Food Items	Collection Dates										Average
	5/29	6/10	7/03	7/23	8/13	9/03	9/25	10/17	11/17	12/11	
Zooplankton	73.26	47.94	37.59	0.81	0.22	0.0	0.35	15.21	5.51	0.0	16.24
Cladocera	31.89	39.03	31.63	0.67	0.16	0.0	0.35	11.25	5.50	0.0	10.50
Copepoda	41.37	8.47	5.96	0.13	0.05	0.0	0.0	3.96	0.01	0.0	5.71
Aquatic insects	11.90	29.82	37.37	34.79	76.29	72.79	61.53	43.72	28.24	70.70	47.72
Chironomidae	11.90	18.75	12.05	1.70	1.26	3.38	1.82	2.65	9.17	0.37	5.51
Ephemeroptera	0.0	7.47	15.27	10.60	18.17	40.14	42.25	24.56	11.11	8.81	19.35
Zygoptera	0.0	0.31	7.68	15.33	40.06	27.05	15.32	9.78	7.86	56.16	17.85
Anisoptera	0.0	0.0	0.0	0.65	8.18	0.90	0.0	0.98	0.0	1.51	1.32
Hemiptera	0.0	1.11	2.31	6.45	6.52	1.32	2.07	5.75	0.0	3.85	3.26
Mesoveliidae	0.0	0.0	0.0	0.0	0.18	0.21	0.0	0.0	0.0	0.0	0.04
Gerridae	0.0	0.22	0.0	2.97	1.04	0.0	0.0	0.0	0.0	0.0	0.57
Corixidae	0.0	0.89	2.31	3.48	5.31	1.08	2.07	5.75	0.0	3.85	2.64
Terrestrial arthropods	0.0	0.02	0.0	0.86	3.03	11.12	3.91	2.89	5.80	0.91	2.83
Zygoptera	0.0	0.0	0.0	0.0	1.20	11.12	0.0	0.0	0.0	0.0	1.21
Fish	0.0	16.93	24.34	54.43	19.42	15.45	31.96	11.48	43.35	28.07	25.65
Lepomis macrochirus	0.0	0.0	4.17	23.32	8.92	9.87	11.62	2.22	16.34	9.52	9.39
Dorosoma cepedianum	0.0	0.0	0.0	1.32	0.0	0.0	0.0	0.0	0.0	0.0	0.20
Cyprinidae	0.0	0.0	0.0	2.28	2.78	0.0	2.32	0.0	0.0	0.0	0.99
Nematoda	0.14	0.0	0.0	0.37	0.32	0.29	0.48	5.20	5.65	0.01	1.07
Plant matter	0.0	0.0	0.0	0.77	0.32	0.16	0.37	6.05	0.20	0.13	0.84
Unidentified organic	11.52	5.29	0.50	7.72	0.41	0.0	1.41	12.28	5.56	0.17	4.58
Inorganic material	0.0	0.0	0.0	0.0	0.0	0.18	0.0	0.0	0.13	0.0	0.03
Number empty	0	0	1	0	2	1	6	6	7	12	35
Number examined	29	23	25	43	35	29	49	35	25	33	326

Table 6.—Average weight percentages of major food items of young-of-the-year bass from the discharge arm of Lake Sangchris in 1975.

Food Items	Collection Dates										Average
	5/29	6/10	7/03	7/23	8/13	9/03	9/25	10/17	11/17	12/11	
Zooplankton	60.13	58.44	21.64	0.02	0.10	6.40	7.47	13.18	0.0	0.0	12.95
Cladocera	43.52	46.81	12.69	0.0	0.10	6.37	6.69	13.06	0.0	0.0	10.20
Copepoda	16.60	11.64	8.76	0.02	0.0	0.03	0.77	0.12	0.0	0.0	2.73
Aquatic insects	24.82	21.26	62.91	35.10	72.42	47.27	18.70	42.41	4.35	17.25	38.20
Chironomidae	20.43	14.01	13.79	0.34	0.66	2.76	6.98	7.13	0.0	11.37	6.36
Ephemeroptera	4.39	4.11	16.74	6.74	16.10	6.94	6.51	5.96	0.0	0.0	7.65
Zygoptera	4.39	3.14	10.62	17.84	28.75	5.51	5.18	7.77	0.0	5.88	9.80
Anisoptera	0.0	0.0	0.0	0.0	22.92	2.32	0.0	8.32	0.0	0.0	3.81
Hemiptera	0.0	0.0	21.62	9.80	3.86	29.74	0.0	10.46	4.35	0.0	10.29
Mesoveliidae	0.0	0.0	0.0	0.0	3.54	2.29	0.0	0.16	0.0	0.0	0.74
Gerridae	0.0	0.0	0.0	5.83	0.02	6.54	0.0	0.0	0.0	0.0	1.78
Corixidae	0.0	0.0	21.62	3.97	0.30	20.92	0.0	10.09	4.35	0.0	7.75
Terrestrial arthropods	0.0	0.0	0.0	8.61	11.79	26.81	39.61	9.37	0.0	6.27	12.34
Zygoptera	0.0	0.0	0.0	0.0	5.75	17.80	0.44	0.0	0.0	0.0	3.29
Fish	6.36	9.41	13.69	52.00	12.14	10.96	25.89	27.92	89.38	64.07	29.75
Lepomis macrochirus	0.0	0.0	2.85	14.80	3.11	2.33	3.03	2.71	30.43	29.41	7.84
Dorosoma cepedianum	0.0	0.0	0.0	21.54	0.0	0.0	10.53	2.94	0.0	0.0	4.54
Cyprinidae	0.0	0.0	2.34	0.0	0.0	0.0	6.34	0.0	0.0	0.0	0.99
Nematoda	0.0	0.0	0.0	0.0	3.25	0.77	0.43	0.17	0.0	1.18	0.60
Plant matter	0.0	0.0	0.10	3.14	0.30	2.73	0.0	2.26	0.09	6.52	1.53
Unidentified organic	6.24	10.88	0.87	1.16	0.0	2.36	7.91	1.54	4.07	0.0	3.13
Inorganic material	0.0	0.0	0.07	0.06	0.0	2.70	0.0	0.18	1.83	4.71	0.85
Number empty	0	0	0	4	7	5	7	2	8	26	59
Number examined	11	24	35	45	39	48	40	36	31	43	352

found more frequently than any other. Bass from the intake and discharge arms showed little difference in species preference for most taxa. Different Corixidae, however, were used in the two study areas. *Trichocorixa calva* predominated in fish from the discharge arm while *Palmacorixa* spp. was found most often in bass from the intake arm. Distributional differences of these two corixids in Lake Sangchris may have accounted for their differential usage by bass; however, Webb (1981) did not collect corixids in sufficient numbers in his benthic samples to confirm this hypothesis. Aquatic insects other than those mentioned above were also utilized in both arms, but made a comparatively small contribution to the overall diet. Those littoral-dwelling macroinvertebrates indicate that bass were feeding in vegetated, shallow areas of the lake.

Fish accounted for 25.7 percent (by weight) of the diet of bass from the intake arm and 29.8 percent of the diet of bass from the discharge arm. Bluegills, *Lepomis macrochirus,* were the most frequently identified fish in samples from both study areas; however, most fish were too digested for identification. Fish utilization by bass from the intake arm was equal to or greater than that in the discharge arm until the last three collections of 1975, at which time consumption of fish by bass in the discharge arm increased considerably.

Zooplankton accounted for an average of 16.2 percent of the food matter of bass from the intake arm and 13.0 percent for those from the discharge arm. In both study areas Cladocera constituted the major portion of the zooplankton consumed (65 percent in the intake arm and 79 percent in the discharge arm) while Copepoda made up the remainder. Several species of Cladocera were of major importance in the composition of zooplankton used as forage. Those species most frequently found in stomachs were *Bosmina longirostris, Scapholeberis kingi, Simocephalus serrulatus,* and *Sida crystallina.* Those species were used in similar quantities in both arms of the lake. When a cladoceran species was the predominant prey of bass in one arm, it also tended to be the predominant cladoceran prey in the other arm. Seasonal pulses of different species of zooplankter may have developed simultaneously in the two arms of the lake, or the water current associated with the cooling loop of Lake Sangchris may have tended to reduce species segregation between the two arms. Some cladoceran species, however, were known to occur throughout the year in both arms of the lake (Steve Waite, Illinois Natural History Survey, personal communications) but were consumed by bass mainly during a particular time of year. The data indicated that small, round cladocerans, such as *Bosmina longirostris* and *Chydorus sphaericus,* were used early in the year when bass were small. Later in the year when bass were larger, bigger cladocerans such as *Simocephalus serrulatus, Daphnia parvula, Sida crystallina,* and *Diaphanosoma leuchtenbergianum* were the predominant cladocerans consumed. In general, the species of Cladocera consumed by bass are typically found in shallow vegetated areas, indicating the type of habitat in which bass fed.

Bass consumption of terrestrial and aerial insects was typically low (intake 2.8 percent, discharge 12.3 percent). Predominant in this food category were emergent aquatic insects. Zygopteran adults accounted for an average of 42.8 percent and 26.6 percent of the weight ingested of this food category in the intake and discharge arms, respectively. As in the nymphal stages, *Enallagma* spp. was the only adult zygopteran found.

The most obvious trend in the food habits was the shift in food selection which occurred with changes in bass total length (Fig. 7). Bass of comparable size used the same type of food resources in similar quantities in both the intake and discharge arms. Bass from 18 to 50 mm fed heavily on zooplankton. Chironomids were also frequently eaten by small bass but were utilized to some extent by fish as large as 130 mm. Other aquatic insects were utilized over a broad range of bass

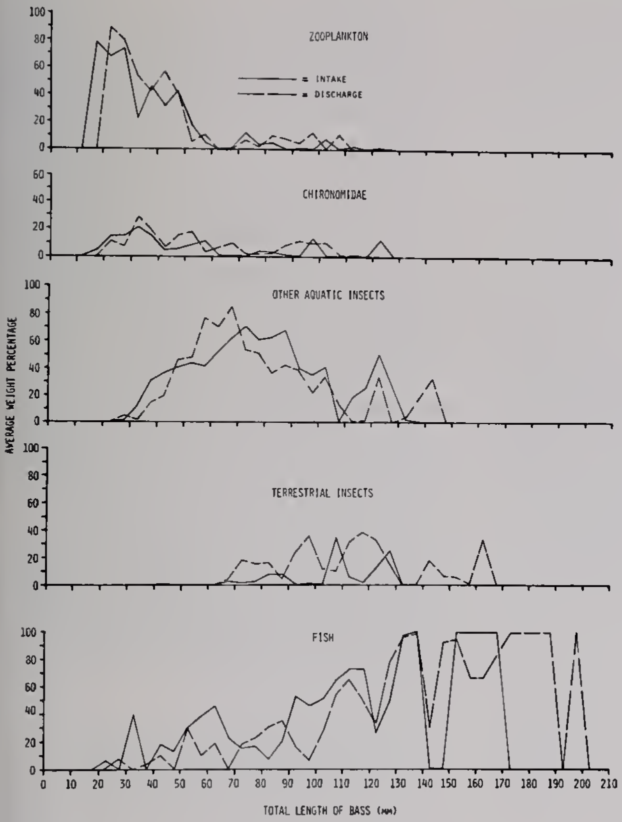

Fig 7—Average weight percentage of major food categories utilized by young-of-the-year bass of different lengths in Lake Sangchris during 1975.

sizes and generally in great quantities. Dependence upon this food source was greatest for bass between 40 mm and 140 mm in total length. Terrestrial and aerial insects were mainly consumed by bass between 70 mm and 170 mm. Consumption of these types of insects, however, was generally lower than consumption of aquatic insects or fish. While fish were used as a food resource by bass as small as 22 mm, they were not a consistantly important food item until bass reached a total length of 90–100 mm. As bass increased in length, there was a general increase in the utilization of fish as food. These findings agree well with Keast & Webb (1966) who found that young bass from 30 to 50 mm had a diverse diet of Cladocera, Ephemeroptera, Amphipoda, and Chironomidae, while fish were not predominant in the diet until bass reached a length of 80 mm. These data are also similar to those reported by McCammon et al. (1964) who found that bass less than 66 mm in length fed on insects and plankton while larger bass primarily ate fish.

Since bass from both areas of Lake Sangchris exhibited similar food habits, it was hypothesized that differences in growth rates near the end of the normal growing season resulted from decreased feeding in the intake arm. Although bass in the discharge arm continued to grow rapidly late in the season while those in the intake arm did not, the percentage of empty stomachs in bass from the two study areas did not support the hypothesis consistently. However, the frequency of empty stomachs may not be a reliable indicator of feeding rate, since factors such as the time of collection, rate of digestion, and type of food consumed also need to be considered when evaluating growth. Greater predation on fish by bass from the discharge arm from 17 October through 11 December 1975 probably was paramount in affecting late season bass growth. Bennett (1948) stated that, as food items for bass in Illinois, Cladocera and aquatic insects were not conducive to rapid growth when compared to fish or crayfish. The higher growth efficiency associated with consuming fish matter and the higher fish metabolism in the warmer water may well have accounted for the faster growth rate of bass in the discharge arm during the last part of the 1975 growing season. The greater size of young-of-the-year bass in the discharge arm by the end of the normal growing season was a result of the size advantage initiated earlier in the year and maintained throughout the growing season. Consequently, even with similar feeding habits exhibited throughout most of the year by bass from the intake and discharge arms of Lake Sangchris, the normal shift of larger bass to a more piscivorous habit helped stimulate growth of bass in the discharge arm during the latter part of the year. Since bass in the discharge arm were larger and could utilize the more highly efficient fish diet, bass from that area were able to benefit both from their size advantage and the thermally extended growing season in the fall.

First-year growth increases offer many possible benefits to both fishermen and resource managers. Enhanced growth probably offers survival advantages for bass as well as producing a more efficient fish predator. Earlier recruitment into the fishable bass stock is another possible merit of thermal enrichment that might increase the fishing pressure that a body of water could withstand.

SUMMARY

1.—On each collection date, juvenile bass from the warmer discharge arm had significantly greater lengths and weights than those from the cooler intake arm.

2.—Since bass in the discharge arm were spawned earlier and continued to grow later in the season than those in the intake arm, the elevated temperatures in the heated area extended the actual growing season for bass residing there.

3.—Growth rates were similar for juvenile bass in the two study areas throughout most of the study period, except near the end of the normal growing season when bass in the discharge arm continued to grow rapidly while those in the intake arm did not.

4.—Condition factors of bass were lower in the discharge area, possibly associated with higher metabolic rates of fish in the warmer water. Bass were not considered in poor condition in either area.

5.—The composition of the stomach contents was closely correlated with the size of bass examined. Small bass from both areas fed heavily on zooplankton, while larger bass shifted initially to aquatic insects and later to fish.

6.—The extended growing season in the discharge arm consequently allowed more young bass to grow to a predominantly piscivorous size during their first year of life.

REFERENCES CITED

BENNETT, D. H., and J. W. GIBBONS. 1974. Growth and condition of juvenile largemouth bass from a reservoir receiving thermal effluent. Pages 246–254 *in* J. W. Gibbons and R. R. Sharitz, ed., Thermal ecology. AEC Symposium Series (CONF-730505). Augusta, GA.

BENNETT, G. W. 1937. The growth of the large mouthed black bass, *Huro salmoides* (Lacepede), in the waters of Wisconsin. Copeia (2):104–118.

———. 1948. The bass-bluegill combination in a small artificial lake. Illinois Natural History Survey Bulletin 24(3):377–412.

BUSACKER, G. P. 1971. The age and growth of the largemouth bass, *Micropterus salmoides* (Lacepede), in a thermally loaded reservoir. M.A. Thesis, University of Missouri, Columbia.

CARLANDER, K. D. 1969. Handbook of freshwater fishery biology. Volume I. The Iowa State University Press, Ames. 752 p.

———. 1977. Handbook of freshwater fishery biology. Volume II. The Iowa State University Press, Ames. 431 p.

CLUGSTON, J. P. 1964. Growth of the Florida largemouth bass, *Micropterus salmoides floridanus* (LeSueur), and the northern largemouth bass, *M. s. salmoides* (Lacepede), in subtropical Florida. American Fisheries Society Transactions 93(2): 146–154.

JOY T. 1976. Lake Shelbyville fish populations. Pages 4.12–4.30 *in* R. W. Larimore and J. M. McNurney, eds., Evaluation of a cooling lake fishery. First annual report by Illinois Natural History Survey to electric Power Research Institute, Palo Alto, Ca (unpublished).

KEAST, A., and D. WEBB. 1966. Mouth and body form relative to feeding ecology in the fish fauna of a small lake, Lake Opinicon, Ontario, Canada Fisheries Research Board Journal 23(12):1845–1874.

KRAMER, R. H., and L. L. SMITH, JR. 1960. First-year growth of the largemouth bass, *Micropterus salmoides* (Lacepede), and some related ecological factors. American Fisheries Society Transactions 89(2):222–233.

LARIMORE, R. W., and J. A. TRANQUILLI. 1981. The Lake Sangchris project. Pages 279–289 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32 (4).

MCCAMMON, G. W., D. A. LAFAUNCE, and C. M. SEELEY. 1964. Observations on the food of fingerling largemouth bass in Clear Lake, Lake County, California. California Fish and Game 50 (3):158–169.

MRAZ, D., S. KMIOTEK, and L. FRANKENBURGER. 1961. The largemouth bass, its life history, ecology, and management. Wisconsin Conservation Department Publication 232. 15 p.

STRAWN, K. 1961. Growth of largemouth bass fry at various temperatures. American Fisheries Society Transactions 90(3):334–335.

STROUD, R. H. 1948. Growth of the basses and black crappie in Norris Reservoir, Tennessee. Tennessee Academy of Science Journal 23(1):31–99.

TRANQUILLI, J. A., R. KOCHER, and J. M. MCNURNEY. 1980. Population dynamics of the Lake Sangchris fishery. Pages 413–499 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

TREMBLY, F. J. 1965. Effects of cooling water from steam-electric power plants on stream biota. Pages 334–345 *in* Biological problems in water pollution. Third Seminar 1962. U. S. Public Health Service Publication 999-WP-25.

WEBB, D. 1981. The benthic macroinvertebrates from the cooling lake of a coal-fired electric generating station. Pages 358–377 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

Results of a Multiple-Objective Fish-Tagging Program in an Artificially Heated Reservoir

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ABSTRACT

A multiple-objective fish-tagging program was conducted from 1974 to 1976 to obtain data on largemouth bass, carp, and white bass that could not be obtained by other methods and to clarify some conflicting results regarding fish growth, movements, and population densities found in other fishery investigations of Lake Sangchris, a power plant cooling lake. Including multiple recaptures and fish recaptured without tags (marks only), 38.4 percent of the 2,390 largemouth bass, 8 percent of the 1,492 carp, and 5.6 percent of the 1,133 white bass were subsequently recovered.

Largemouth bass populations were estimated by mark-and-recapture methods with 95 percent confidence to be 11,561 ± 2,952 fish $\geq$ 150 mm in total length in 1974 and 9,444 ± 1,700 fish $\geq$ 200 mm in 1975. From these estimates an average standing crop of 8.8 kg/ha was determined. In 1976 the number of carp was estimated with 95 percent confidence to be 13,194 ± 2,408 fish $\geq$ 275 mm in total length, or a standing crop of 20.0 kg/ha.

Analyses of fish movements indicated no relationship between the size of the fishes tagged and the distances they traveled. The grand mean for distances traveled by fish from all areas of the lake combined was 5,845 m for white bass, 1,635 m for largemouth bass, and 1,389 m for carp. Largemouth bass tagged at stations in the discharge and intake areas traveled significantly farther than did bass from stations in the middle of the cooling loop, perhaps because those habitats represented extreme thermal conditions and the fish at those sites may have been seasonally attracted to or repelled from thermal gradients in the lake.

Movements by all three species between heated and unheated areas had no effect on their average growth in length or weight, but larger individuals grew more rapidly than smaller ones. Composite growth data obtained from recapture records showed that largemouth bass and white bass growth was rapid, but that little, if any, carp growth had occurred.

The effects of thermal discharge on annulus formation by largemouth bass in cooling lakes was examined by comparing scales taken from the same fish at the time of tagging and again upon recapture. Annulus formation occurred during the spring, but false annuli were especially common in fish from the heated area and could not easily be distinguished from true annuli. Consequently, interpretation of annual growth from marks on scales was not suggested for cooling lake bass populations in this region of the USA.

INTRODUCTION

A multiple-objective fish-tagging program was initiated as part of a broad ecological study of thermal effects at Lake Sangchris. The tagging studies were initiated to obtain data that could not be obtained by other methods and to clarify some conflicting results regarding fish growth, movements, and population

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densities obtained in other fishery investigations of this cooling lake. Largemouth bass *(Micropterus salmoides)*, carp *(Cyprinus carpio)*, and white bass *(Morone chrysops)* were tagged. Objectives of the study included: (1) estimation of population size and standing crops, (2) comparison of composite growth of each species relative to its movements among heated and unheated areas, (3) quantitative analysis of fish movements within different thermal regions, and (4) determination of thermal discharge effects on annulus formation.

METHODS

From 1974 to 1976 a total of 5,015 fish (2,390 largemouth bass, 1,492 carp, and 1,133 white bass) was captured from Lake Sangchris, tagged, and released within 100 m of the original points of capture. Each fish was tagged with an individually numbered Floy anchor tag (Model FD-67 in 1974 and Model FD-68B in 1975 and 1976). The tags and applicator are described by Dell (1968). The tags were inserted diagonally, as he suggested. In 1974 each tagged fish was given two permanent marks (fin clips) to indicate the area of the lake (station) and year in which tagging occurred. In 1975 and 1976 each tagged fish was given only one permanent mark to indicate the year of tagging. From such distinctive marks, fish that lost their tags could always be recognized as belonging to a group tagged during a specific year. Gross movement between stations could be determined for recaptured fish that had lost their tags if they were in the group tagged and marked during 1974.

To equalize the distribution of tagged fish in relation to their population density, largemouth bass and carp were captured throughout the lake by using an alternating-current electrofishing apparatus. In 1974 and 1975, total lengths of 150 and 200 mm, respectively, were selected as minimum sizes of largemouth bass to be tagged. A total of 1,035 largemouth bass was tagged in 1974, and 1,355 in 1975; 439 carp were tagged in 1975, and 1,053 in 1976. From 1974 to 1976, largemouth bass and carp were tagged between 13 April and 15 May. White bass were captured by hook and line or with a direct-current electrofishing apparatus in the discharge canal only. The direct-current apparatus was used because we observed poor recovery from electronarcosis with an alternating-current electrofishing apparatus. In 1975, 200 white bass were tagged between 9 April and 18 April, and in 1976, 933 white bass were tagged between 27 February and 8 May.

During all 3 years of the study, fish captured for tagging were processed in small groups (10—20 fish) to reduce handling stress. The release locations were carefully noted on detailed maps so that movements of individual fish could

Fin-clipped white bass tagged with an anchor tag.

be determined accurately. The anchor end of the tag was inserted between the interneural rays near the posterior end of the dorsal fin with the colored informational end of the tag trailing outside of the fish. The tags instructed fishermen to report their catch by telephone to the Illinois Natural History Survey. The sex of each mature fish was determined at the time of tagging by external examination. The fish was sexed again upon recapture. Each fish was weighed, measured, and marked permanently with a fin clip prior to being tagged with a Floy anchor tag. A series of scales was taken from each fish during the tagging process and stored in individual envelopes.

An attempt was made to collect as much information as possible on each recaptured fish. For each recapture, the method of recapture and the method of information retrieval was recorded. Only lengths and weights of recaptured fishes measured by biologists were used in the analysis of fish growth. The highly irregular shoreline of the lake, with many distinctive coves and landmarks, permitted very accurate location of recapture sites. The shortest distance from point of release to point of recapture was measured on a large aerial photograph of the lake to determine the distance traveled by individual fish. The distances traveled by tagged fish were determined only from those fish recaptured with intact tags. Tag retention rates were determined from the number of marked fish of each species recaptured with tags each month.

For descriptive purposes, and to compare growth and movements of fishes tagged in different regions, the entire lake was divided into eight contiguous stations (Fig. 1). Stations 0, 1, 2, 7, and 8 represented regions with unheated water, and stations 3, 4, and 5 represented regions with heated water for some comparisons. No fish were tagged at Station 6, the slag pond adjacent to the power plant, because it is not part of the lake.

Population estimates for largemouth bass and carp were based on Petersen mark-and-recapture methods. Lewis et al. (1962) had previously used an electric shocker in conjunction with mark-and-recovery methods to estimate populations of largemouth bass. The rationale is that the total population size is related to the number marked and released in the same way as the total caught at a subsequent time is related to the number of marked fish recaptured. This relationship was expressed mathematically according to this equation (Robson & Regier 1971):

$$\hat{N} = mc/r$$

Where

N = total number of fish in population (unknown)

m = total number of marked fish in population (known)

c = number of fish in subsequent sample

r = number of marked fish recaptured in sample

$\hat{N}$ = estimate of N

The 95-percent confidence limits were approximated by adding two standard errors to the estimate and subtracting two from it. The standard error of $\hat{N}$ was estimated by the following equation:

$$SE(\hat{N}) = \hat{N}\sqrt{\frac{(\hat{N}-m)(\hat{N}-c)}{mc(\hat{N}-1)}}$$

The mark-and-recapture methods were based on these assumptions (Ricker 1958): (1) marked fish did not lose their identifying marks (fin clips) throughout the study period, (2) marking effort was proportional to the density of the population throughout the body of water or marked individuals were randomly distributed in the population, (3) marked and unmarked fish were equally susceptible to capture, (4) numbers of fish were not increased via recruitment from growth or immigration, and (5) losses through death or emigration were the same for both marked and unmarked fish.

The effect of thermal discharge on annulus formation by largemouth bass was studied by comparing growth marks on scales taken from each fish at the time of tagging with growth marks on scales

Fig. 1.—Lake Sangchris, showing stations for fish-tagging studies. Shaded zones represent areas where largemouth bass were tagged in 1974. In subsequent years largemouth bass and carp were tagged along the entire shoreline of the lake, which was divided into eight contiguous stations for descriptive purposes.

taken from the same fish when it was recaptured. The scales were cleaned in water and impressions were made of the scales in acetate by means of a roller press (Smith 1954). The acetate impressions were viewed on an Eberbach scale projector at 40 × magnification.

Data were analyzed by species using Statistical Analysis System (SAS) procedures (Barr et al. 1976) on an IBM 360/75 computer at the University of Illinois, Urbana. The frequency program (FREQ) within SAS was used to compile methods of recapture and information retrieval, to determine tag retention rates, and to categorize movements between stations. A one-way analysis of variance, using initial size as a covariable, was used to compare distances traveled by male and female fish (Table 10). To compare distances traveled by fish tagged in different areas of the lake, an analysis of variance was used with initial length and time as covariables (Table 13). When significant differences were found, a Duncan multiple range test was used to compare the means. The relationship between fish growth and movements within and between heated and unheated portions of the lake was examined by an analysis of variance that used year of recapture and size (initial length and weight) as covariables (Tables 15 and 16).

RESULTS AND DISCUSSION

METHODS OF RECAPTURE AND INFORMATION RETRIEVAL

From the 5,015 fish tagged and marked in Lake Sangchris from 1974 to 1976, 1,100 recapture records were obtained (Table 1). Sport fishing (49.8 percent) and electrofishing (48.5 percent) accounted for approximately equal proportions of the 918 largemouth bass recoveries. For carp, electrofishing ac-

Table 1.—Numbers and percentages of tagged and marked fish recaptured in Lake Sangchris by various methods.

Species and Year	Sport Fishing N (%)	Bow & Arrow N (%)	Electro-fishing N (%)	Gill Net N (%)	Rotenone N (%)	Hoop Net N (%)	Found Dead N (%)	Total N (%)
Largemouth bass								
1974	241(48.5)	0(0.0)	250(50.3)	1(0.2)	0(0.0)	0(0.0)	5(1.0)	497(100.0)
1975	216(51.3)	0(0.0)	195(46.3)	2(0.5)	2(0.5)	0(0.0)	6(1.4)	421(100.0)
Subtotal	457(49.8)	0(0.0)	445(48.5)	3(0.3)	2(0.2)	0(0.0)	11(1.2)	918(100.0)
Carp								
1975	8(23.5)	0(0.0)	25(73.5)	1(3.0)	0(0.0)	0(0.0)	0(0.0)	34(100.0)
1976	5(5.9)	1(1.2)	75(88.2)	0(0.0)	0(0.0)	1(1.2)	3(3.5)	85(100.0)
Subtotal	13(10.9)	1(0.8)	100(84.0)	1(0.8)	0(0.0)	1(0.8)	3(2.6)	119(100.0)
White bass								
1975	12(57.1)	0(0.0)	5(23.8)	3(14.3)	0(0.0)	0(0.0)	1(4.7)	21(100.0)
1976	25(59.5)	0(0.0)	2(4.8)	1(2.4)	0(0.0)	0(0.0)	14(33.3)	42(100.0)
Subtotal	37(58.7)	0(0.0)	7(11.1)	4(6.3)	0(0.0)	0(0.0)	15(23.8)	63(100.0)
Total	*507(46.1)*	*1(0.1)*	*552(50.2)*	*8(0.7)*	*2(0.2)*	*1(0.1)*	*29(2.6)*	*1,100(100.0)*

counted for a much greater proportion (84 percent) of the 119 recoveries than did sport fishing (10.9 percent), while for white bass, sport fishing accounted for a greater proportion (58.7 percent) of the 63 recoveries than did electrofishing (11.1 percent). Other methods of fish recapture included the use of bow and arrow, experimental gill nets, rotenone in standing crop surveys, and hoop nets as well as the recovery of dead fish. None of those recovery methods was important for largemouth bass or carp, but gill nets and recovery of dead fish were important for white bass. Gill nets (6.3 percent) probably accounted for a greater percentage of the 63 white bass recoveries than of the largemouth bass and carp recoveries because of the pelagic nature of the white bass. The relatively high proportion of white bass recovered dead (23.8 percent) may be indicative of the inability of that species to handle the stress of (1) capture by electrofishing or hook and line, (2) the marking and tagging procedure itself, or (3) tagging during its spawning migration, which probably is a very demanding period in its life history.

Fishes were recaptured for information retrieval by field biologists who sampled the fish population or by sport fishermen who reported tagged fish to a creel clerk, took them to the field laboratory, or reported them by telephone. Considering the three species of fish together, the majority (669, 60.8 percent) of the 1,100 recoveries resulted from samples collected by field biologists (Table 2). Sport fishermen reported 187 tagged fish (17.0 percent) to the creel clerk, reported 189 (17.2 percent) by telephone, and took 55 (5 percent) to the field laboratory.

Of the 2,390 largemouth bass tagged and marked in 1974 and 1975, 649 (27.2 percent) (including multiple recaptures) were recaptured with intact tags and 269 (11.3 percent) were recaptured without tags (Table 3). A total of 918 tagged and marked largemouth bass were recaptured for a total recovery rate of 38.4 percent. Excluding multiple recaptures of largemouth bass and fish without tags, a total of 583 individuals were recaptured, yielding a recovery rate of 24.4 percent. The recovery rate of largemouth bass was more than three times greater than that for either carp or white bass.

Including multiple recaptures and fish recaptured without tags in 1975 and 1976, only 119 (8 percent) of the 1,492 tagged and marked carp and 63 (5.6 percent) of the 1,133 white bass were recovered. A greater proportion of the tagged largemouth bass were recovered because they were easily captured by electrofishing, there was an excellent sport fishery for that species in Lake Sangchris, and the help of largemouth bass sportsmen's clubs in the immediate area was solicited. In contrast, very few carp were captured by sport fishermen, and white

Table 2.—Methods of information retrieval from tagged and marked fish recaptured in Lake Sangchris.

	Method of Information Retrieval				
Species and Year	Caught by Field Biologists	Taken to Field Laboratory	Reported by Telephone	Reported to Creel Clerk	Total
Largemouth bass					
1974	286	14	73	124	497
1975	241	35	84	61	421
Subtotal	527	49	157	185	918
Carp					
1975	26	3	5	0	34
1976	78	0	7	0	85
Subtotal	104	3	12	0	119
White bass					
1975	13	1	6	1	21
1976	25	2	14	1	42
Subtotal	38	3	20	2	63
Total	*669*	*55*	*189*	*187*	*1,100*

Table 3.—Numbers of tagged and marked fish recaptured from Lake Sangchris with tags present (including multiple recaptures, i.e., 1x, 2x, etc.) or absent and percentages of recovery.

Species and Year	Number Tagged & Marked	Recaptured Fish						
		Tag Absent	Tags Present					
		N (%)	1x	2x	3x	4x	(%)	Total (%)
Largemouth bass								
1974	1,035	180(17.4)	232	38	3	0	(30.6)	497(48.0)
1975	1,355	89(6.6)	289	19	1	1	(24.5)	421(31.1)
Subtotal	2,390	269(11.3)	521	57	4	1	(27.2)	918(38.4)
Carp								
1975	439	3(0.7)	26	1	1	0	(7.1)	34(7.7)
1976	1,053	5(0.5)	70	5	0	0	(7.6)	85(8.1)
Subtotal	1,492	8(0.5)	96	6	1	0	(7.4)	119(8.0)
White bass								
1975	200	1(0.5)	20	0	0	0	(10.0)	21(10.5)
1976	933	0(0.0)	40	1	0	0	(4.5)	42(4.5)
Subtotal	1,133	1(0.1)	60	1	0	0	(5.5)	63(5.6)
Total	*5,015*	*278(5.5)*	*677*	*64*	*5*	*1*	*(16.4)*	*1,100(21.9)*

bass were difficult to recapture by electrofishing due to their pelagic nature (Table 1). Other factors that contributed to the relatively good overall recovery rate for tagged fishes in a lake of this size were (1) an intensive fish sampling program, (2) a full-time creel survey, (3) the location of a field laboratory at the site, and (4) public announcement of the tagging program by local newspapers and radio stations.

TAG RETENTION AND EFFECTS OF TAGS ON FISH GROWTH AND SURVIVAL

Due to tag failures encountered during this study, tag retention rates were determined by species and year of study. In 1974, largemouth bass were tagged with Floy Model FD-67 tags, consisting of two parts joined together with glue: a t-bar monofilament anchor and a plastic sleeve with printed information. Within just a few months, many bass were recaptured with only the anchor end of the tag and not the informational sleeve. Although accurate records of the frequency of tag failure were not kept, it was a serious problem that got progressively worse as time passed. In this study, tag retention rates were determined by the ratio of fish captured each month with intact tags (all parts) in relation to the number marked and/or carrying only the anchor end of the tag. Since most fish were tagged during April and May, tag retention rates calculated about 6 months later (September and October) and during April and May of the following year were most descriptive. Thus, for largemouth bass tagged with Floy FD-67 tags in 1974, tag retention was 51 percent at about 6 months and 24 percent after 1 year (Fig. 2).

In 1975, largemouth bass were tagged with Floy Model FD-68B tags that consisted of three parts: an anchor end with a longer monofilament bar, a plastic sleeve, and a short piece of monofilament with a knob on the end to prevent the loss of the sleeve. The monofilament parts were glued together within the sleeve. According to the manufacturer, those tags were designed to prevent the kind of separations experienced with the FD-67 tags. However, failures occurred again, and many fish were recaptured with the anchor end intact but without the informational sleeve.

Tag retention for largemouth bass tagged with Floy FD-68B tags in 1975 was 88 percent after about 6 months and 47 percent after 1 year. Fewer failures occurred with the FD-68B than with the FD-67 tags, but failures were still much too high. The FD-68B tags were also used to tag white bass during 1975, but recapture numbers were quite low and valid tag retention numbers could not be estimated for that species.

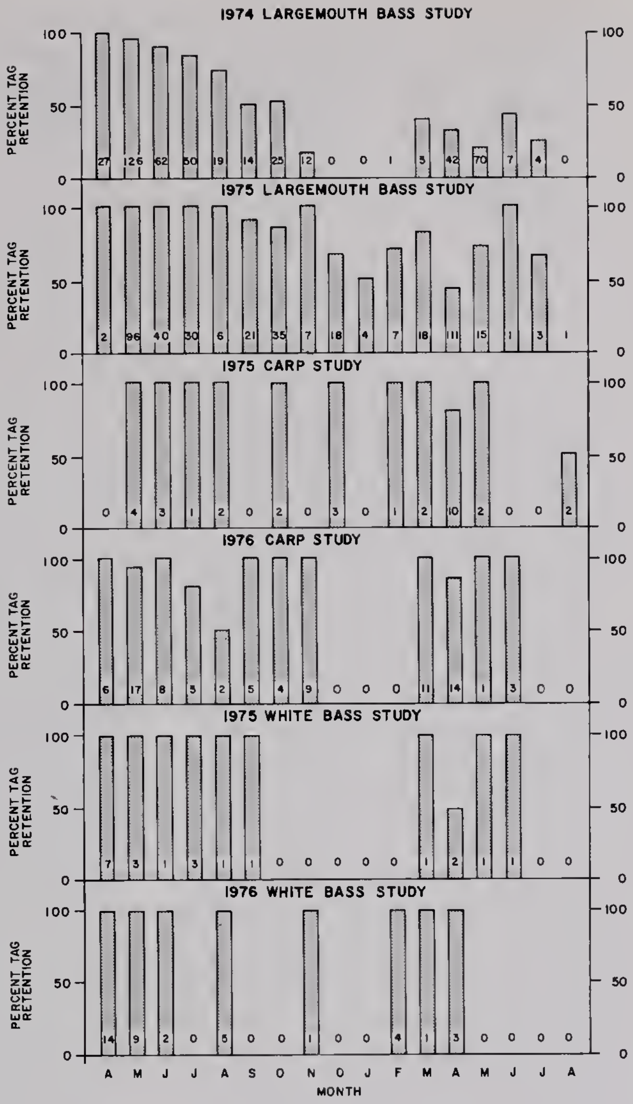

Fig. 2.—Tag retention rates determined from the percentage of tagged and marked fishes recovered each month with intact tags. The total number of fish examined each month is shown at the base of the histogram.

In 1975, carp were tagged with FD-67 tags that were reinforced with a rubber-base glue. The additional glue corrected the tag failure problem . The tag retention for carp tagged with modified FD-67 tags during 1975 was 100 percent after 6 months and 83 percent after 1 year (Fig. 2).

The manufacturer was informed of our problems with the FD-68B tags in 1975 and the order was replaced. Thereafter, we had no problems with tag separation. The replacement FD-68B tags were used to tag carp and white bass in 1976. Tag retention rates for carp were 100 percent after 6 months and 87 percent after 1 year (Fig. 2). It was difficult to make broad comparisons between species because the performance of the tags was so variable, but it did appear that carp retained tags somewhat better than largemouth bass, possibly because the skin beneath their scales appeared to be much tougher. Both Bryant & Houser (1971) and Zweiacker (1972) tagged largemouth bass with similar Floy anchor tags and apparently experienced no problems with tag separation.

Kimsey (1956) and Chadwick (1966) have compiled data that show how various marking and tagging procedures may significantly alter the growth and survival of a particular fish species and thus invalidate research results. Consequently, Tranquilli, McNurney, & Kocher (1979) conducted studies in small ponds under controlled conditions to determine the effect of the type of tags and marks used in this study on the growth and survival of largemouth bass and carp. We found no significant difference (0.05 level) in the growth of experimental fishes (tagged and fin clipped) and control fishes, and the survival of the experimental groups was 100 percent. These results indicated that the tagging and marking procedures used at Lake Sangchris probably had no effect on the growth or survival of largemouth bass or carp.

Zweiacker (1972) used similar tags to study largemouth bass in Lake Carl Blackwell, Oklahoma, and found that the calculated condition factors were not significantly different between recaptured tagged fish and fish without tags. These results indirectly indicated that the tags did not affect fish growth. While white bass were tagged in Lake Sangchris, we did not examine the effects of tagging and marking this species under controlled pond conditions. Although no effects were found on the growth and survival of largemouth bass or carp, we would not assume, without testing, that the same result would be found for white bass. Field observations of tagged white bass indicated that they did not react well to handling, and we suspect that tagging mortality for that species may have been substantial.

MARK-AND-RECAPTURE ESTIMATES OF POPULATIONS AND STANDING CROPS

Population estimates of largemouth bass in Lake Sangchris during 1974 and 1975, and of carp during 1976 were calculated by mark-and-recapture methods. In 1975, too few carp were marked and recaptured to permit estimation of that population. Estimates of white bass populations in 1975 and 1976 were not attempted because the marking effort occurred exclusively in the discharge canal, and therefore marked individuals may not have been randomly distributed throughout the lake.

In 1974, 1,035 largemouth bass $\geq$ 150 mm in total length were tagged in April and May. The recapture sample (c) extended through October of that year and recruitment (by growth) of fish into the population of marked fish was accounted for by calculating the growth of 150-mm fish from length frequency distributions. Of the 592 fish examined in the recapture samples, 53 were identified by marks and/or tags as belonging to the 1,035-fish sample tagged in April and May. The estimated size of the largemouth bass population of Lake Sangchris during spring, with 95-percent confidence limits, was 11,561 ± 2,952 fish $\geq$150mm (Table 4). The estimate was equivalent to 13.2 bass per hectare in this 876-ha lake. The mean weight of the 1,035 largemouth bass at the time of tagging was 0.709 kg. Multiplication of the population estimate by the mean weight provided an estimated standing crop of 9.4 kg/ha for largemouth bass $\geq$150 mm.

Only largemouth bass 200 mm or more in total length were marked and tagged during 1975. As in 1974, the recapture sample was taken over a 6-month period and recruitment was accounted for by relating the growth of $\geq$ 200-mm fish to length frequency distributions. Of the 1,355 tagged and/or marked fish, 98 individuals were subsequently recognized in the recapture sample of 683 bass (Table 5). The estimated size of the spring 1975 largemouth bass population, with 95-percent confidence limits, was 9,444 ± 1,700 fish $\geq$200 mm. This estimate was equivalent to 10.8 fish per hectare. The average weight of the bass tagged in 1975 was 0.752 kg, somewhat larger than the average size marked in 1974, when the minimum length of the tagged fish was 50 mm less. Multiplication of the population estimate by the average weight gave an estimated standing crop of 8.1 kg/ha for largemouth bass $\geq$200 mm.

Table 4.—Population estimate for largemouth bass (≥150 mm in total length) in Lake Sangchris during 1974.

Month	Number of Fish in Sample (c)	Number of Marked Fish Recaptured in Sample (r)	Recruitment[a]
May	139	23	>150 mm
July	83	12	>220 mm
September	89	4	>240 mm
October	281	13	>260 mm
Total	*592*	*53*	

$$\hat{N} = \frac{1,035(592)}{53} = 11,561 \quad \text{SE } (\hat{N}) = 1,476$$

[a] The progressive minimum limit accounts for growth.

A standing crop of largemouth bass in Lake Sangchris of 8.8 kg/ha was determined by averaging the estimates for 1974 and 1975. The average was conservative because smaller fish were excluded from the estimates in both years. The average standing crop of bass in Lake Sangchris (8.8 kg/ha) was similar to the 10.0 kg/ha average standing crop of bass found in 170 reservoirs in the mid-South by Jenkins (1975). The estimated average standing crop of bass in Lake Sangchris was also consistent with results of quantitative fish surveys (Tranquilli, Kocher, & McNurney 1981) which showed a relatively large bass population that constituted 16.3 percent by weight of the total catch. The mark-and-recapture estimate of the average standing crop of largemouth bass (8.8 kg/ha), which excluded fish < 150 mm in 1974 and < 200 mm in 1975, was thus considered to be more accurate than the estimate determined from cove rotenone samples (3.5 kg/ha), which consisted almost entirely of young-of-the-year fish (Tranquilli, Joy, & McNurney 1979). In large coves of Beaver and Bull Shoals reservoirs, on the White River in Arkansas and Missouri, Bryant & Houser (1971) estimated standing crops of largemouth bass by mark-and-recapture methods during 2 successive years and found results that were comparable to data derived from cove rotenone samples on those lakes.

The 1,053 carp tagged and marked during 1976 ranged from 275 to 675 mm in total length. No recruitment by growth was assumed for the carp population estimate and the recapture sample was extended for 1 full year because (1) little evidence of successful carp reproduction had been found in previous studies at Lake Sangchris (Tranquilli, Kocher, & McNurney 1981) and (2) preliminary data from recaptured carp indicated that very little growth had occurred. Of the 1,053 carp tagged, 100 were subsequently identified in a recapture sample of 1,253 fish (Table 6). The estimated number of

Table 5.—Population estimate for largemouth bass (≥200 mm in total length) in Lake Sangchris during 1975.

Month	Number of Fish in Sample (c)	Number of Marked Fish Recaptured in Sample (r)	Recruitment[a]
May	380	63	≥200 mm
July	51	10	≥260 mm
September	44	4	≥280 mm
October	208	21	≥300 mm
Total	*683*	*98*	

$$\hat{N} = \frac{1,355(683)}{98} = 9,444 \quad \text{SE } (\hat{N}) = 850$$

[a] The progressive minimum limit accounts for growth.

Table 6.—Population estimate for carp in Lake Sangchris during 1976.

Month and Year	Number of Fish in Sample (c)	Number of Marked Fish Recaptured in Sample (r)	Recruitment
May, 1976	267	19	≥275 mm
June	126	4	
July	86	5	
August	84	1	
September	100	6	
October	131	13	
November	113	13	no growth
December	19	0	
February, 1977	26	0	
March	115	16	
April	172	22	
May	14	1	≥275 mm
Total	*1,253*	*100*	

$$\hat{N} = \frac{1{,}053(1{,}253)}{100} = 13{,}194 \quad SE\,(\hat{N}) = 1{,}204$$

carp in Lake Sangchris during 1976, with 95-percent confidence limits, was 13,194 ± 2,408, equivalent to 15.1 carp per hectare. The average weight of the carp tagged during 1976 was 1.322 kg, and the estimated standing crop was calculated to be 20.0 kg/ha.

The standing crop of carp calculated from the mark-and-recapture estimate (20.0 kg/ha) was lower than the 27.0 kg/ha standing crop of carp determined from cove rotenone samples (Tranquilli, Kocher, & McNurney 1981). Since carp seemed to be attracted to the upper ends of shallow coves in Lake Sangchris, perhaps the standing crop of carp was slightly overestimated from the cove rotenone samples. The difference in the two estimates was relatively minor when compared with the 70.8 kg/ha standing crop of carp in Lake Shelbyville (Tranquilli, Joy, & McNurney 1979) or the 112 kg/ha average found in other midwestern reservoirs by Carlander (1955). The standing crops of carp estimated by mark-and-recapture methods and from cove rotenone samples at Lake Sangchris were similar to values reported by Jenkins (1975) for carp in reservoirs of the mid-South (25.5 kg/ha).

MOVEMENTS OF TAGGED FISH

Lake Sangchris was subdivided into eight contiguous stations so that movements of fishes between tagging and recapture locations could be categorized and related to the thermal gradient (Fig. 1). Fish from the lake were captured and tagged in proportion to their population densities and care was not taken to tag equal numbers of fish within the borders of each station. The stations selected were neither equidistant from each other nor of equivalent area. Consequently, statistical comparisons were not made between the frequency of recaptures at each station. The examination of data on recapture locations for each species, however, provided a summary of fish movements by indicating the general directions and relative distances traveled. For example, movement from a tagging location in the discharge canal (Station 5) to a recapture location in the intake canal (Station 1) showed that the fish had traveled a minimum total distance of 16.1 km (10 miles) around the cooling loop in the direction of cooler water (Fig. 1).

Totals of 824 largemouth bass, 111 carp, and 62 white bass were recaptured, for which movements of individuals among stations were determined from tags or distinctive marks (Tables 7, 8, and 9). Examination of the mark-and-recapture locations indicated that for all three species the majority of recaptures occurred at the stations where the fish were originally tagged. These limited movements within stations accounted for

Table 7.—Mark-and-recapture locations for largemouth bass tagged in Lake Sangchris during 1974 and 1975, illustrating direction of movements. The number and percentage (in parentheses) recaptured at each station are shown.

Station Where Marked	Station Where Recaptured								
	0	1	2	3	4	5	7	8	Total
1	1 (0.12)	79 (9.59)	25 (3.03)	15 (1.82)	3 (0.36)	0 (0.00)	1 (0.12)	1 (0.12)	125 (15.17)
2	1 (0.12)	12 (1.46)	88 (10.68)	11 (1.33)	4 (0.49)	1 (0.12)	1 (0.12)	0 (0.00)	118 (14.32)
3	0 (0.00)	6 (0.73)	7 (0.85)	116 (14.08)	10 (1.21)	1 (0.12)	4 (0.49)	1 (0.12)	145 (17.60)
4	0 (0.00)	1 (0.12)	4 (0.49)	13 (1.58)	95 (11.53)	20 (2.43)	22 (2.67)	6 (0.73)	161 (19.54)
5	0 (0.00)	4 (0.49)	2 (0.24)	7 (0.85)	39 (4.73)	51 (6.19)	7 (0.85)	3 (0.36)	113 (13.71)
7	0 (0.00)	2 (0.24)	5 (0.61)	10 (1.21)	15 (1.82)	4 (0.49)	83 (10.07)	21 (2.55)	140 (16.99)
8	0 (0.00)	1 (0.12)	0 (0.00)	0 (0.00)	2 (0.24)	0 (0.00)	5 (0.61)	14 (1.70]	22 (2.67)
Total	*2* (0.24)	*105* (12.74)	*131* (15.90)	*172* (20.87)	*168* (20.39)	*77* (9.34)	*123* (14.93)	*46* (5.58)	*824*[a] (100.00)

[a] Movement information was not determined for 94 fish that lost their tags or did not have an identifying mark.

63.8 percent of the largemouth bass recaptures (Table 7), 77. 5 percent of the carp recaptures (Table 8), and 50.0 percent of the white bass recaptures (Table 9). For the two species tagged throughout the lake, these data indicated that largemouth bass tended to travel between stations more than carp did. Although more largemouth bass than carp were recaptured, inspection of the data further suggested that largemouth bass were also more inclined to travel farther from the location at which they were tagged than were carp.

Comparisons of movements between heated (stations 3, 4, and 5) and unheated (stations 0, 1, 2, 7, and 8) areas of Lake Sangchris were made for largemouth bass

Table 8.—Mark-and-recapture locations for carp tagged in Lake Sangchris during 1975 and 1976, illustrating direction of movements. The number and percentage (in parentheses) recaptured at each station are shown.

Station Where Marked	Station Where Recaptured							
	1	2	3	4	5	7	8	Total
1	12 (10.81)	4 (3.60)	1 (0.90)	0 (0.00)	1 (0.90)	0 (0.00)	0 (0.00)	18 (16.22)
2	1 (0.90)	9 (8.11)	0 (0.00)	0 (0.00)	1 (0.90)	0 (0.00)	0 (0.00)	11 (9.91)
3	0 (0.00)	0 (0.00)	5 (4.50)	3 (2.70)	2 (1.80)	0 (0.00)	0 (0.00)	10 (9.01)
4	0 (0.00)	1 (0.90)	1 (0.90)	12 (10.81)	2 (1.80)	0 (0.00)	1 (0.90)	17 (15.32)
5	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.90)	22 (19.82)	0 (0.00)	2 (1.80)	25 (22.52)
7	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.90)	19 (17.12)	1 (0.90)	21 (18.92)
8	1 (0.90)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.90)	7 (6.31)	9 (8.11)
Total	*14* *(12.61)*	*14* *(12.61)*	*7* *(6.31)*	*16* *(14.41)*	*29* *(26.13)*	*20* *(18.02)*	*11* *(9.91)*	*111*[a] *(100.00)*

[a] Movement information was not obtained for eight fish that lost their tags or did not have an identifying mark.

Table 9.—Mark-and-recapture locations for white bass tagged in Lake Sangchris during 1975 and 1976, illustrating direction of movements. The number and percentage (in parentheses) recaptured at each station are shown.

Station Where Marked	Station Where Recaptured							
	1	2	3	4	5	7	8	Total
5	9 (14.52)	5 (8.06)	6 (9.68)	1 (1.61)	31 (50.00)	6 (9.68)	4 (6.45)	62[a] (100.00)

[a]Movement data were incomplete for one fish.

and carp. For largemouth bass, 67 (16.0 percent) of 419 recaptures of fish tagged in heated areas occurred in unheated areas and 65 (16.1 percent) of 405 recaptures of fish tagged in unheated areas occurred in heated areas (Table 7). For carp, 4 (7.7 percent) of 52 recaptures of fish tagged in heated areas occurred in unheated areas, while 4 (6.8 percent) of 59 recaptures of fish tagged in unheated areas occurred in heated areas (Table 8). These data indicate that for each species directed movements between heated and unheated areas were approximately equal.

The exchange of largemouth bass between heated and unheated areas of Lake Sangchris revealed in the tagging results was consistent with those suggested by (1) observations of radiotagged fish (Tranquilli, Dufford, & Larimore 1979), and (2) seasonal movements at the population level shown by quantitative (catch per standard unit of effort) samples (Tranquilli, Kocher, & McNurney 1981). However, we feel that long-range movements and free exchange of fish between heated and unheated areas of Lake Sangchris are characteristic of the population and that interpretation of movement data from tag returns could be misleading. The following example might clarify this point. A fish tagged in a heated area during the spring might have moved to an unheated area during the summer and back to the heated area during the fall. If it were recaptured in the fall, the tag return information would imply that the fish remained in the heated area during the entire period, which would not have been true in this hypothetical case.

Quinn et al. (1978) examined movements of largemouth bass in Par Pond, a cooling reservoir for a nuclear production reactor, and reported that 99 percent of the 100 recaptures of bass tagged in heated areas occurred in heated areas and that only 9 percent of 88 recaptures that occurred in unheated areas showed movement to heated areas. Thus, movements were more frequent from unheated to heated than from heated to unheated waters. They concluded that the exchange of individuals between heated and unheated locations was not extensive and that long-distance movement was exceptional rather than characteristic. Furthermore, they explained contrasting conclusions (Clugston 1973, Gibbons & Bennett 1973, and Dupont 1976) regarding the frequency of long-distance movement of bass in Par Pond by suggesting that selection bias for larger individuals implanted with sonic tags resulted in the use of fish more likely to move long distances. Effects of fish size on movement are discussed later in this report, but our data could not substantiate that relationship.

All white bass were tagged in the discharge arm (Station 5) during the spring spawning period. The relatively high percentage (38.7 percent) of recaptures in unheated areas (stations 1, 2, 7, and 8) suggested that white bass from throughout the lake migrated to the heated discharge arm to spawn. These data support the results of lakewide fish population surveys (catch-effort samples), which demonstrated that white bass were concentrated in the discharge arm during early spring (Tranquilli, Kocher, & McNurney 1981) where they probably were attracted to spawn by the heated effluent and/or the flowing

Table 10.—Analysis of variance comparing the mean distances traveled by male and female largemouth bass, carp, and white bass tagged and recaptured in Lake Sangchris. The initial size (weight) of the fish was used as a covariable[a] in the analysis. Significance at the 0.05 level is indicated by an asterisk.

		F Value		
Source of Variation	d.f.	Largemouth Bass	Carp	White Bass
Sex	1	4.31*	1.26	0.89
Initial weight[a]	1	1.94	0.27	1.23
Coefficient of determination (R^2)		0.02	0.01	0.04

waters. In Lake Mendota, Wisconsin, Hasler et al. (1969) found that spawning (displaced 1.6 km) and nonspawning (displaced 3.1 km) white bass maintained steady courses over long distances and showed distinct directional preferences for areas of the lake where the spawning grounds were located. This study demonstrated that white bass possess mechanisms for orienting to directional cues present in their natural environment.

Interpretation of information on fish movement obtained in tagging studies is difficult because the actual distance traveled is only represented by the distance from the release area to the point of recapture, a value sensitive only to general movement, and because there is no way of measuring the majority of variables that probably affected that movement. These difficulties were reflected in the extremely low coefficients of determination (R^2) of our statistical models of the movement data, indicating that much of the variability was unaccounted for by the model. Compilation and comparison of fish movements derived from tagging studies are worthwhile and add to our knowledge of fish behavior, but they are undoubtedly inadequate descriptions by themselves. Consequently, great care should be taken in drawing conclusions from them.

The mean distances traveled by males and females of each species were compared, using the initial size of the fish as a covariable. The differences found were difficult to interpret due to the high degree of variation present, as measured by R^2 (Table 10). Results indicated that the relationship between the amount of movement and the size of the fish for each of the three species was small. Significant differences in movement between sexes were found for largemouth bass but not for carp or white bass. While not significantly different, greater movement was also characteristic of male carp and of female white bass (Table 11). The mean distance traveled by male largemouth bass (1,892 m) was significantly greater than the distance traveled by the females (1,475 m). Radiotelemetry studies of largemouth bass movements in Lake Sangchris and Lake Shelbyville also showed that males traveled farther than females, but statistically significant differences were not revealed (Tranquilli, Dufford, & Larimore 1979). Since the statistical analysis of the radiotelemetry comparison accounted for a much greater proportion of the variation, results of that study probably answered the question more accurately than did these results.

A summary of the distances traveled by fishes tagged in different areas (stations) of Lake Sangchris is presented in Table 12. The mean length at recapture, the mean time interval (days) between liberation and recapture, and the range of distances traveled by fish released at each station are indicated. Movement data were obtained for 647 largemouth

Table 11.—Mean distances in meters traveled by male and female largemouth bass, carp, and white bass tagged and recaptured in Lake Sangchris. The number of fish in each sample is given in parentheses.

	Distance in Meters			
Species	Males	(N)	Females	(N)
Largemouth bass	1,892	(193)	1,475	(220)
Carp	1,686	(48)	1,125	(60)
White bass	5,256	(38)	6,673	(22)

Table 12.—Mean distances in meters traveled by fishes in Lake Sangchris in relation to the area (station) at which they were originally tagged, the number of fish in each sample (N), the mean distance moved ± the standard error, the range of distances, the mean time interval (in days), and the mean total length (in mm) of the recaptured fish (for which these data were available) are given.

Species and Station	N	Mean Distance in Meters	Range of Distances in Meters	Mean Time Interval in Days	N	Mean Length at Recapture in mm
Largemouth bass						
Station 1	86	2,028 ± 292	7–13,563	96 ± 13	25	374 ± 15
Station 2	92	1,345 ± 184	14– 9,600	92 ± 12	26	431 ± 14
Station 3	130	1,150 ± 128	7– 7,575	105 ± 12	36	430 ± 11
Station 4	131	1,519 ± 144	7– 8,286	139 ± 13	46	401 ± 9
Station 5	68	2,137 ± 222	50–10,871	153 ± 18	36	415 ± 8
Station 7	118	1,876 ± 220	14–11,538	135 ± 15	38	401 ± 9
Station 8	22	2,024 ± 681	14–13,893	61 ± 13	4	342 ± 3
Carp						
Station 1	18	2,308 ± 823	72–14,080	243 ± 33	14	477 ± 13
Station 2	11	1,076 ± 557	36– 6,053	184 ± 43	9	506 ± 9
Station 3	10	1,486 ± 782	108– 8,049	206 ± 44	6	488 ± 17
Station 4	17	1,050 ± 391	14– 4,674	293 ± 40	17	513 ± 14
Station 5	25	1,445 ± 557	50–13,118	91 ± 20	18	510 ± 12
Station 7	21	779 ± 313	129– 6,519	234 ± 41	17	523 ± 12
Station 8	9	1,733 ± 1,348	50–12,471	159 ± 47	7	501 ± 25
White bass						
Station 5	61	5,845 ± 715	7–15,508	107 ± 18	15	330 ± 11

bass, 111 carp, and 61 white bass. The grand means for distances traveled by fish from all areas combined were 5,845 m for white bass, 1,635 m for largemouth bass, and 1,389 m for carp.

The distances traveled by fishes tagged at different stations were compared to determine whether thermal discharge affected fish movements. In addition, the effects of fish size (initial length) and the time interval between liberation and recapture were tested as covariables that may have affected the movements of tagged fish. Results of these analyses were difficult to interpret because most of the variation was unaccounted for by this statistical model. The sample size for analysis was reduced by six largemouth bass and one carp due to incomplete recapture information for those individuals. No relationship was found between fish size and the distance traveled for any of the three species (Table 13). The time interval between liberation and recapture was a significant ($P < 0.001$) factor affecting distances traveled by largemouth bass but not white bass or carp. As the time period between tagging and recapture increased, the distance traveled by largemouth bass increased an average of 2.1 m per day. In contrast to this result, Lewis & Flickinger (1967) found that the extent of movement by tagged bass in a farm pond did not increase with time.

Comparisons among stations could

Table 13.—Analysis of variance for distances traveled by fishes tagged in different areas (stations) of Lake Sangchris. The initial length of the recaptured fish and the time interval between tagging and recapture were used as covariables[a] in the analysis. The sample size (N) and the coefficient of determination (R^2) are given.

Source of Variation	N = 641 Largemouth Bass d.f.	F Value	N = 110 Carp d.f.	F Value	N = 61 White Bass d.f.	F Value
Area where tagged	6	3.28**[b]	6	0.67		. . .
Initial length[a]	1	1.80	1	0.70	1	0.08
Time interval[a]	1	11.33***	1	0.06	1	0.51
Coefficient of determination (R^2)		0.05		0.05		0.01

[b] Significance at the 0.05, 0.01, and 0.001 levels is indicated by one, two and three asterisks, respectively.

not be made for white bass, since all were tagged in one area. Significant differences (0.01 level) were found between distances traveled by largemouth bass from different areas but not for carp (Table 13). Comparisons of station means revealed that largemouth bass tagged in the discharge (Station 5) and intake (Station 1) arms traveled significantly (0.05 level) farther than bass from stations 2 or 3 in the middle region of the cooling loop (Table 14). In a cooling lake, water currents created by pumping are most evident at the intake and discharge areas. These two areas are also characterized by having the greatest temperature differential. Fish tagged in those areas may have traveled farther because those habitats represent extreme thermal conditions; consequently, those fish may have been seasonally attracted to or repelled from thermal gradients in the lake.

In a review of the literature dealing with movements of tagged largemouth bass, it soon became apparent that the amount of movement observed was limited by the physical characteristics of the aquatic habitats studied (ponds, lakes, and rivers) and that the average movements observed in Lake Sangchris were not exceptionally large for this species. Dequine & Hall (1949) recaptured 308 Florida largemouth bass in six large interconnected lakes of central Florida and found that 39.6 percent were caught within a 1-mile^2 area in which they were released, and more than 84 percent were caught within 5 miles of the point of release. In Clear Lake, California, Kimsey (1957) obtained 80 recapture records, determined that the average distance traveled was 4.5 miles (7,241 m), and noted that, in general, movements were undirected. Hulse & Miller (1958) described movements of 74 fish in Wheeler Reservoir, Alabama, and found an average movement of 2.7 miles (4,344 m). They suggested the average movements of bass were less in Wheeler, a mainstream reservoir, than in Norris Reservoir, Tennessee (4 miles, 6,436 m), because the latter was a storage reservoir in which water levels fluctuated more. Moody (1960) reported that 61.9 percent of 189 recaptures occurred within 10 miles (16,100 m) or less of their points of

Table 14.—Duncan's multiple range test for comparison of mean distances traveled by fishes tagged in different areas (stations) of Lake Sangchris. Means with the same grouping letter are not significantly different at the 0.05 level.

Largemouth Bass				Carp				White Bass			
Grouping	Mean Distance in Meters	N	Station Where Tagged	Grouping	Mean Distance in Meters	N	Station Where Tagged	Grouping	Mean Distance in Meters	N	Station Where Tagged
A	2,137	68	5	A	2,308	18	1	A	5,897	59	5
A	2,034	85	1	A	1,733	9	8	...	...	...	...
BA	2,024	22	8	A	1,486	10	3	...	...	...	...
BA	1,856	114	7	A	1,474	24	5	...	...	...	...
BA	1,529	130	4	A	1,076	11	2	...	...	...	...
B	1,345	92	2	A	1,050	17	4	...	...	...	...
B	1,150	130	3	A	779	21	7	...	...	...	...

tagging in Lake George on the St. John's River in Florida. He suggested that the Lake George population consisted of a resident segment with restricted range and a mobile group that tended to move more freely through the St. John's River. In an 8.4-acre (3.24-ha) farm pond in Illinois, Lewis & Flickinger (1967) found that 96 percent of the 96 recaptures occurred within 300 feet (91 m) of the original point of capture. Rawstron (1967) observed that bass moved very little in Folsom Lake, California, averaging only 0.7 mile (1,126 m) from point of tagging to point of recapture. In Lake Carl Blackwell, Oklahoma, Zweiacker (1972) reported that 92.2 percent of the bass were recaptured in the area where tagged. Gibbons & Bennett (1973) followed movements of bass in Par Pond, a reservoir receiving heated water, and concluded that bass were highly mobile with travel of more than 6,000 m being of frequent occurrence.

GROWTH IN HEATED AND UNHEATED AREAS

The annual growth of tagged fish in Lake Sangchris was studied in relation to movements within and between heated and unheated areas. For this analysis, recapture data for each species were used to describe the composite growth of the population of tagged fish, which consisted of individuals of various sizes and ages. The annual growth of largemouth bass of specific size in Lake Sangchris was determined from recapture records and was described in a separate study (Joy & Tranquilli 1979).

Composite growth data obtained from tagging records were analyzed in relation to movements of fish within and between heated and unheated areas and the year of recapture. Stations 3, 4, and 5 represented heated (H) areas and stations 0, 1, 2, 7, and 8 represented unheated (U) areas. Movements were categorized as (U-U) tagged and recaptured in the unheated area, (U-H) tagged in the unheated and recaptured in the heated area, (H-U) tagged in the heated and recaptured in the unheated area, and (H-H) tagged and recaptured in the heated area. For comparison, we assumed that fish tagged and recaptured within the same thermal area remained there during the interim period. To compare the growth of fish with different thermal histories and of different sizes, all fish of each species were adjusted to a common initial size by analysis of covariance. The initial size (length and weight) of the fish was tested as an independent variable affecting mean annual growth. Results were presented as least-squares means, which are averages adjusted to a common sample size and modified by covariable effects.

Sample sizes for the growth analyses of largemouth bass, carp, and white bass were 181, 78, and 14 fish, respectively. For comparison of mean annual growth, common initial lengths and weights were 365 mm and 821 g for largemouth bass, 504 mm and 1,605 g for carp, and 300 mm and 363 g for white bass.

Results of the two-way analyses of variance revealed that movements within and between heated and unheated areas had no effect on growth in length or weight for any of the three species (Tables 15 and 16). These data suggested that growth was similar for fish which remained in heated or unheated areas of the cooling lake. If food resources were similar throughout the lake, the greatest growth advantage would occur for those fish that moved to the thermally affected area during early spring, avoided that zone during the summer, and returned to it during the fall, thus benefitting from an extended growing season. Since we could not detect that kind of detailed movement with this tagging procedure, we could not test that hypothesis.

All recapture data were used in the two-way analyses of variance, including records of fish that were at large for only a few months. However, by selecting only those largemouth bass that had been at large for approximately one complete growing season (N = 69 fish), Joy & Tranquilli (1979) were able to show that the annual growth of largemouth bass of known sizes was significantly greater in heated than in unheated areas of Lake Sangchris. They attributed that difference in growth rate to the length of the growing season, about 245 and 194 days in the heated and unheated areas, respectively. In Lake Sangchris, estimated

Table 15.—Two-way analysis of variance for recapture lengths and weights of fishes tagged in Lake Sangchris (1974–1976) in relation to their movements within and between heated and unheated areas and year of recapture. Initial length and initial weight were covariables[a] in the analysis.

	Largemouth Bass			Carp			White Bass		
Source of Variation	d.f.	Length *F* Value	Weight *F* Value	d.f.	Length *F* Value	Weight *F* Value	d.f.	Length *F* Value	Weight *F* Value
Movements	3	1.63	0.41	2	0.37	0.74	1	0.55	0.09
Year of recapture	3	13.15***[b]	15.36***	2	3.53*	2.54	2	1.02	0.04
Initial length[a]	1	911.49***	...	1	674.17***	...	1	20.55***	...
Inital weight[a]	1	...	707.35***	1	...	362.47***	1	...	36.65***
Coefficient of determination(R^2)		0.87	0.85		0.91	0.84		0.87	0.87

[b] One, two, and three asterisks denote significance at the 0.05, 0.01, and 0.001 levels, respectively.

Table 16.—Least-square means ± their standard errors for lengths and weights of fishes tagged in Lake Sangchris (1974–1976) for comparison of growth in relation to movements within and between heated and unheated areas and year of recapture. Movements were categorized as (U-U) tagged and recaptured in the unheated area, (U-H) tagged in the unheated and recaptured in the heated area, (H-U) tagged in the heated and recaptured in the unheated area, and (H-H) tagged and recaptured in the heated area.

	Largemouth Bass		Carp		White Bass	
Growth Variable	Recapture Length in mm	Recapture Weight in grams	Recapture Length in mm	Recapture Weight in grams	Recapture Length in mm	Recapture Weight in grams
Movement						
U-U	405 ± 4	1,215 ± 48	508 ± 4	1,554 ± 39	...	...
U-H	419 ± 6	1,274 ± 61	...	...	...	...
H-U	399 ± 9	1,183 ± 91	494 ± 16	1,642 ± 170	326 ± 9	442 ± 49
H-H	409 ± 4	1,206 ± 43	509 ± 3	1,516 ± 33	334 ± 6	459 ± 32
Year of recapture						
1974	385 ± 4	946 ± 43	...		...	...
1975	409 ± 3	1,189 ± 34	516 ± 7	1,512 ± 77	321 ± 12	448 ± 61
1976	417 ± 4	1,281 ± 41	500 ± 6	1,640 ± 65	325 ± 7	460 ± 40
1977	420 ± 12	1,462 ± 140	495 ± 7	1,560 ± 69	343 ± 11	443 ± 59

lengths at ages I through VI, respectively, were 138, 278, 380, 434, 462, and 477 mm in heated areas; 100, 260, 325, 378, 415, and 441 mm in unheated areas; and 121, 274, 358, 411, 444, and 465 mm in all areas combined (Joy & Tranquilli 1979). From these data they concluded that after age I the estimated annual growth of largemouth bass in Lake Sangchris (Fig. 3) was more rapid than in Lake Shelbyville; other Illinois waters in general (Bennett & Thompson 1939, Starrett & Fritz 1965, Carlander 1977); and waters of the upper Midwest, including Illinois (Carlander 1977). While it may appear that the growth data presented by Joy & Tranquilli (1979) and those which appear in this study for largemouth bass are contradictory, both studies can be reconciled if one considers that seasonal movements in Lake Sangchris are an important factor affecting the results of growth analyses.

For all three species, the initial length and initial weight of the fish had a highly significant ($P < 0.001$) effect on the amount of growth achieved by the individual (Table 15) with larger fish growing faster than smaller ones. Gizzard shad were the most important food resource of adult largemouth bass and white bass (Sule et al. 1981), and larger fish could have consumed the larger gizzard shad forage at any time during the year,

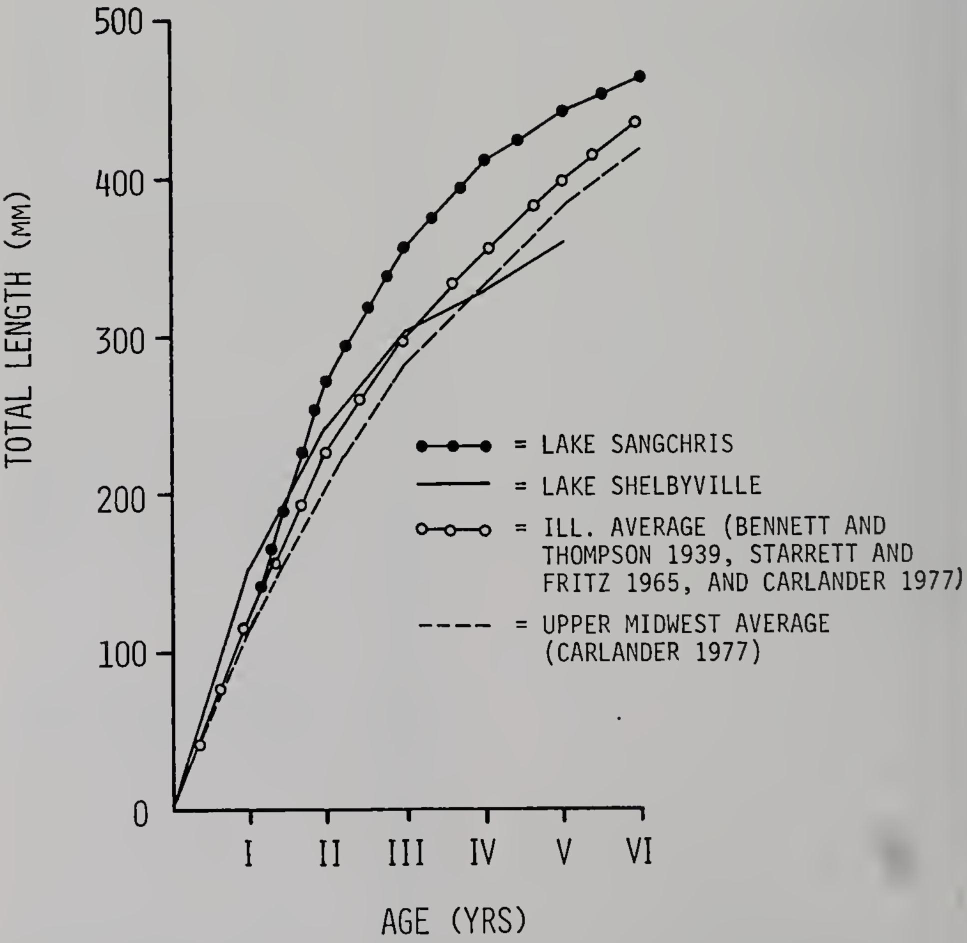

Fig. 3.—Comparison of largemouth bass growth in Lake Sangchris; Lake Shelbyville; other Illinois waters; and waters of the upper Midwest, including Illinois (From Joy & Tranquilli 1979).

whereas, because of size, that food resource may have been unavailable to smaller predators.

Significant differences occurred among years for growth in length and weight of largemouth bass and for growth in length of carp (Table 15). For largemouth bass, the progressive increase in mean length from 385 to 420 mm and in mean weight from 946 to 1,462 g from 1974 to 1977 demonstrated that rapid growth was occurring (Table 16). Growth records were obtained from only a few white bass, but a progressive increase in length and weight also indicated that they were growing. However, examination of yearly recapture records indicated that little, if any, carp growth had occurred.

Many carp were recaptured that had decreased in length and weight. The decrease in length may have been due to small errors made in measuring these relatively large and difficult-to-handle fish, and decreases in weight may have been the result of tagging the fish during early spring before females had spawned. In most cases the effect of these factors would be masked by new growth, but it is now apparent that carp in Lake Sangchris were not growing; so those differences were noticeable. The initial and final mean lengths of tagged carp were exactly the same (504 mm), and the mean weight of carp at recapture was only 29 g greater than at tagging. Population density probably was not a factor affecting the growth of carp, because the standing crop of that species in Lake Sangchris was only 27.0 kg/ha, much lower than the average in other midwestern reservoirs (Tranquilli, Joy, & McNurney 1979). Since carp from Lake Sangchris exhibited good growth in a controlled pond environment during the study of tagging effects, it appears that the lack of growth in the cooling lake was due to a shortage of food resources. The lack of carp growth may also be related directly to the absence of recruitment observed for this species in Lake Sangchris (Tranquilli, Kocher, & McNurney 1981).

THE EFFECT OF THERMAL DISCHARGE ON ANNULUS FORMATION BY LARGEMOUTH BASS

To determine the effect of thermal discharge on annulus formation, scale samples collected from largemouth bass as they were tagged were compared with scales from the same fish at the time of recapture. Scales were obtained from 50 bass recaptured with intact tags. The minimum time interval between tagging and recapture was 2 months, and the maximum was 18 months. Twenty-three of the 50 recaptures occurred at least 12 months after tagging. Double recaptures were obtained on four fish, and one was recaptured three times.

Inspection of scales from tagged fish showed that annulus formation occurred during the spring in both heated and unheated areas of Lake Sangchris. Annuli on scales from bass tagged and recaptured in unheated areas were more distinct than annuli from bass tagged and recaptured in heated areas of the lake. When we examined fish scales, we often made errors in age determination, which could only be recognized and corrected by examining another series of scales from the same fish on a different date. Annuli were not absent on any scales examined, but false annuli were common. Thus, investigators analyzing scales of bass from cooling lakes in the Midwest probably would be inclined to underestimate growth and overestimate ages of those fish most affected by the thermal effluent. Witt et al. (1970) reported difficulty in reading scales of largemouth bass from Thomas Hill Reservoir, a cooling lake in Missouri, apparently because the bass moved in and out of heated water. Siler & Clugston (1975) found that some bass of all size groups, subjected to highly elevated temperatures (50°C) from a nuclear production reactor in South Carolina, failed to show an annulus or growth check, whereas others had numerous marks that resembled annuli. In the latter study, annuli were formed in October and November, when bass resumed growth after being confined to small refuge areas by the high summer water temperatures. In Lake Sangchris, largemouth bass annulus formation occurred in the spring, as it does in noncooling lakes in this region of the Midwest. The annulus appears as the result of an increase in growth after a slowing or cessation of growth during the winter.

Dramatic shifts in population density and movements of radiotagged individuals demonstrated that largemouth bass move long distances in Lake Sangchris on a seasonal basis, apparently selecting preferred water temperatures (Tranquilli, Dufford, & Larimore 1979 and Tranquilli, Kocher, & McNurney 1981). The fish were attracted to the discharge area during winter, and avoided that area during summer. Since it is practically impossible to determine the thermal history of individual bass in the population, the scale reading technique should not be used for age and growth analysis of cooling-lake bass populations in this region of the United States.

SUMMARY

1.—A total of 1,100 recapture records were obtained from the 5,015 largemouth bass, carp, and white bass tagged and marked in Lake Sangchris from 1974 to 1976. Including multiple recaptures and fish recaptured without tags (marks only), 38.4 percent of the 2,390 largemouth bass, 8 percent of the 1,492 carp, and 5.6 percent of the 1,133 white bass were subsequently recovered.

2.—Tag failures were encountered during 2 of the 3 years of study.

3.—Largemouth bass populations in Lake Sangchris were estimated with 95-percent confidence by mark-and-recapture methods during 1974 and 1975, respectively, to be 11,561 ± 2,952 fish $\geq$150 mm in total length and 9,444 ± 1,700 fish $\geq$200 mm. From these estimates an average standing crop of 8.8 kg/ha was determined.

4.—In 1976, the number of carp in Lake Sangchris was estimated with 95-percent confidence to be 13,194 ±2,408 fish $\geq$275 mm in total length, which was calculated to be a standing crop of 20.0 kg/ha.

5.—Analysis of movements between point of tagging and point of recapture indicated that there was no relationship between the size of largemouth bass, carp, or white bass and the distance moved. The grand mean for distances traveled by fish from all areas of the lake combined was 5,845 m for white bass, 1,635 m for largemouth bass, and 1,389 m for carp.

6.—Largemouth bass tagged at stations in the discharge and intake areas traveled significantly farther than bass from stations in the middle of the cooling loop. It was suggested that fish from the intake and discharge areas traveled farther because those habitats represented extreme thermal conditions and the fish at those sites may have been seasonally attracted to or repelled from thermal gradients in the lake.

7.—Movements of largemouth bass, carp, and white bass between heated and unheated areas had no effect on their average growth in length or weight, and larger individuals of all three species grew more rapidly than smaller ones.

8.—Composite growth information obtained from recapture records indicated that largemouth bass and white bass growth was rapid, but indicated that little, if any, carp growth had occurred.

9.—The effects of thermal discharge on annulus formation by largemouth bass in cooling lakes were examined by comparing scales taken from the same individual at the time of tagging and again upon recapture. Annulus formation occurred during spring, but false annuli were especially common in fish from the heated area and could not easily be distinguished from true annuli. Consequently, interpretation of annual growth from marks on scales was not suggested for cooling-lake bass populations in this region of the United States.

REFERENCES CITED

BARR, A. J., J. H. GOODNIGHT, J. P. SALL, and J. T. HELWIG. 1976. A user's guide to SAS 76. Statistical Analysis System Institute, Inc., Raleigh, N. C. 329 p.

BENNETT, G. W., and D. H. THOMPSON. 1939. Lake management reports. 3. Lincoln Lakes near Lincoln, Illinois. Illinois Natural History Survey Biological Notes 11. 24 p.

BRYANT, H. E., AND A. HOUSER. 1971. Population estimates and growth of largemouth bass in Beaver and Bull Shoals Reservoirs. Pages 349–357 *in* Gordon E. Hall, ed., Reservoir fisheries and limnology. American Fisheries Society Special Publication 8.

CARLANDER, K. D. 1955. The standing crop of fish in lakes. Canada Fisheries Research Board Journal 12(4):543–570.

———. 1977. Handbook of freshwater fishery biology. Vol. II. Iowa State University Press, Ames. 431 p.

CHADWICK, H. K. 1966. Fish marking. Pages 18–40 *in* A. Calhoun, ed., Inland fisheries management. California Department of Fish and Game.

CLUGSTON, J. P. 1973. The effects of heated effluents from a nuclear reactor on species diversity, abundance, reproduction, and movement of fish. Ph.D. Thesis. University of Georgia, Athens.

DELL, M. B. 1968. A new fish tag and rapid cartridge-fed applicator. American Fisheries Society Transactions 97:57–59.

DEQUINE, J. F., and C. E. HALL, JR. 1949. Results of some tagging studies of the Florida largemouth bass, *Micropterus salmoides floridanus* (Le Sueur). American Fisheries Society Transactions 79:155–166.

DUPONT, S. P. 1976. The behavior of largemouth bass *(Micropterus salmoides)* in a reservoir receiving a thermal effluent. M. S. Thesis. University of Georgia, Athens.

GIBBONS, J. W., and D. H BENNETT. 1973. Abundance and local movement of largemouth bass *(Micropterus salmoides)* in a reservoir receiving heated effluent from a reactor. Pages 524–527 *in* D. J. Nelson, ed., Radioecology. 3rd National Radioecology Symposium Proceedings, Oak Ridge, TN.

HASLER, A. D., E. S. GARDELLA, R. M. HORRAL, and H. F. HENDERSON. 1969. Open water orientation of white bass *(Roccus chrysops)* as determined by ultrasonic tracking methods. Canada Fisheries Research Board Journal 26:2173–2192.

HULSE, D. C., and L.F. MILLER.1958. Harvesting of largemouth bass on Wheeler Reservoir, Alabama, 1952–1956. Tennessee Academy of Science Journal 33:78–83.

JENKINS, R. M. 1975. Black bass crops and species associations in reservoirs. Pages 114–124 *in* R. H. Stroud and H. Clepper, eds., Black bass biology and management. Sport Fishing Institute, Washington, D. C.

JOY, T., and J.A. TRANQUILLI. 1979. Annual growth of largemouth bass in Lake Sangchris, Lake Shelbyville, and other midwestern waters. Pages 10-1–10-14 *in* Evaluation of a cooling lake fishery. Vol. III. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

KIMSEY, J. B. 1956. Largemouth bass tagging. California Fish and Game 42(4):337–346.

———. 1957. Largemouth bass tagging at Clear Lake, Lake County, California. California Fish and Game 43(2):111–118.

LEWIS, W. M., R. C. SUMMERFELT, and M. BENDER. 1962. Use of an electric shocker in conjunction with the mark-and-recovery technique in making estimates of largemouth bass populations. Progressive Fish-Culturist 24(1):41–45.

———, and S. FLICKINGER. 1967. Home range tendency of the largemouth bass *(Micropterus salmoides).* Ecology 48(6):1020–1023.

MOODY, H. L. 1960. Recaptures of adult largemouth bass from the St. John's River, Florida. American Fisheries Society Transactions 89(3):295–300.

QUINN, T., G. W. ESCH, T. C. HAZEN, and J. W. GIBBONS. 1978. Long range movement and homing by largemouth bass *(Micropterus salmoides)* in a thermally altered reservoir. Copeia (3):542–545.

RAWSTRON, R. B. 1967. Harvest, mortality, and movement of selected warmwater fishes in Folsom Lake, California. California Fish and Game 53(1):40–48.

RICKER, W. E. 1958. Handbook of computations for biological statistics of fish populations. Canada Fisheries Research Board Bulletin 119. 300 p.

ROBSON, D. S., and H. A. REGIER. 1971. Estimation of population number and mortality rates. Pages 131–165 *in* W.E. Ricker, ed., Methods for assessment of fish production in fresh waters. I. B. P. Handbook 3, 2nd ed. Blackwell Scientific Publications, Oxford.

SILER, J. R., and J. P. CLUGSTON. 1975. Largemouth bass under conditions of extreme thermal stress. Pages 333–341 *in* R. H. Stroud and H. Clepper, eds., Black bass biology and management. Sport Fishing Institute, Washington, D. C.

SMITH, S. H. 1954. Method of producing plastic impressions of fish scales without using heat. Progressive Fish-Culturist 16(2):75–78.

STARRETT, W. C., and W. FRITZ. 1965. A biological investigation of the fishes of Lake Chautauqua, Illinois. Illinois Natural History Survey Bulletin 29:1–104.

SULE, M. J., J. M. MCNURNEY, and D. R. HALFFIELD, JR. 1981. Food habits of some common fishes from heated and unheated areas of Lake Sangchris. Pages 500–519 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

TRANQUILLI, J.A., D. W. DUFFORD, and R. W. LARIMORE. 1979. Activity and preferred temperature of radiotagged largemouth bass in Lake Sangchris and Lake Shelbyville. Pages 5-1–5-23 *in* Evaluation of a cooling lake fishery. Vol. III. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

______, T. JOY, and J. M. MCNURNEY. 1979. A comparison of fish standing crops in Lake Sangchris and Lake Shelbyville. Pages 2-1–2-7 *in* Evaluation of cooling lake fishery. Vol. III. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

______, R. KOCHER, and J. M. MCNURNEY. 1981. Population dynamics of the Lake Sangchris fishery. Pages 413–499 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

______, J. M. MCNURNEY, and R. KOCHER. 1979. Growth, movements, and population estimates for fishes from Lake Sangchris determined by tagging studies. Pages 4-1–4-35 *in* Evaluation of a cooling lake fishery. Vol. III. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

WITT, A., JR., R. S. CAMPBELL, and J. D. WHITLEY. 1970. The evaluation of environmental alterations by thermal loading and acid pollution in the cooling reservoir of a steam-electric station. Missouri Water Resources Research Center, University of Missouri, Columbia. 99 p.

ZWEIACKER, P. L. 1972. Population dynamics of largemouth bass in an 808-hectare Oklahoma reservoir. Ph.D. Thesis. Oklahoma State University, Stillwater. 126 p.

Radiotelemetry Observations on the Behavior of Largemouth Bass in a Heated Reservoir

John A. Tranquilli, Donald W. Dufford, R. Weldon Larimore, Richard Kocher, and John M. McNurney

ABSTRACT

Small radio transmitters were surgically implanted in 37 largemouth bass from heated, unheated, and transition zones of Lake Sangchris and in 35 bass from unheated Lake Shelbyville to observe their behavior in the wild. Primary objectives were to follow long-term movements and to observe temperature selection by individual fish. There were no significant differences in the daily movements of male and female fish from either lake. The average daily movement of bass from the heated zone of Lake Sangchris (248.3 m) was significantly greater than that of fish from the unheated zone (126.1 m), the transition zone (91.1 m), or Lake Shelbyville (116.3 m). The final preferred temperatures selected by radio-tagged fish from the heated zone of Lake Sangchris during July and August (30.5°C) were significantly greater than that of fish from any other study area. Temperatures selected by fish from the unheated (29.1°C) and transition (28.2°C) zones of Lake Sangchris were not statistically different from each other but were significantly higher than those selected by fish from Lake Shelbyville (26.1°C). In Lake Sangchris, movements of largemouth bass were influenced by temperature changes, whereas in Lake Shelbyville directed movements were related to fluctuations in water level.

INTRODUCTION

Largemouth bass activity was examined by radiotelemetry in Lake Sangchris, an Illinois cooling lake, and at Lake Shelbyville, a nearby unheated reservoir, to make a comparative evaluation of bass behavior. The comparative study at Lake Shelbyville became necessary because a relatively new technology was being used which allowed more intensive investigation than had previously been possible. The objectives of the study were to compare activity and temperature selection of fish in the two reservoirs and thereby determine the effects of thermal discharge on fish behavior in the cooling lake. The radiotelemetry studies conducted at Lake Shelbyville were funded by the Electric Power Research Institute, Palo Alto, California.

METHODS

Radio transmitters (50 MHz) developed by William Cochran, a wildlife specialist for the Illinois Natural History Survey, and marketed by AVM Instrument Co., Champaign, Illinois, were used in this study. The radio tags consisted of a miniature radio crystal, a battery, and a loop antenna; the total package resembled a small padlock 55 x 25 x 10 mm that weighed 15–20 g.

Wild largemouth bass were captured from Lake Sangchris and Lake Shelbyville by AC electrofishing and

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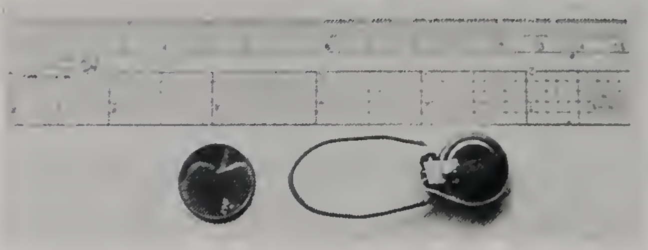


Fifty-MHz radio transmitter used to study the behavior of largemouth bass in Lake Sangchris. The transmitters were encased in a plastic material before they were implanted in fish.

transported to a field laboratory. The bass were anesthetized with MS-222 and quinaldine, and radio tags were inserted into the body cavity through a 40-mm incision in the ventrolateral musculature of each fish. The incision was closed with five or six stitches of nylon thread. A numbered Floy Anchor tag (Model FD68-B), with instructions to notify the Natural History Survey by telephone, was inserted behind the dorsal fin of each radio-tagged bass. The fish were released at their places of capture following a very short surgical recovery period (usually 1–2 hours), and generally were returned to the lake within 24 hours after their capture. We found it best to return the tagged fish to their natural environment as soon as possible to minimize the effects of captivity on their behavior. Some sham operations were conducted and it was observed that the incisions of fish held in laboratory captivity became infected, whereas incisions of radio-tagged fish recaptured from the lake did not. An attempt was made to tag equal numbers of male and female fish of the same approximate size (1 kg) in each study area.

Radiotelemetry studies of largemouth bass were conducted in Lake Sangchris and Lake Shelbyville over a 4-year period (1974–1977). During 1974 and 1975, equal numbers of fish were radio tagged during early spring in heated (stations 3, 4, and 5) and unheated (stations 1, 2, and 7) zones of Lake Sangchris (Fig. 1). In 1976, all radio-tagged fish in Lake Sangchris were released during the first week of September in a transition zone, a study area representing the outermost limit of the thermal gradient between the dam and the northern part of the eastern arm. Studies in the transition zone were initiated in September rather than in spring to observe fish behavior in relation to thermal discharge during winter. For comparative purposes, the Lake Sangchris data were analyzed according to the particular study area where radio-tagged fish were originally released: the heated, transition, and unheated zones. Bass tagged throughout Lake Shelbyville were considered as being from one study area and having behavior characteristic of fish in an unheated reservoir (Fig. 1). In Lake Shelbyville, most fish were released during the spring, but a few were released as late as mid-July.

In both lakes, attempts were made to locate each radio-tagged fish three times per week. Tracking was conducted by boat, and locations were determined by triangulation of radio signals with a directional yagi antenna. The depth at which each fish was located was estimated by comparing the distance over which the signal could be heard with known signal attenuation for known depths. Fish locations were plotted on detailed maps. In Lake Sangchris, water temperatures were not taken at each fish location during 1974, but in 1975 and 1976 they were recorded for the depth at which the fish was found. In Lake Shelbyville, for each fish location, a water temperature was taken at the surface in 1975 and 1976, and at the depth of the fish during 1977.

Movements were measured on a large map as straight line (by water) distances between fish locations. As used in the tables and text, total travel was calculated for each fish as the sum of distances between consecutive locations, the maximum range was defined as the total distance between the two most distant observations, and the range from release point was the distance between the original capture point (release point) and the most distant observation. Average daily movement was calculated by dividing the total distance traveled by the number of days in the study period. As a result of wide variation in study periods for individual fish, the average daily movement was selected as the best

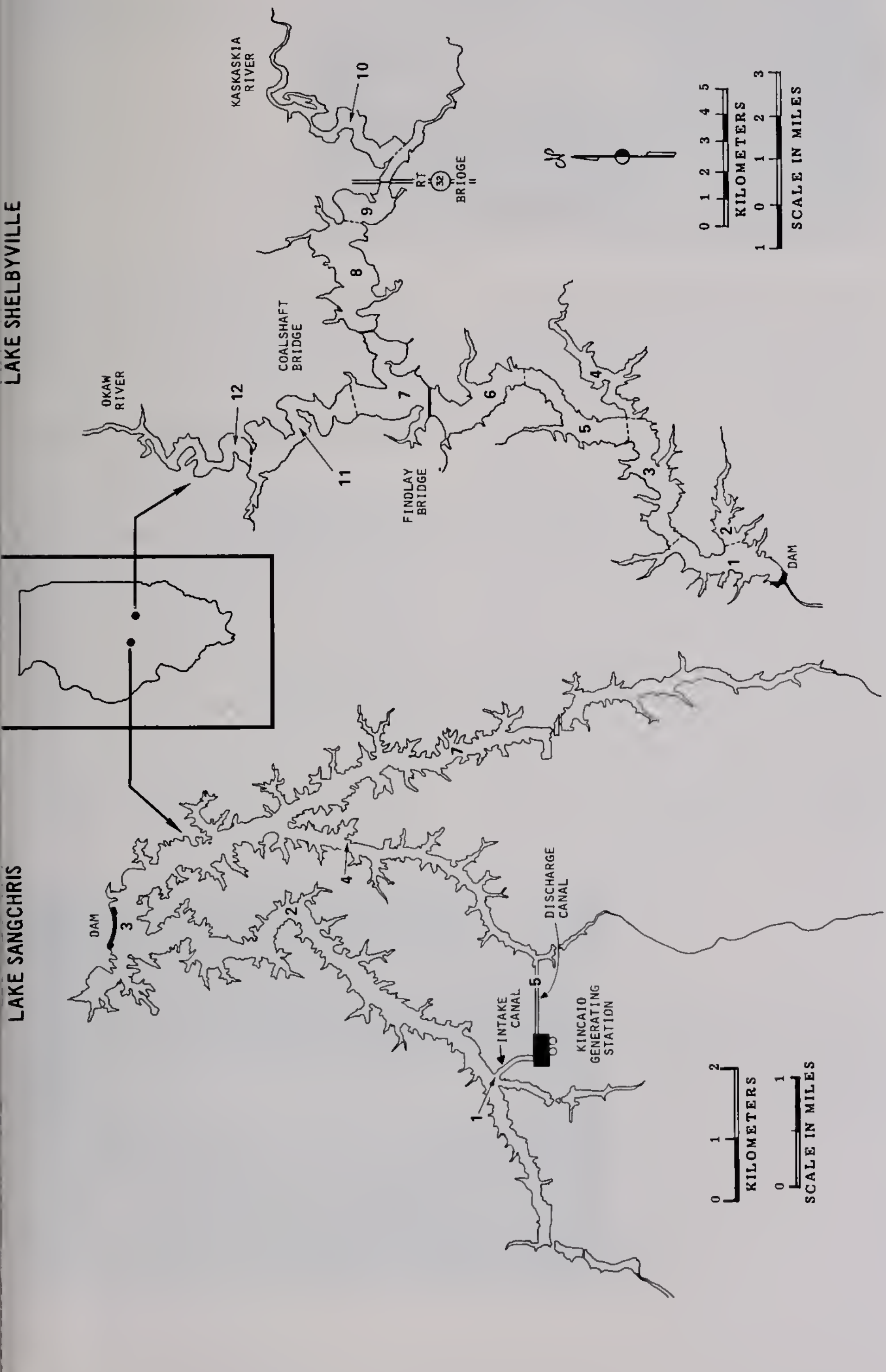
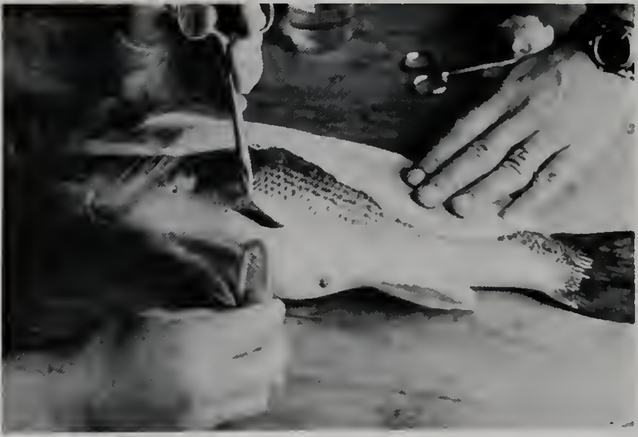


Fig. 1.—Lake Sangchris and Lake Shelbyville showing locations of radio-tagging stations.



Surgical implantation of a radio transmitter in a largemouth bass.

measure for comparing fish activity between study areas. The final mean preferred temperature (°C) was determined for fish observed six or more times during July and August.

Data were analyzed using the Statistical Analysis System (SAS) GLM procedure (Barr et al. 1976) on an IBM 360/75 computer at the University of Illinois Urbana campus. Analysis of variance was used to compare the average daily movement of the radio-tagged fish; study area (heated, unheated, and transition zones of Lake Sangchris and Lake Shelbyville) and sex were tested as main effects. Initial length of the fish was used as a covariable. Analysis of variance was also used to compare the final preferred temperature selected by largemouth bass released in different study areas. Initial length of the fish was again used as a covariable for this analysis. When significant differences were found, a Duncan Multiple Range Test was used to compare the means.

RESULTS AND DISCUSSION

Observations on the movements of radio-tagged largemouth bass from heated, unheated, and transition zones of Lake Sangchris, and from unheated Lake Shelbyville are summarized in Tables 1–4, respectively. In Lake Sangchris, 37 largemouth bass were studied: 13 from the heated zone, 13 from the unheated zone, and 11 from the transition zone. Thirty-five bass were studied in Lake Shelbyville. The average weight of the radio-tagged fish from the heated, unheated, and transition zones of Lake Sangchris and from Lake Shelbyville were

A largemouth bass that has had a temperature-sensitive radio transmitter implanted in its body. Note the external thermistor.

1.32, 1.36, 0.98, and 1.20 kg, respectively. In each of the heated and unheated zones, 7 female and 6 male fish were studied; in the transition zone, 4 females and 7 males were studied; and in unheated Lake Shelbyville, 20 females,

Table 1.—Summary of radiotelemetry observations on the movements of largemouth bass released in the heated zone of Lake Sangchris during 1974 and 1975.

Tag No.	Sex	Study Period (Days)	Number Observations (N)	Maximum Range (km)	Range from Release Point (km)	Avg. Daily Movement (m)	Total[a] Travel (km)	Stations[b] Visited
1-74	F	240	90	11.02	10.50	104	24.99	1,2,3,$\underline{4}$
2-74	M	183	81	12.26	11.32	156	28.53	1,2,3,$\underline{4}$
3-74	F	196	78	7.52	7.49	254	49.85	1,2,3
4-74	M	42	16	7.23	7.23	244	10.24	1,2,$\underline{3}$
5-74	F	251	95	7.72	7.21	215	53.84	4,5, 7
6-74	M	338	85	3.74	3.63	135	45.55	4,$\underline{5}$
1-75	M	136	47	11.24	10.99	521	70.83	1,2,3,$\underline{4}$
2-75	F	86	38	2.16	2.16	115	9.89	$\underline{4}$
3-75	F	108	48	2.29	2.17	115	12.41	3,$\underline{4}$
4-75	F	113	45	12.64	12.64	275	31.07	2,3,4,5
5-75	F	15	15	5.26	5.26	791	11.86	4,$\underline{5}$
6-75	M	155	57	3.30	3.30	170	26.31	$\underline{4}$
7-75	M	113	48	4.96	4.96	133	15.06	$\underline{4}$
Mean		*152.0*	*57.2*	*7.03*	*6.84*	*248.3*	*30.03*	
SD		*89.2*	*26.7*	*3.78*	*3.62*	*197.5*	*19.51*	

[a] Sum of all observed movements within the study period.

[b] Underlined station designates release area; other stations represent locations where tagged fish was subsequently observed; see Fig. 1.

12 males, and 3 fish of unknown sex were studied.

The average study period for each radio-tagged bass from the heated, unheated, and transition zones of Lake Sangchris was 152, 143, and 311 days,

Table 2.—Summary of radiotelemetry observations on the movements of largemouth bass released in the unheated zone of Lake Sangchris during 1974 and 1975.

Tag No.	Sex	Study Period (Days)	Number Observations (N)	Maximum Range (km)	Range from Release Point (km)	Avg. Daily Movement (m)	Total[a] Travel (km)	Stations[b] Visited
7-74	M	4	4	0.67	0.67	469	1.88	$\underline{2}$
8-74	F	267	68	5.72	3.22	47	12.44	1,$\underline{2}$,3
9-74	F	259	73	6.90	5.47	116	30.04	$\underline{1}$,2
10-74	M	200	66	3.63	3.63	50	9.94	$\underline{1}$,2
11-74	F	64	29	0.24	0.24	14	0.89	$\underline{7}$
12-74	M	74	26	5.19	4.79	176	13.05	$\underline{7}$
8-75	M	244	82	3.58	3.48	65	15.81	$\underline{2}$,3
9-75	F	132	54	0.65	0.65	19	2.46	$\underline{2}$
10-75	F	12	5	0.88	0.88	150	1.80	$\underline{2}$
11-75	F	125	47	2.16	2.14	110	13.74	$\underline{1}$
12-75	F	163	60	7.85	6.90	255	41.62	$\underline{1}$,2,3
13-75	M	198	71	5.96	4.42	115	22.83	0,$\underline{1}$,2
14-75	M	118	48	2.56	2.56	53	6.21	$\underline{1}$
Mean		*143.1*	*48.7*	*3.54*	*3.00*	*126.1*	*13.29*	
SD		*88.6*	*25.6*	*2.59*	*2.07*	*123.5*	*12.17*	

[a] Sum of all observed movements within the study period.

[b] Underlined station designates release area; other stations represent locations where tagged fish was subsequently observed; see Fig. 1.

respectively. The longer study period for fish tagged during September in the transition zone probably was due to greater battery life of the radio tags at low winter temperatures. In Lake Shelbyville, the average study period for each fish was 98

Table 3.—Summary of radiotelemetry observations on the movements of largemouth bass released in the transition zone of Lake Sangchris during 1976.

Tag No.	Sex	Study Period (Days)	Number Observations (N)	Maximum Range (km)	Range from Release Point (km)	Avg. Daily Movement (m)	Total[a] Travel (km)	Stations[b] Visited
1-76	M	277	92	7.14	7.14	126	34.90	2,3,4, $\underline{7}$
2-76	M	386	140	4.50	2.96	129	49.96	3,4, $\underline{7}$
3-76	M	348	126	6.09	3.57	88	30.76	3,4, $\underline{7}$
4-76	M	303	109	3.32	1.69	69	20.90	3,$\underline{4}$, 7
5-76	M	308	111	2.16	1.39	65	20.07	$\underline{4}$, 7
6-76	F	386	139	4.13	2.53	97	37.44	$\underline{4}$, 7
7-76	F	233	83	4.05	2.41	108	25.22	$\underline{3}$,4
8-76	M	232	69	5.67	5.55	186	43.17	$\underline{3}$,4,5
9-76	F	295	103	3.16	1.71	62	18.35	$\underline{3}$,4
10-76	M	371	108	2.96	2.82	38	14.16	$\underline{3}$
11-76	F	284	103	2.49	2.40	34	9.58	$\underline{3}$,4, 7
Mean		*311.2*	*107.5*	*4.15*	*3.11*	*91.1*	*27.68*	
SD		*55.5*	*21.8*	*1.58*	*1.75*	*44.8*	*12.65*	

[a] Sum of all observed movements within the study period.

[b] Underlined station designates release area; other stations represent locations where tagged fish was subsequently observed; see Fig. 1.

days. The shorter average study period in Lake Shelbyville was partially accounted for by 12 radio-tagged fish that were caught and removed from the lake or that died after being captured and released by fishermen.

Table 4.—Summary of radiotelemetry observations on the movements of largemouth bass in Lake Shelbyville during 1975, 1976, and 1977.

Tag No.	Sex	Study Period (Days)	Number Observations (N)	Maximum Range (km)	Range from Release Point (km)	Avg. Daily Movement (m)	Total[a] Travel (km)	Stations[b] Visited
1-75	F	23	6	0.68	0.68	29	0.68	8
2-75	M	189	72	3.33	3.14	72	13.69	8,9
3-75	M	119	44	13.19	11.44	171	20.38	7,8,9,10
4-75	-	75	31	3.38	2.45	170	12.76	10
5-75	-	96	39	5.82	5.82	147	14.07	7,8,9
6-75	F	145	45	9.09	9.09	121	17.48	7,8,9
1-76	-	131	50	4.42	4.03	63	8.28	7,8
2-76	F	119	40	2.49	1.33	44	5.26	6,7
3-76[c]	M	30	13	0.93[d]	0.93[d]	98	2.94	5,6
4-76	F	73	29	1.47	1.14	131	9.54	5
5-76[c]	F	240	83	3.82[d]	3.00[d]	85	20.35	1,2, 5,6
6-76	F	31	15	0.22	0.22	33	1.02	7
7-76[c]	F	119	42	1.33[d]	1.03[d]	186	22.10	1, 3
8-76	M	15	7	0.87	0.87	69	1.04	3
9-76	F	84	28	14.34	11.86	363	30.48	3, 5,6,7, 11
10-76	F	61	19	4.93	4.93	83	5.05	3,4
11-76[c]	F	34	12	0.77[d]	0.77[d]	62	2.11	1, 6
12-76	F	99	30	7.26	7.12	105	10.43	1, 3
13-76	M	22	11	3.43	3.26	257	5.65	3, 5
14-76	M	52	18	0.32	0.17	15	0.78	5
15-76	F	176	67	0.61	0.49	33	5.88	8
1-77	F	35	8	2.49	2.49	129	4.50	3,4
2-77[c]	F	82	21	11.03[d]	11.03[d]	201	16.48	1,2, 4,5,6
3-77	F	231	49	6.19	5.86	73	16.82	6,7
4-77	M	58	15	4.20	4.15	105	6.10	4,5
5-77	F	231	70	7.95	7.95	102	23.56	3, 5
6-77	F	54	18	0.97	0.77	92	4.95	5
7-77	F	211	55	13.32	12.93	206	43.57	7, 11,12
8-77	M	32	4	3.87	3.48	180	5.76	7,8
9-77[c]	F	179	56	1.35[d]	1.22[d]	82	14.66	1,2
10-77	M	22	8	1.82	1.38	151	3.32	1
11-77	F	128	36	0.77	0.44	39	5.02	1
12-77	M	79	19	3.70	3.70	208	16.43	9
13-77	M	128	39	4.72	4.72	185	23.65	9,10
14-77	M	26	10	0.12	0.12	11	0.28	8
Mean		*98.0*	*31.7*	*4.15*	*3.83*	*117.2*	*11.29*	
SD		*67.6*	*21.4*	*3.97*	*3.72*	*76.1*	*9.8*	

[a] Sum of all observed movements within the study period.

[b] Underlined station designates release area; other stations represent locations where tagged fish was subsequently observed; see Fig. 1

[c] These fish were captured by fishermen and released at a different station

Largemouth bass from the unheated zone of Lake Sangchris showed the smallest maximum range (average 3.54 km). Fish in Lake Shelbyville and those from the transition zone were intermediate (4.15 km), while fish from the heated zone showed the largest maximum range (7.03 km). A pattern similar to that for maximum range was found among the study areas for the range from point of release. In Par Pond, a cooling lake for a nuclear reactor in South Carolina, similar observations were made by Dupont (1976) who reported movements as large as 6.5 km for largemouth bass tagged in heated areas while bass from unheated areas tended to move in a more localized area near their release site. Fish from the heated area of Lake Sangchris may have shown greater range because they were most influenced by the thermal discharge and traveled farther because of seasonal attraction and/or avoidance of it. Total distance traveled by bass from the heated and transition zones of Lake Sangchris averaged 30.03 and 27.68 km, respectively, while total travel by fish from the unheated zone in Lake Sangchris and from Lake Shelbyville was much lower at 13.29 and 11.29 km, respectively. Although these measurements—maximum range, range from release point, and total travel—are all general indices of fish movement, the duration of the study period for individual fish undoubtedly affected these measures. To avoid the influence of time each fish was followed, an average daily movement was calculated for each fish and was found to be the most comparable measure of fish activity among the different study areas.

The average daily movements of largemouth bass might be affected by the fish's sex, size (initial length), and time of the year. May was selected to represent the spawning season and October to represent the autumn activity period. A two-way analysis of variance, incorporating these variables, was used to compare the activity of radio-tagged bass from the three different thermal zones of Lake Sangchris and from Lake Shelbyville (Table 5). There was no significant difference (0.05 level) in the average daily movement of male and female largemouth bass at any time of the year. Average daily movements of male (N = 31) and female (N = 38) largemouth bass were 145.5 and 133.7 km, respectively. For our fish, there was no interaction between sex and study area at any time of the year. The size differences among the fish had no effect on their average daily movements; however, the fish studied were all mature adults of the same general size. An ultrasonic telemetry study of largemouth bass movements using fish of different sizes in Lake Keowee, a South Carolina cooling lake, revealed that age, length, and weight were positively correlated with the size of the home range (Chappell 1974).

There was a significant difference ($P < 0.05$) in fish activity between study areas for the entire year, but not for movements by fish in different areas dur-

Table 5.—Analysis of variance comparing average daily movement of radio-tagged largemouth bass released in different areas of Lake Sangchris and Lake Shelbyville during May, October, and the entire year. Areas of release were heated, unheated, and transition zones of Lake Sangchris and unheated Lake Shelbyville. Initial length was used as a covariable[a] in the analysis.

		Average Daily Movement (m)		
Source of Variation	d.f.	May *F* Value	October *F* Value	All Year *F* Value
Area	3	1.62	0.67	11.63*
Sex	1	2.40	2.38	0.33
Sex x Area	3	1.38	0.83	0.36
Initial Length[a]	1	1.46	1.86	2.39
Coefficient of Determination (R^2)		0.27	0.20	0.24

*Significant at the 0.05 level.

Table 6.—Duncan's multiple-range test comparing average daily movement of radio-tagged largemouth bass released in the heated (HT), unheated (UH), and transition (TR) zones of Lake Sangchris and unheated Lake Shelbyville (SH). Means with the same group letter are not significantly different at the 0.05 level.

Grouping	Mean Average Daily Movement (m)	N	Area
A	248.3	13	HT
B	126.1	13	UH
B	116.3	32	SH
B	91.1	11	TR

ing May or October (Table 5). The average daily movement (Table 6) of bass from the heated zone of Lake Sangchris (248.3 m) was significantly ($P < 0.05$) greater than that of fish from the unheated zone (126.1 m), the transition zone (91.1 m), or from Lake Shelbyville (116.3 m). In a telemetry study at Center Hill Reservoir in Tennessee, Petersen (1975) presented data for 10 largemouth bass which were not displaced and from his data an average daily movement of 232 m was calculated. In similar studies at Lake Keowee, a cooling lake in South Carolina, Smith (1974) reported a preoperational average daily movement of 192 m for two largemouth bass, and Chappell (1974) reported a postoperational average daily movement of 64 m for four fish.

The greater activity of largemouth bass released in the heated zone of Lake Sangchris was clearly demonstrated in a month-by-month comparison of daily movement of fish in the two lakes. Daily movements were weighted by the number of observations of each fish to determine a monthly mean (Table 7). Throughout the year, bass from the heated zone of the cooling lake were more active than bass from the unheated zone, the transition zone, or from Lake Shelbyville (Fig. 2). Fish from the heated zone also were active earlier in the spring and later in

Radiotelemetry boat used for tracking and locating fish that had radio transmitters placed within their bodies.

Table 7.—Average daily movement (m) by radio-tagged largemouth bass released in the heated (HT), transition (TR), and unheated (UH) zones of Lake Sangchris and in Lake Shelbyville, 1974–1977. The mean daily movement (m) (weighted by the number of observations), the number of observations (in parentheses), and the number of fish studied each month are indicated.

Lake and Area	Average Daily Movement (m)											
	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March
Lake Sangchris												
HT Zone	314.2(60)	223.7(149)	238.4(155)	197.6(135)	161.8(88)	166.8(58)	245.7(54)	259.8(30)	298.8(13)	152.9(2)		
	10	11	13	12	10	7	5	4	3	2		
TR Zone	143.9(124)	104.1(117)	40.2(89)	136.3(33)	137.7(50)	96.4(130)	109.5(121)	58.1(96)	71.6(120)	61.1(94)	91.4(117)	96.8(92)
	11	9	9	7	4	11	11	10	11	11	11	
UH Zone	149.8(25)	211.6(74)	118.0(110)	56.0(121)	57.5(112)	40.8(50)	46.2(52)	76.5(39)	72.9(30)	72.1(12)	37.6(7)	
	7	7	11	11	11	7	6	5	4	3	3	
Lake Shelbyville	130.0(115)	128.0(158)	101.7(139)	134.8(121)	96.7(152)	68.7(113)	119.3(143)	130.7(94)	115.2(55)	22.2(16)		
	16	25	20	19	16	14	14	12	11	3		

the fall, probably as a result of the higher water temperatures in the cooling lake. Peaks of activity of bass from the heated and transition zones of Lake Sangchris during April, and from the unheated zone during May, can be related to the spawning time of fish in those zones.

Largemouth bass have been found in other studies to be most active or move more at random during spring and fall (Hasler & Wisby 1958, Zweiacker 1972, Petersen 1975, Warden & Lorio 1975). Increased activity of radio-tagged bass from Lake Shelbyville was not apparent during the spring spawning season. The relatively high activity level of Lake Shelbyville fish from October through December can be related to down-reservoir movements triggered by dropping water levels in 1975 and 1977. The greater activity during July and August of bass from the heated and transition zones of Lake Sangchris was surprising because by mid-summer many had traveled to unheated areas of the lake. Since those fish had moved to avoid elevated temperatures, they probably were behaving as displaced fish moving around without an established home area. In relation to the amount of movement shown by radio-tagged bass in Lake Sangchris and Lake Shelbyville during spring, summer, and fall, winter activity was higher than expected. Although others (Warden & Lorio 1975, Petersen 1975) reported minimum bass movement during winter, the activity of bass in Lake Sangchris apparently was influenced by elevated temperatures and circulation of water around the cooling loop. In contrast to those findings at Lake Shelbyville, Lorio et al. (1973) reported that water level fluctuations did not affect movements of tagged largemouth bass in Loakfora Lake, Mississippi.

From 1975 to 1977, temperatures selected by radio-tagged largemouth bass were recorded several times per week as the fish were located. The average temperature selected by each fish, weighted by the number of observations, was used to determine the average monthly preferred temperature of fish in each

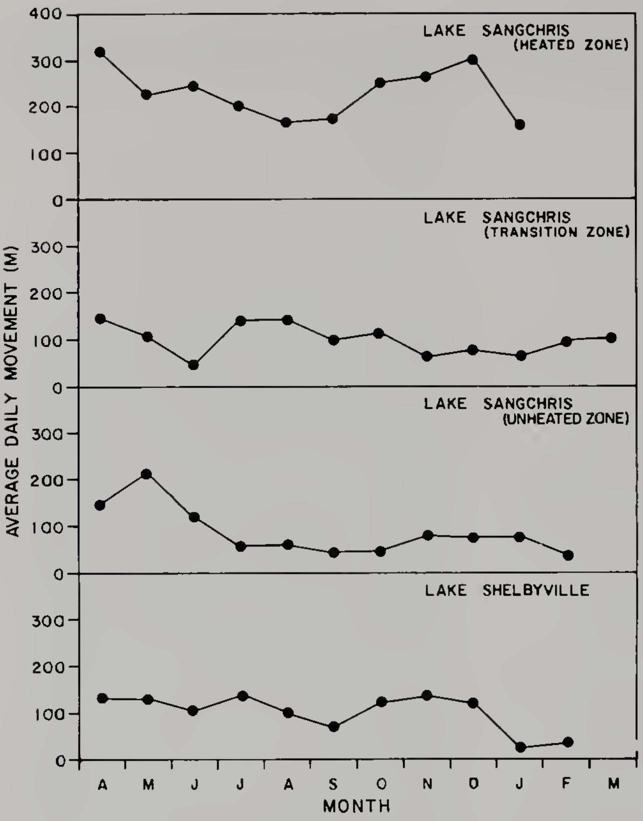


Fig. 2.—Average daily movement of radio-tagged largemouth bass from heated, transition, and unheated zones of Lake Sangchris and from Lake Shelbyville from 1974 to 1977.

study area (Table 8). Throughout the year, preferred temperatures of largemouth bass from all areas in Lake Sangchris were higher than those from Lake Shelbyville (Fig.3). From April through September, temperatures selected by bass from the heated zone averaged 2.0°C warmer than temperatures selected by bass from the transition zone of Lake Sangchris. During the same 6-month period, bass from the transition zone selected temperatures that averaged only 0.1°C warmer than those selected by bass from the unheated zone. That small difference probably would have been greater if bass had not been released in the transition zone during September 1976, when temperatures were lower than normal because there had been a 6-week power plant shut down. From April to September, bass from the unheated zone of Lake Sangchris selected water temperatures that averaged 2.0°C warmer than those selected by bass from Lake Shelbyville. Largemouth bass from the cooling lake, particularly the fish released in the transition zone during September 1976, did not select the warmest water temperatures available in Lake Sangchris during winter. Clugston (1973), using temperature-sensing transmitters in Par Pond, also found that largemouth bass did not utilize the warmest water available during the winter months.

For each study area, a final preferred temperature was determined for fish that had been observed 6 or more times during July and August. An analysis of variance was used to compare the final preferred temperatures selected by fish from each study area, using initial length of the fish as a covariable (Table 9). A highly significant difference ($P < 0.001$) was found among study areas for the final preferred temperatures selected. The length of the fish had no significant effect on the final preferred temperatures selected by radio-tagged fish, but, as mentioned previously, the fish used were all adults of similar size. The final preferred temperatures of radio-tagged bass from the heated zone of Lake Sangchris (30.5°C) were significantly ($P < 0.05$) greater than that of fish from any other study area (Table 10). The final preferred temperatures of fish from the unheated (29.1°C) and transition (28.2°C) zones were not significantly different from each other, but were significantly higher than temperatures selected by fish from Lake Shelbyville (26.5°C). The abnormally low final preferred temperature of bass from Lake Shelbyville resulted, in part, because warmer temperatures were not always available. In Par Pond, Dupont (1976) found that largemouth bass tagged with ultrasonic temperature-senstitive tags selected temperatures of 28.8°–30.3°C in heated areas and 26.3°–27.7°C in unheated areas. Dupont also found, as we did, that mean selected temperatures of both groups of bass were significantly different from each other during July and August.

Table 8.—Preferred temperatures (°C) selected by radio-tagged largemouth bass released in the heated (HT), transition (TR), and unheated (UH) zones of Lake Sangchris and in Lake Shelbyville, 1975–1977. The mean temperature (weighted by the number of observations), the number of observations (in parentheses), and the number of fish studied each month are indicated

Lake and Area	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
	Preferred Temperature (°C)											
Lake Sangchris												
HT Zone	19.5(18)	23.6(70)	25.9(89)	30.5(58)	31.0(28)	28.2(9)						
	6	6	7	6	5	2						
TR Zone	19.3(124)	22.7(117)	25.9(89)	29.7(33)	27.2(50)	21.7(130)	17.1(121)	10.4(96)	6.2(120)	6.8(94)	10.7(117)	15.3(92)
	11	9	9	7	4	11	11	10	11	11	11	11
UH Zone	16.4(43)	21.7(71)	25.0(74)	28.6(70)	29.8(61)	24.3(23)	19.0(20)	16.8(6)	9.4(7)			
	7	7	6	6	4	3	3	2	1			
Lake Shelbyville	16.4(115)	19.5(158)	23.1(135)	27.2(121)	25.9(152)	21.4(113)	14.7(143)	9.5(94)	3.3(55)	0.0(16)	0.4(5)	
	16	25	17	19	16	14	14	12	11	3	1	

The outward migration of radio-tagged bass from the heated zone of Lake Sangchris during the summer of 1974 and 1975 was attributed to avoidance of elevated temperatures. The final preferred temperatures selected by those bass were generally unavailable in the middle arm of the cooling lake from the discharge area to the junction of the middle arm with the control arm (Fig. 1). However, even after bass from the heated zone of the cooling lake had traveled to unheated regions, they still selected warmer temperatures than bass from unheated zones. The comparison of temperature preferences and activity patterns of largemouth bass from three thermal zones of Lake Sangchris and from Lake Shelbyville suggested that perhaps acclimatization to higher temperatures may have occurred in the cooling lake through genetic selection for tolerance of higher temperatures. The genetic variability of largemouth bass populations in Lake Sangchris and Lake Shelbyville was studied by Childers (1979), who found a significant difference in the frequency of alleles at the

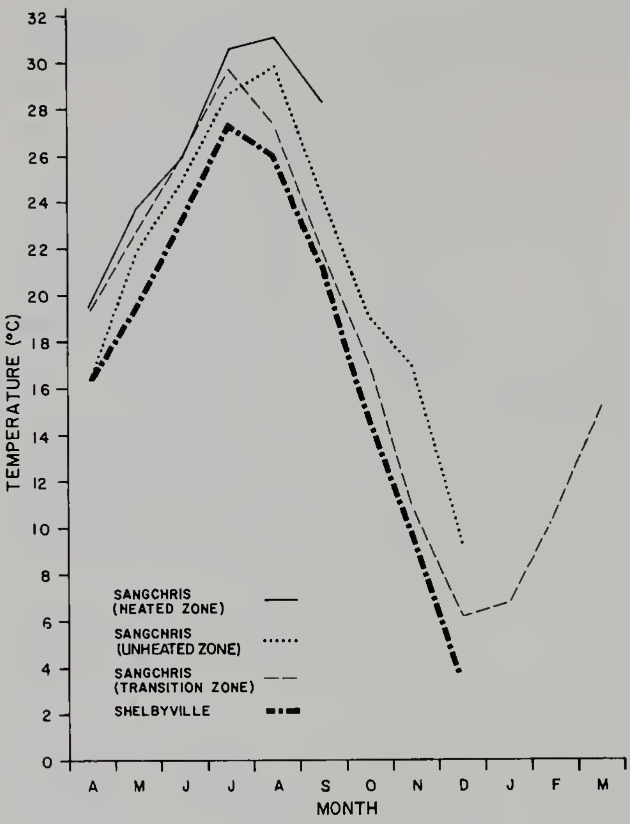


Fig. 3.—Preferred temperatures selected by radio-tagged largemouth bass from heated, transition, and unheated zones of Lake Sangchris and Lake Shelbyville (1975–1977).

Table 9.—Analysis of variance for summer preferred temperatures (°C) selected by radio-tagged largemouth bass released in heated, unheated, and transition zones of Lake Sangchris and in unheated Lake Shelbyville. Initial length was used as a convariable[a] in the analysis.

Source of Variation	d.f.	*F* Value
	Summer Preferred Temperature (°C)	
Area	3	45.76*
Initial Length[a]	1	0.01
Coefficient of Determination (R^2)		0.84

* Significant at the 0.001 level.

Mdh-B locus. Since the Mdh-B locus apparently is related to temperature tolerance, Childer's work provides evidence that genetic selection has occurred and that some genetic differences are present in the bass populations of the two reservoirs.

The final preferendum was defined by Fry (1947) as that temperature within an infinite range of temperature where a given population will eventually congregate given sufficient time. The preferred range is believed to be the optimum temperature for activity and growth of

Table 10.–Duncan's multiple-range test comparing summer preferred temperatures (°C) selected by radio-tagged largemouth bass released in the heated (HT), unheated (UH), and transition (TR) zones of Lake Sangchris and in unheated Lake Shelbyville (SH). Means with the same group letter are not significantly different at the 0.05 level.

Grouping	Area	Mean Summer Preferred Temperature (°C)	No. of Temp. Observations	No. of Fish
A	HT	30.5	86	6
B	UH	29.1	131	6
B	TR	28.2	79	4
C	SH	26.5	269	17

the fish (Brett 1956). Comparison of literature on preferred temperature for largemouth bass can be misleading because various investigators have expressed the preferendum as a modal temperature, others as a mean selected temperature. In addition, studies for temperature preference have been conducted in both laboratory and field environments, using fish of different sizes, at different times of the year, in different geographic locations, and with different genetic backgrounds.

Laboratory studies have generally shown higher temperature preferenda for largemouth bass than have field studies. Ferguson (1958) first noted the lack of agreement and attributed it to the differences in size and age of the fish studied; laboratory experiments were conducted with young fish and field studies with older fish. In laboratory studies, Ferguson (1958) cited a preferred temperature of 30°–32°C for largemouth bass, while Strawn (1961) found that largemouth bass grew best at about 30°C. Dendy (1948) determined the preferred temperature of largemouth bass in Norris Reservoir, Tennessee, to be 26.6°–27.7°C. Coutant (1974) found, via acoustic telemetry, that largemouth bass had a final temperature preferendum of about 27°C in small Tennessee lakes. In Wisconsin, Neill & Magnuson (1974) found the median body temperature of largemouth bass during the afternoon in a thermal outfall at Lake Monona to be 29.7°C which agreed well with the midpoint of the preferred temperature (29.1°C) observed in their laboratory for this species. By concentrating their sampling effort in the area of thermal discharge at Lake Sangchris, Smith & McNurney (1981) found a final preferred temperature for largemouth bass of 32.4°C, which was very near the highest preferred temperature previously reported in the literature.

The final preferred temperatures selected by radio-tagged largemouth bass from the heated, unheated, and transition zones of Lake Sangchris, 30.5°, 29.1°, and 28.2°C, respectively, were in general agreement with the preferred range of temperatures reported in the literature for this species. The final preferred temperature of largemouth bass from Lake Shelbyville (26.5°C) was slightly lower, probably because, as mentioned earlier, higher temperatures were not always available in July and August.

Seasonal movements of largemouth bass in Lake Sangchris are discussed in relation to the study area (heated, unheated, and transition) and year in which they were originally tagged and released. The behavioral movements of individual fish relative to the thermal outfall in the cooling lake are shown in Fig. 4–13.

Five of the six fish tagged and released in the thermal zone during the spring of 1974 migrated away from the thermal outfall (Fig.4) and arrived in cooler refuge areas by 1 August. These five fish each made directed movements of at least 7.24 km (4.5 miles). By midsummer, four of these fish (No. 1,2,3, and 4) had congregated at the cooling water intake of the power plant. Only one of the six fish released in the heated area (No. 6) remained in the southern portion of the discharge arm during midsummer. When water temperatures were highest, this fish was found in the deepest, coolest water available in that region of the lake. During October and November when water temperatures in the lake began to cool naturally, two of the five remaining fish (No. 3 and No. 5) reversed direction and migrated back toward the thermal outfall.

The movements of the six fish released in unheated areas during spring 1974 were relatively small in comparison to those observed for fishes from the heated area and were not generally directed away from the thermal discharge during midsummer (Fig. 5). Of the three remaining fish, two (No. 9 and No. 10) made substantial movements toward the thermal discharge during October and November, and the third fish (No. 8) moved in that direction in December.

Of the seven fish tagged and released within the southern end of the discharge

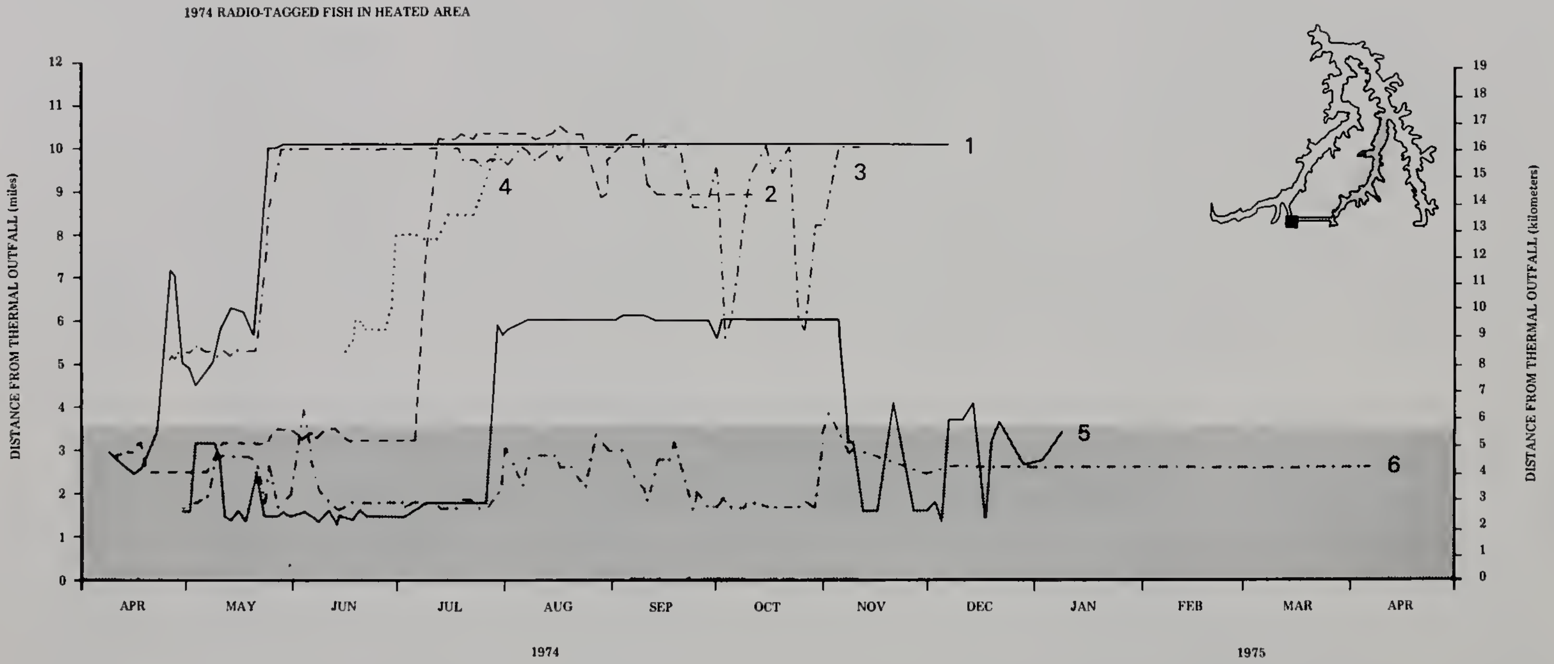


Fig. 4.—Radiotelemetry observations on movements in relation to the thermal outfall of six largemouth bass tagged and released in heated areas of Lake Sangchris (No. 1–6) during spring 1974. The shaded area represents that portion of the discharge arm most highly influenced by elevated water temperatures.

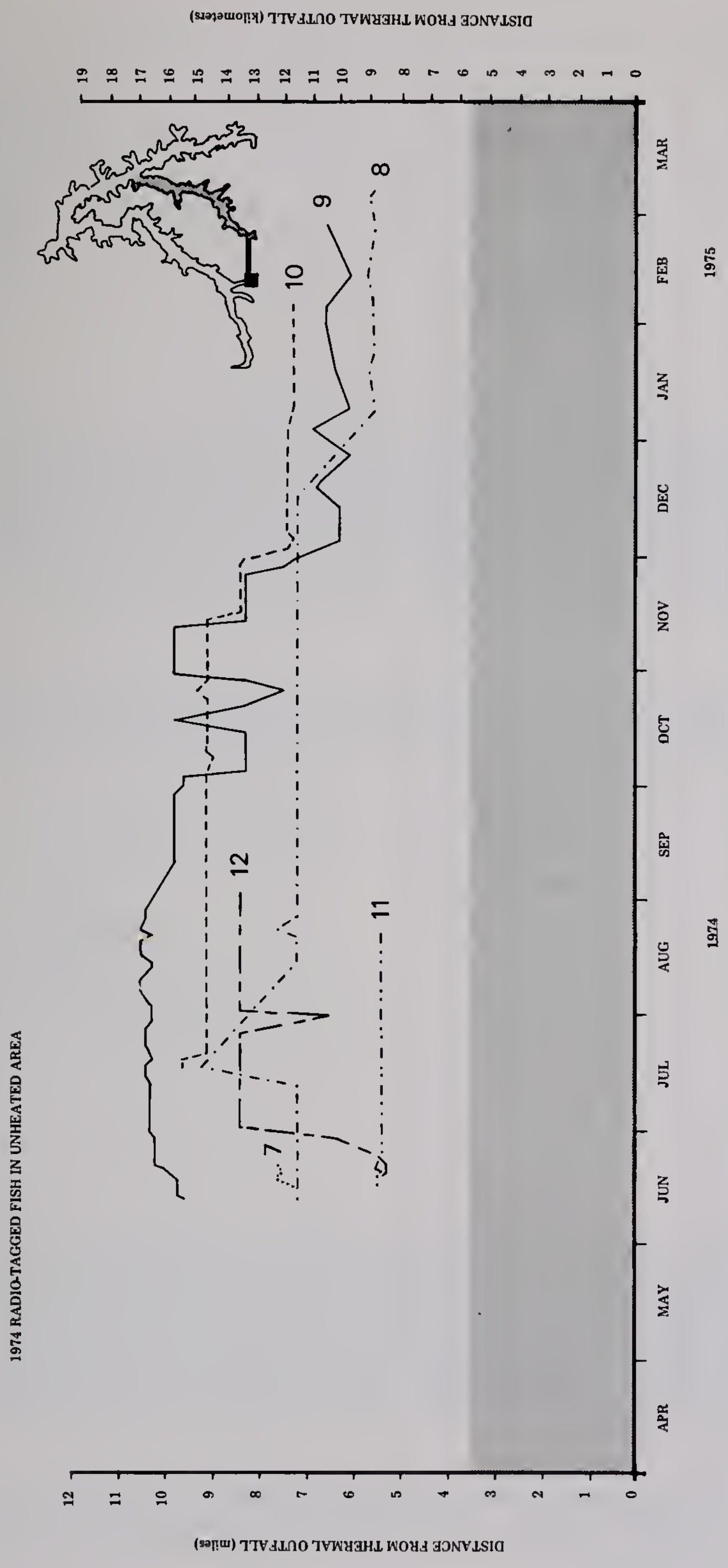


Fig. 5.—Radiotelemetry observations on movements in relation to the thermal outfall of six largemouth bass tagged and released in unheated areas of Lake Sangchris (No. 7–12) during spring 1974. The shaded area represents that portion of the discharge arm most highly influenced by elevated water temperatures.

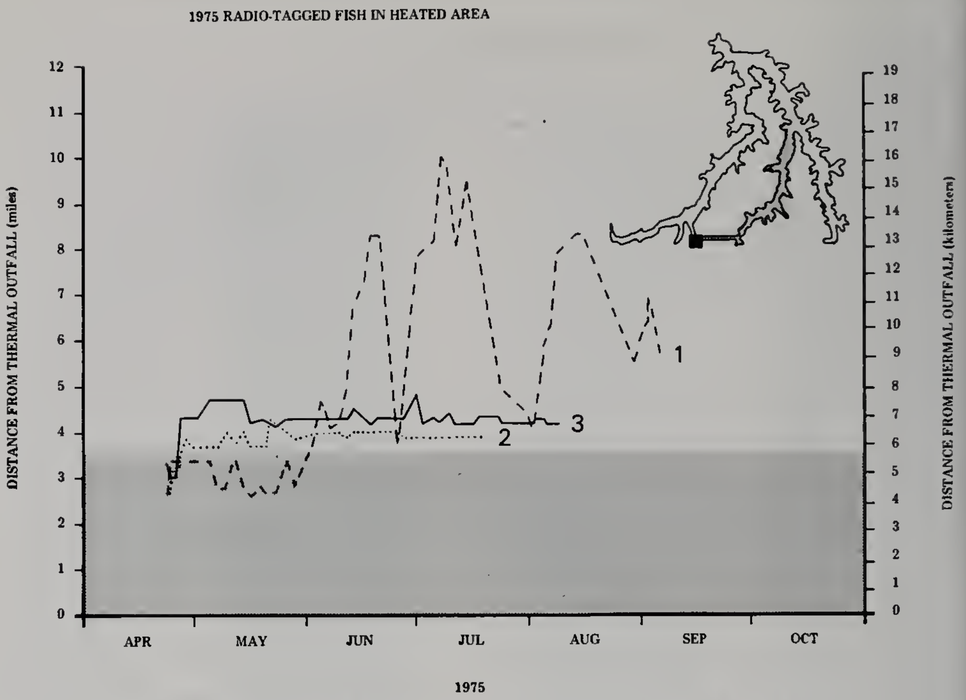


Fig. 6.—Radiotelemetry observations on movements in relation to the thermal outfall of three largemouth bass tagged and released in heated areas of Lake Sangchris (No. 1–3) during spring 1975. The shaded area represents that portion of the discharge arm most highly influenced by elevated water temperatures.

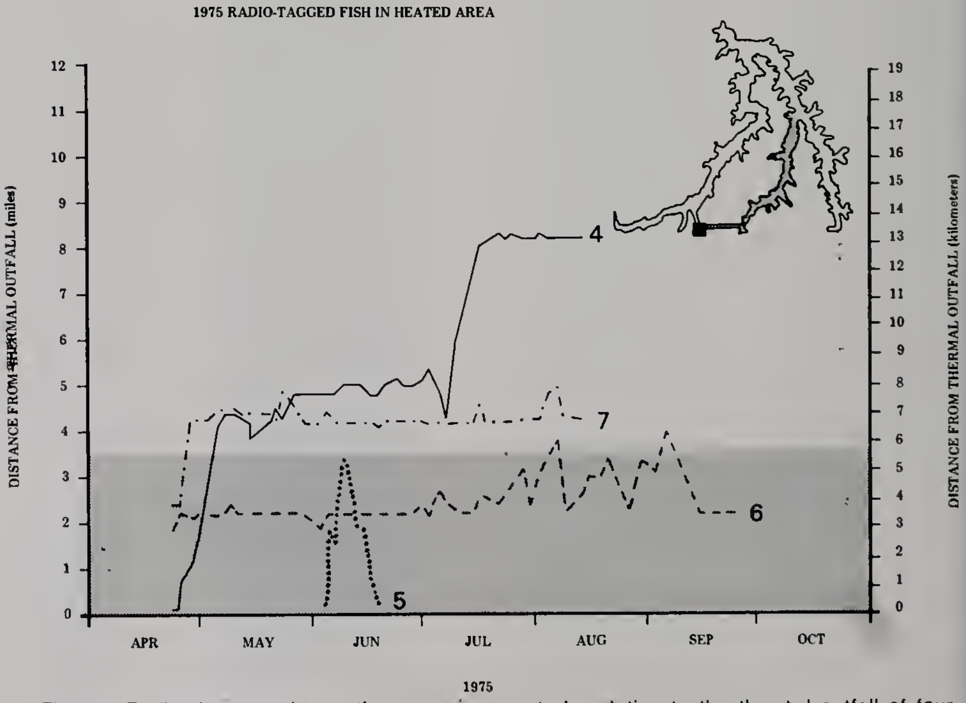


Fig. 7.—Radiotelemetry observations on movements in relation to the thermal outfall of four largemouth bass tagged and released in heated areas of Lake Sangchris (No. 4–7) during spring 1975. The shaded area represents that portion of the discharge arm most highly influenced by elevated water temperatures.

arm during the spring of 1975 (Fig. 6 and 7), four (No. 2,3,4, and 7) migrated beyond the 5.6 km mark (mile 3.5) to reach the control arm and another (No. 1) traveled between the intake and discharge arm several times. Within a 15-day period, fish No. 5 was tracked from its point of release, near the thermal outfall, to the junction of the discharge and control arms and back to its point of release. Throughout the spring, summer, and fall, fish No. 6 remained mostly within the southern portion of the discharge arm. During midsummer this fish took refuge in an extensive stand of American lotus in a cove where temperatures were 5°–6°C cooler than in adjacent midlake areas.

The movements of the seven fish released in the intake arm during the spring of 1975 are shown in Fig. 8 and 9. Fish No. 9,10 11, and 14 moved relatively small distances from the point of tagging and release. In late June, fish No. 12, released near the intake canal, moved toward the thermal outfall, but took refuge near the dam during midsummer. Fish No. 13 remained in the southern portion of the intake arm all summer but during the fall it moved approximately 6.4 km (4 miles) in the direction of the thermal outfall.

Nine of the 11 fish released in the transition zone of Lake Sangchris during September 1976 were attracted to the discharge arm during winter (Fig.10,11,12, and 13). However, those fish did not seek the warmest temperatures (those available in the discharge canal), but instead congregated in the heated middle arm near its junction with the unheated east arm where intermediate temperatures prevailed.

Relatively small seasonal activity centers were established by most bass in Lake Sangchris. Major movements occurred over a relatively short time span (a few hours to a few days). In Lake Sangchris, the movements almost always were oriented to the thermal gradient and temperature was consistently indicated as the primary factor affecting movement. Migration by 10 of 13 radio-tagged bass out of the heated zone during midsummer of 1974 and 1975 was apparently caused by elevated water temperatures. The directed movements in Lake Sangchris could be characterized as migrations between relatively small seasonal activity centers determined by behavioral thermoregulation. In Lake Shelbyville, directed movements were related to changing water levels during 1975 and 1977. In 1976, when water levels were stable at Lake Shelbyville, directed movements by several fish at a time were not observed (D. W. Dufford, unpublished data).

Radio-tagged bass in Lake Sangchris and Lake Shelbyville were observed most often in relatively shallow water (1–4 m) along the shoreline. In Lake Sangchris, bass from the heated zone could have avoided elevated temperatures by moving relatively small vertical distances to deeper midlake areas where sufficient dissolved oxygen usually was available. However, the majority of the bass in Lake Sangchris traveled relatively long (several km) horizontal distances to avoid elevated temperatures but remained in relatively shallow water along the shoreline. Radio-tagged bass in Lake Shelbyville also remained in relatively shallow water along the shoreline, rather than move to deeper cooler areas during the summer seasons. In both lakes, bass traveled across open water to get from one shoreline to the other, particularly when the fish were moving between areas. This behavior is in contrast to the observations of Parker & Hasler (1959) and Zweiacker (1972) who reported that bass avoided crossing open water. Although Lewis & Flickinger (1967), Hasler & Wisby (1958), and others found that bass sought deeper water during winter, radio-tagged fish in Lake Sangchris and Lake Shelbyville remained in water of approximately the same depth (1–4 m) throughout the year.

In Lake Shelbyville, none of the six fish studied during 1975 was recovered but 13 of the 15 fish with radios during 1976 were captured by fishermen. Two fish were recaptured three times and two fish were recaptured twice, making a

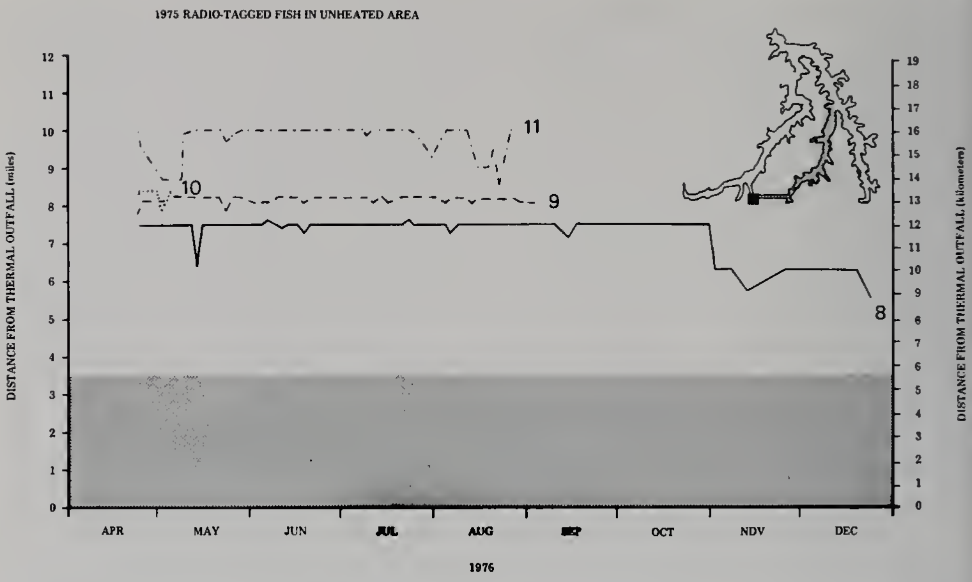


Fig. 8.—Radiotelemetry observations on movements in relation to the thermal outfall of four largemouth bass tagged and released in unheated areas of Lake Sangchris (No. 8–11) during spring 1975. The shaded area represents that portion of the discharge arm most highly influenced by elevated water temperatures.

total of 19 recaptures by fishermen during 1976. Fishermen moved five of the recaptured fish considerable distances before releasing them. None of those fish showed any indication of homing, or returning to the point of capture. Eight of the 19 recaptured fish were released in the area where captured; seven remained in the immediate area, and one moved at least 3.425 km within 20 hours. The other six fish recaptured by fishermen were removed from the lake. Three of the 13

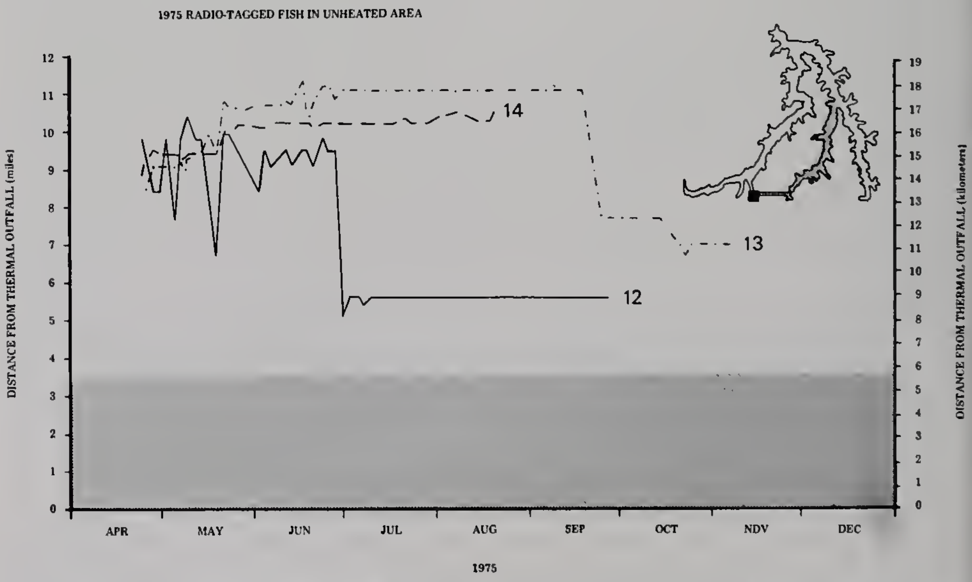


Fig. 9.—Radiotelemetry observations on movements in relation to the thermal outfall of three largemouth bass tagged and released in unheated areas of Lake Sangchris (No. 12–14) during spring 1975. The shaded area represents that portion of the discharge arm most highly influenced by elevated water temperatures.

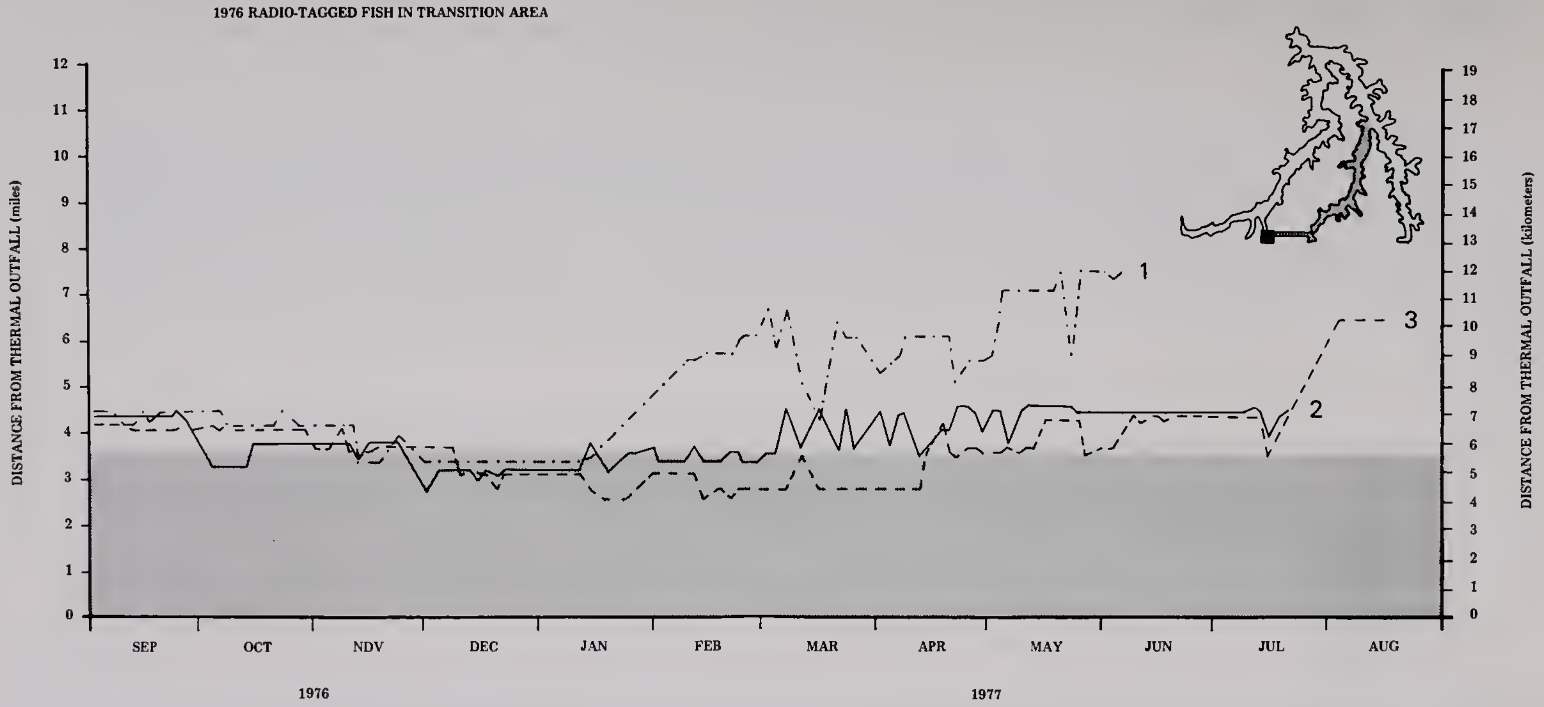


Fig. 10.—Radiotelemetry observations on movements in relation to the thermal outfall of three largemouth bass tagged and released in transition areas of Lake Sangchris (No. 1–3) during fall 1976. The shaded area represents that portion of the discharge arm most highly influenced by elevated water temperatures.

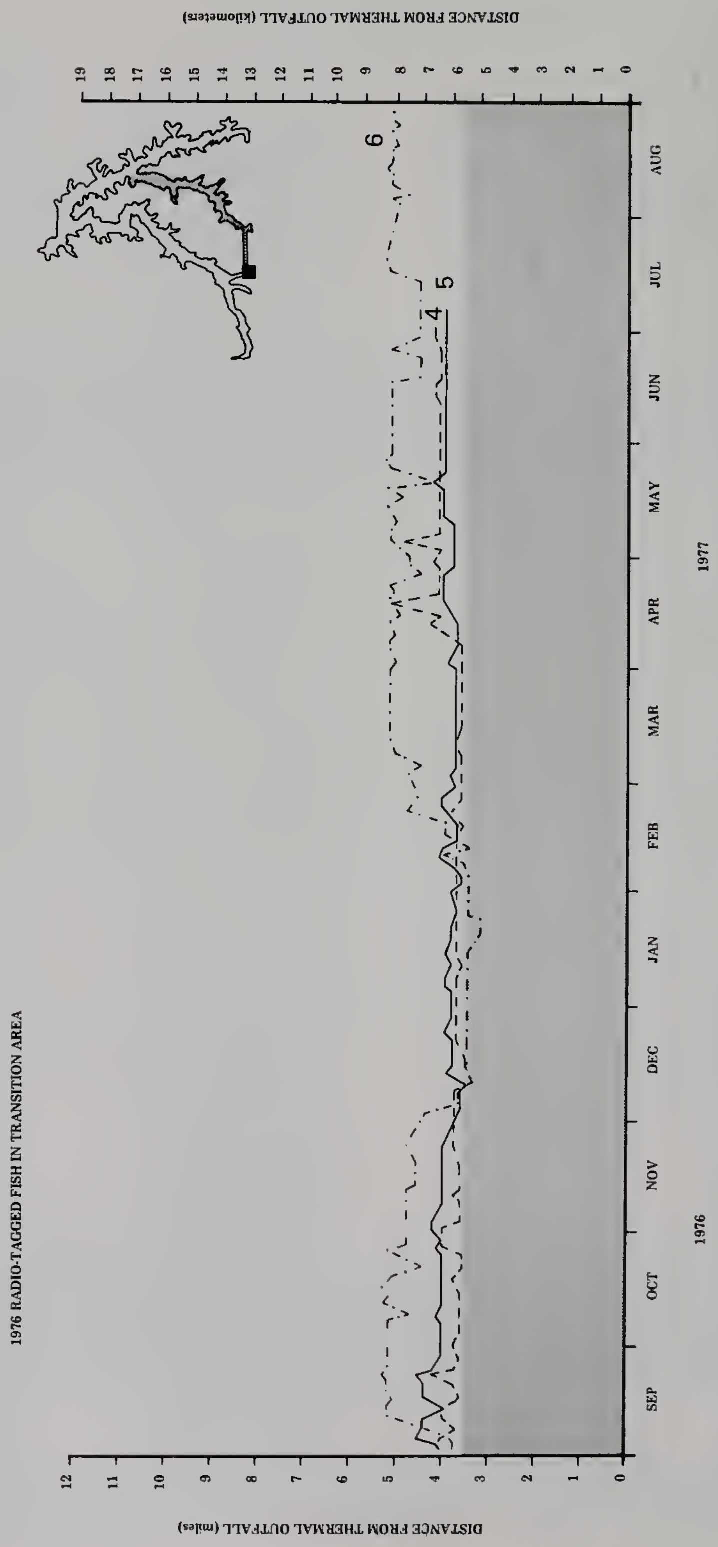


Fig. 11.—Radiotelemetry observations on movements in relation to the thermal outfall of three largemouth bass tagged and released in transition areas of Lake Sangchris (No. 4–6) during fall 1976. The shaded area represents that portion of the discharge arm most highly influenced by elevated water temperatures.

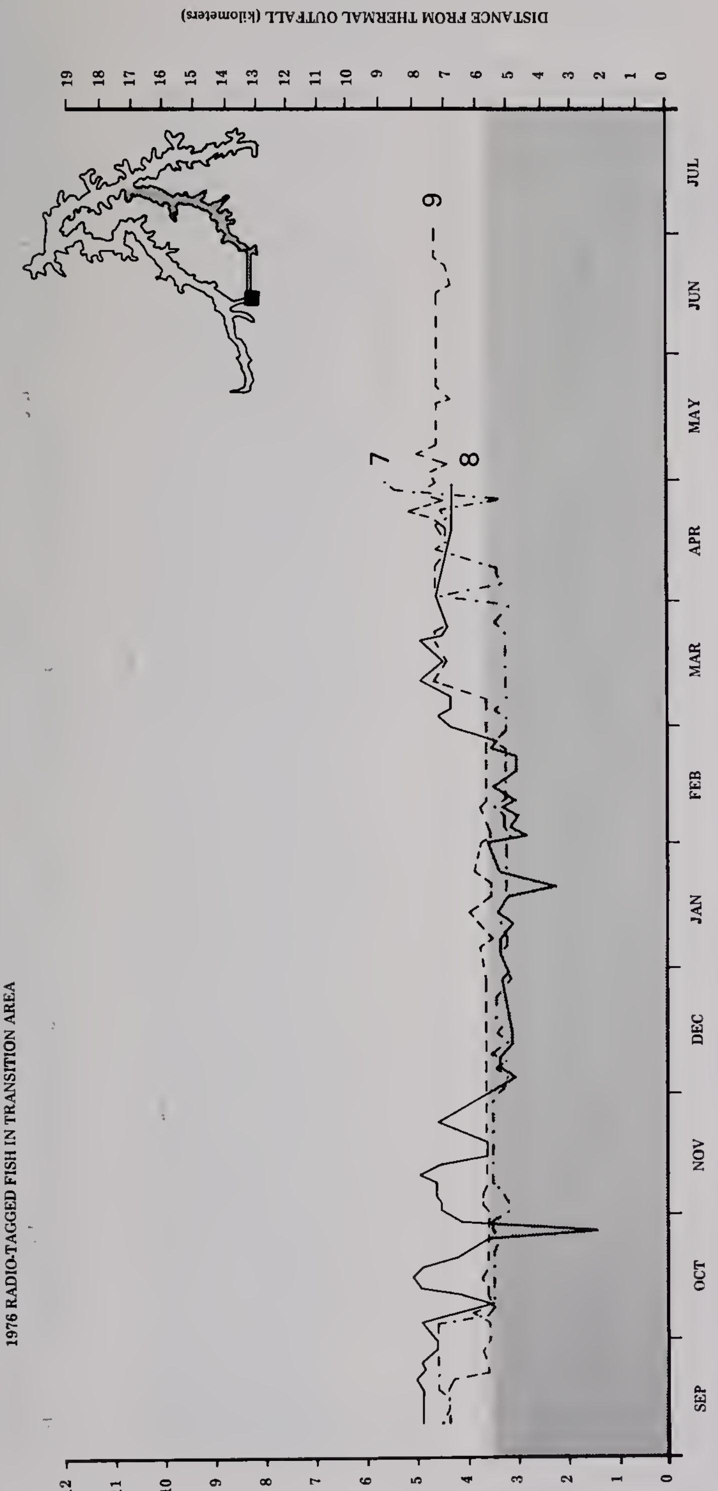


Fig. 12.—Radiotelemetry observations on movements in relation to the thermal outfall of three largemouth bass tagged and released in transition areas of Lake Sangchris (No. 7–9) during fall 1976. The shaded area represents that portion of the discharge arm most highly influenced by elevated water temperatures.

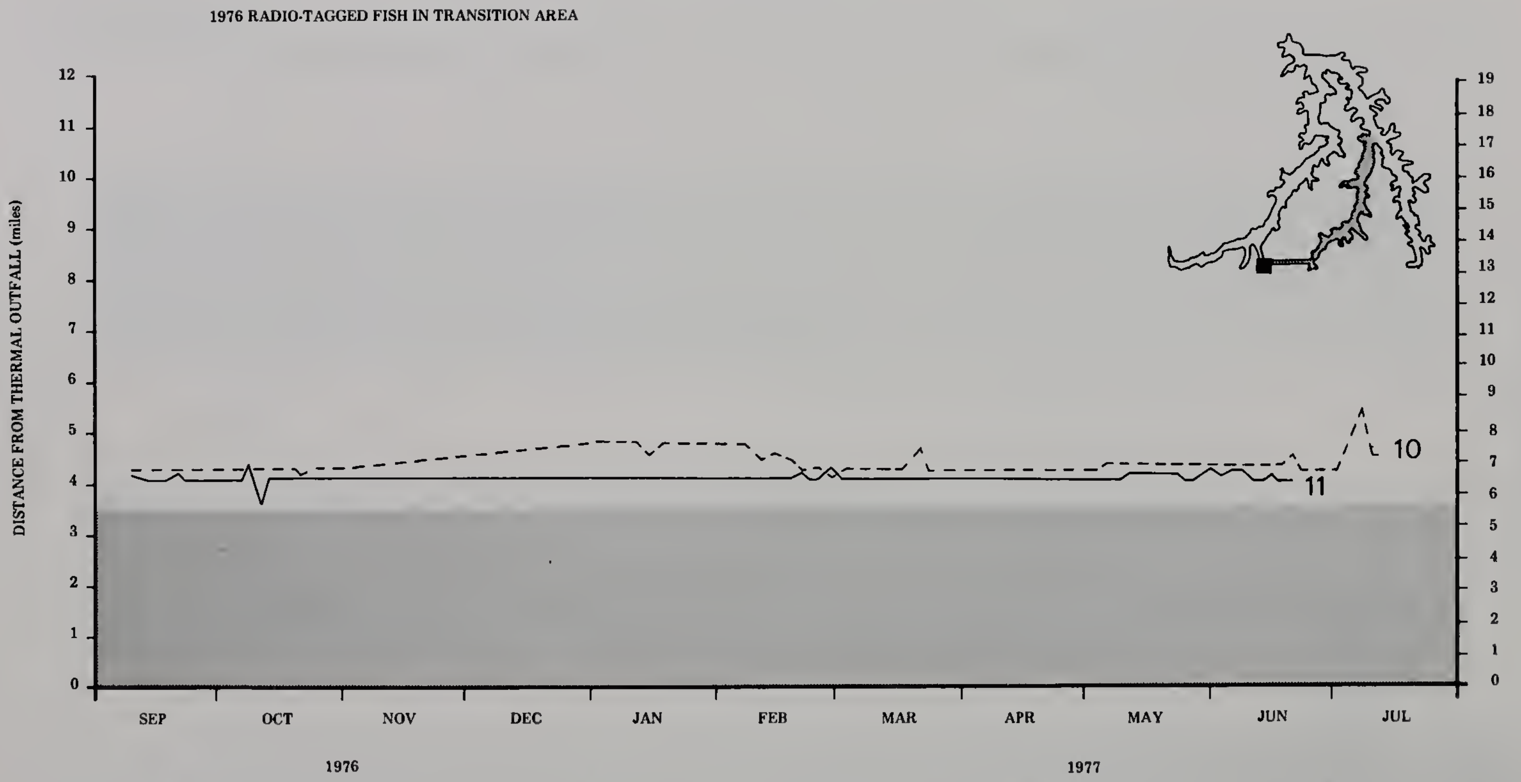


Fig. 13.—Radiotelemetry observations on movements in relation to the thermal outfall of two largemouth bass tagged and released in transition areas of Lake Sangchris (No. 10–11) during fall 1976. The shaded area represents that portion of the discharge arm most highly influenced by elevated water temperatures.

bass caught and released by fishermen died within 3 weeks, possibly as a result of being hooked. In 1977, four of 14 radio-tagged fish were caught by fishermen. One of the four fish captured in 1977 was removed from the lake and two others died, 11 and 13 days after being released by the fishermen. The fourth fish was moved across the lake from its place of capture but had returned to it within 17 days. The large number of radio-tagged bass recaptured by fishermen demonstrated that the radio tags did not prevent the fish from feeding.

Only seven of the 37 radio-tagged bass studied in Lake Sangchris (1974–1977) were captured by fishermen; three were caught after the radios had stopped transmitting signals. One fish with an active radio tag was found dead from unknown causes 42 days after being tagged and released. During electrofishing population surveys at Lake Sangchris, four radio-tagged fish were recaptured and released with radios functioning and seven others were recovered with inactive radios.

Of the 37 bass with implanted radios in Lake Sangchris, 16 were examined externally and 12 dissected and examined internally. Those examinations indicated that the external wounds were completely healed in approximately 4 weeks. Apparently, feeding and growth of radio-tagged bass were normal, and several females recaptured during early spring had highly developed ovaries indicating that reproduction was still possible. From these observations, it is believed the internally implanted radio transmitters had little effect on the behavior of the fish, especially after the incision had healed, and that the observed behavior of largemouth bass in this long-term study was normal and highly characteristic of the species.

SUMMARY

1.—There were no significant differences in the daily movements of male and female fish.

2.—The average daily movement of largemouth bass from the heated zone of Lake Sangchris (248.3 m) was significantly ($P < 0.05$) greater than that of fish from the unheated zone (126.1 m), the transition zone (91.1 m), or from Lake Shelbyville (116.3 m).

3.—The final preferred temperature selected by radio-tagged fish from the heated zone during July and August (30.5°C) was significantly greater ($P < 0.05$) than that of fish from any other study area. Fish from the unheated (29.1°C) and transition (28.2°C) zones of Lake Sangchris selected temperatures that were not different from each other, but which were significantly higher than those selected by fish from Lake Shelbyville (26.1°C).

4.—Comparison of temperature preferences and activity patterns of bass from three thermal zones of Lake Sangchris and from Lake Shelbyville suggested that acclimatization to higher temperatures may have occurred in the cooling lake through genetic selection for tolerance to higher temperatures.

5.—In Lake Sangchris, movements by radio-tagged fish were oriented to the thermal gradient, whereas in Lake Shelbyville directed movements were related to changing water levels.

REFERENCES CITED

BARR, A. J., J. H. GOODNIGHT, J. P. SALL, and J. T. HELWIG. 1976. A user's guide to SAS 76. Statistical Analysis System Institute, Inc. Raleigh, NC. 329 p.

BRETT, J. R. 1956. Some principles of the thermal requirements of fishes. Quarterly Review of Biology 31(2):75–87.

CHAPPELL, J. A. 1974. Response of largemouth bass to thermal effluent from Oconee Nuclear Power Plant. M.S. Thesis, Clemson University, Clemson, SC. 39 p.

CHILDERS, W. F. 1979. The effect of a heated effluent on the frequency of two alleles at the Mdh-B locus in largemouth bass, *Micropterus salmoides.* Pages 13-1–13-18 *in* Evaluation of a cooling lake fishery, Vol. III, Illinois Natural History Survey final report to Electric Power Research Institute, Palo Alto, CA.

CLUGSTON, J. P. 1973. The effects of heated effluents from a nuclear reactor on species diversity, abundance, reproduction, and movement of fish. Ph.D. Thesis, University of Georgia, Athens. 104 p.

COUTANT, C. C. 1974. Temperature selection by fish—a factor in power plant inpact assessments *in* Symposium on the physical and biological effects on the environment of cooling systems and thermal discharges at nuclear power stations. Oslo, Norway. 25 p.

Dendy, J. S. 1948. Predicting depth distribution of fish in three TVA storage-type reservoirs. American Fisheries Society Transactions 75:65–71.

Dupont, S. P. 1976. The behavior of largemouth bass *(Micropterus salmoides)* in a reservoir receiving a heated effluent. M.S. Thesis, University of Georgia, Athens. 60 p.

Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. Canada Fisheries Research Board Journal 15(4):607–624.

Fry, F. E. J. 1947. Effects of the environment on animal activity. University of Toronto Studies, Biological Series No. 55. 62 p.

Hasler, A. D., and W. J. Wisby. 1958. The return of displaced largemouth bass and green sunfish to a "home" area. Ecology 39(2):289–293.

Lewis, W. M.,and S. Flickinger. 1967. Home range tendency of the largemouth bass (*Micropterus salmoides*). Ecology 48(6):1020–1023.

Lorio, W. J., R. L. Warden, Jr., and T. D. Thornhill. 1973. The effects of water management practices on the movement of largemouth bass. Water Resources Research Institute, Mississippi State University. 46 p.

Neill, W. H., and J. J. Magnuson. 1974. Distributional ecology and behavioral thermoregulation of fishes in relation to heated effluent from a power plant at Lake Monona, Wisconsin. American Fisheries Society Transactions 103 (4):663–710.

Parker, R. A., and A. D. Hasler. 1959. Movements of some displaced centrarchids. Copeia 1959 (1):11–18.

Petersen, D. C. 1975. Ultrasonic tracking of three species of black basses, *Micropterus* spp., in Center Hill Reservoir, Tennessee. M. S. Thesis, Tennessee Technological University, Cooksville. 129 p.

Smith, D. C. 1974. Movement and home range of largemouth bass (*Micropterus salmoides)* tagged with ultrasonic transmitters. M. S. Thesis, Clemson University, Clemson, SC. 39 p.

Smith, V. J., and J. M. McNurney. 1981. Behavioral thermoregulation of largemouth bass and carp in an Illinois cooling lake. Pages 585–593 *in* R. W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

Strawn, K. 1961. Growth of largemouth bass fry at various temperatures. American Fisheries Society Transactions 90(3):334–335.

Warden, R. L., and W.J. Lorio. 1975. Movements of largemouth bass *(Micropterus salmoides)* in impounded waters as determined by underwater telemetry. American Fisheries Society Transactions 104(4):696–702.

Zweiacker, P. L. 1972. Population dynamics of largemouth bass in an 808-hectare Oklahoma reservoir. Ph.D. Thesis, Oklahoma State University, Stillwater. 126 p.

Behavioral Thermoregulation of Largemouth Bass and Carp in an Illinois Cooling Lake

Valerie J. Smith and John M. McNurney

ABSTRACT

The preferred temperatures of largemouth bass and carp were determined *in vivo* during the summer months at Lake Sangchris, a power plant cooling lake in central Illinois. Their preferred temperatures were inferred from measurements of the internal body temperatures of fish captured in areas where a wide range of water temperatures was available. Most of the samples were taken in the heated arm of the lake, where water temperatures exceeded the previously reported preferred temperatures for largemouth bass and carp. The preferred temperatures determined were approximately 32.3°C for largemouth bass and 31.8°C for carp. These estimates were very near the highest preferred temperatures reported for these species in a variety of laboratory and field investigations.

INTRODUCTION

Fishes, except for some large, fast-swimming marine species (Carey 1973), are incapable of physiological control of body temperature. Many species, however, accomplish a limited amount of temperature regulation through behavioral responses that position them in water of a particular temperature. Such behavioral thermoregulation requires that the fish be capable of accurately detecting water temperature and of responding appropriately to it with respect to a reference, or preferred, temperature. Some fish are sensitive to water temperature differences as small as 0.03°C (Bull 1936), and some are able to distinguish between increasing and decreasing temperature (Bardach & Bjorklund 1957). Characteristic thermal preferenda have also been identified for many species. Such preferences vary for each species depending on acclimation temperature (Ferguson 1958), season of the year (Zahn 1963 and Fry 1967), and age of the fish (Fry 1937).

Water temperature ranges and gradients in cooling lakes are often quite different from those in lakes that do not receive a thermal discharge. Atypically high temperatures may be encountered in cooling lakes, especially during the summer when normal vertical thermal stratification is often disrupted and horizontal thermal gradients may be encountered. In this study, some aspects of the thermoregulatory behavior of largemouth bass (*Micropterus salmoides*) and carp (*Cyprinus carpio*) in Lake Sangchris, a cooling reservoir in central Illinois, were examined during the summer of 1975. Efforts to determine the final preferred temperatures of these species were concentrated in that portion of the reservoir most affected by the thermal effluent.

STUDY AREA AND METHODS

Lake Sangchris, an 876-ha (2,165-acre) reservoir, provides condenser cooling water for Commonwealth Edison Company's Kincaid Generating Station. The reservoir has three arms. Each arm is approximately 8 km (5 miles) in length, and all three extend in a southerly direction from the dam (Fig. 1). Kincaid Generating Station, which houses two coal-fired 616-megawatt generating

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units, is situated between the southern ends of the western and middle arms. Water is taken from the western (intake) arm via the short intake canal, used for cooling in the plant, and pumped into the middle (discharge) arm via the 1,100-m discharge canal. Water in the reservoir circulates, therefore, in a counterclockwise direction in these two arms. The eastern arm is not directly involved in the cooling cycle.

When the power plant is operating, the temperature of the cooling water passing through the plant is elevated 7°–10°C, depending upon the volume of cooling water passing through the plant and the number of units in operation. Water in the entire length of the discharge arm is vertically isothermic due to the design of the discharge structure and the reservoir basin morphometry. Only minor decreases in temperature occur as the water flows from the plant discharge structure to the confluence of the discharge and east arms. Ambient water temperatures prevail in the southern two-thirds of the intake arm and in the eastern arm.

Prior to making the field collections, the effects of an electrical shock on fish body temperatures were examined in the laboratory. An available stock of laboratory-raised bluegills was used to avoid behavior-related activity. Thermocouples were secured in the vent of a bluegill and at five locations in a large aquarium in which the fish was confined. The body temperature of the bluegill and the water temperature were monitored continuously until they

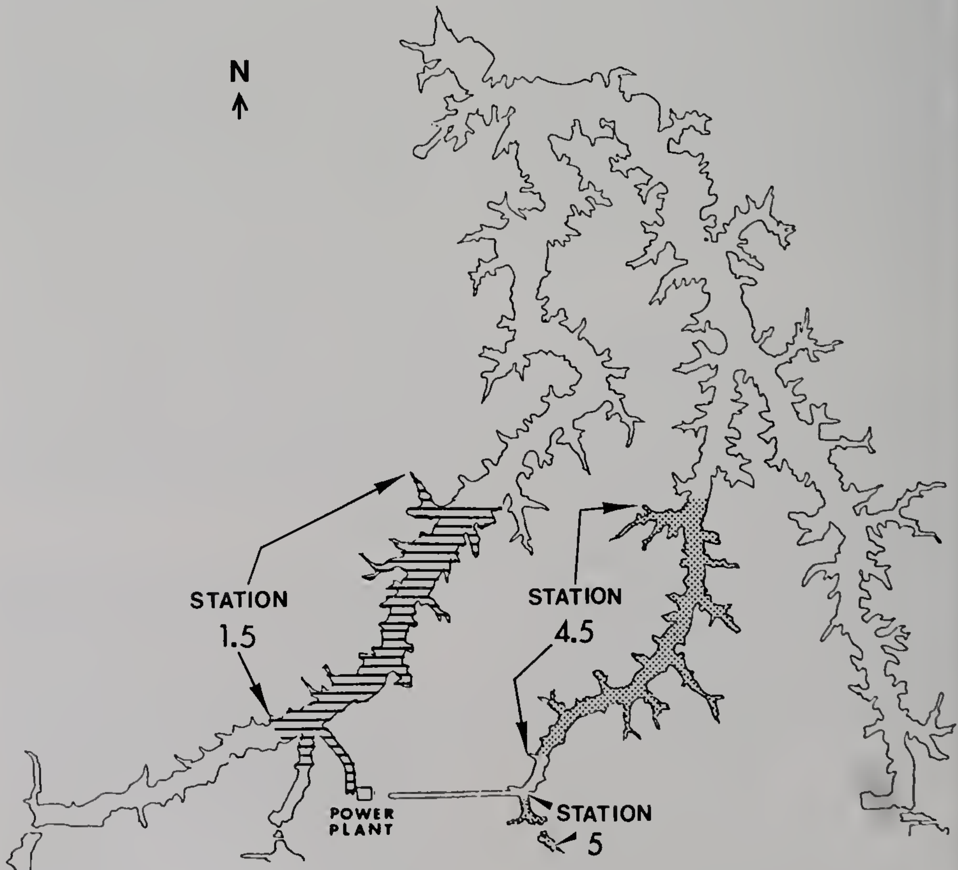


Fig. 1.—Locations of sampling stations for determining deep body temperatures of largemouth bass and carp at Lake Sangchris.

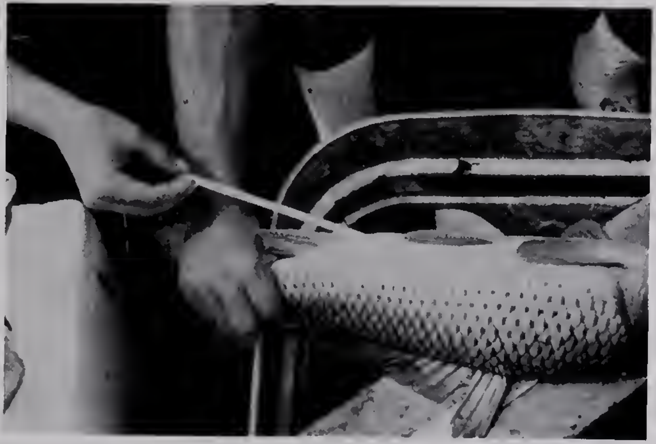
became stable. A 110-volt, 20-ampere alternating current was then passed through the tank, stunning the fish. Temperatures were continuously monitored during the electric shock and for several minutes afterward while the bluegill recovered. In repeated trials, bluegill of various sizes were used, and the duration of the electric shock varied.

Largemouth bass and carp were collected for this study from Lake Sangchris, using a boat-mounted alternating-current electrofishing unit operating at 230 volts and 7.5 amperes. When a fish that weighed more than 450 g (1 lb) was captured, the surface-water temperature was recorded from a continuously operating electronic temperature probe, and the internal body temperature of the fish was determined immediately by inserting a calibrated analytical mercury thermometer 1–5 cm into the vent. Each fish was subsequently weighed, measured, and held temporarily to avoid its recapture. Vertical water temperature profiles were measured periodically with an electronic temperature probe to estimate the range of water temperatures in the collecting area.

Fish were collected from three sampling stations on Lake Sangchris (Fig. 1). Largemouth bass and carp were taken at Station 4.5 on each of the four sampling dates (10 June, 3 July, 22 July, and 1 August 1975). At Station 4.5, near the central portion of the discharge arm and approximately 3 km from the power plant outfall, fish were most often captured in several large coves that contained groundwater sources in the form of springs and field tiles. Fish were collected at Station 5 on all sampling dates except 3 July. In the Station 5 area, where the discharge canal entered the discharge arm of the reservoir, all fish were taken near the highway bridge approximately 200 m south of the mouth of the discharge canal. The bridge structure reduced the cross-sectional area of the middle arm sufficiently at that point to prohibit the flow of the heated surface water south of the bridge. Therefore, a consistent interface resulted between the heated water and the ambient surface water flowing in from the south. Fish were collected only on 10 June and 3 July at Station 1.5 in an area of the intake arm unaffected by the heated discharge. Further sampling was discontinued at Station 1.5 after 3 July because the summer maximum temperature had already been reached in the intake arm and because it was necessary to concentrate collecting efforts in the discharge arm to capture sufficient numbers of fish.

RESULTS AND DISCUSSION

Body temperatures measured according to the methods described were considered accurate indicators of the recent thermal history of the captured fish. Muscular thermogenesis, which might



Recording the internal body temperature of a carp.

have contributed a small amount of excess body heat if a fish had recently swum a long distance (Carey & Teal 1969), was considered negligible. The preliminary laboratory experiments also showed that collecting by shocking with alternating current did not affect body temperatures of bluegills. Since the predominant muscles of bluegill, largemouth bass, and carp are physiologically similar, no effect from the collecting technique was expected. Body temperatures were, therefore, considered to be developed only by conductive heat exchange between the fish and the surrounding water at rates dependent on the existing temperature difference between the fish and the water (Fry 1967) and the size, shape, and respiratory rate of the fish (Spigarelli et al. 1974 and Morrow & Mauro 1950). According to data presented by Spigarelli et al. (1974), a 450-g carp or largemouth bass (the minimum size used in this study) would have gained about one-half of a 5°C temperature increase in approximately 4 minutes. Complete temperature equilibrium would have required about 30 minutes, since the relationship is exponential. Therefore, if a fish with a body temperature of 30°C was captured in water at 35°C, that fish must have remained in water at least as cool as 30°C long enough to have become equilibrated to the lower temperature.

During this study, fish were collected under a variety of water temperature conditions relative to the reported preferred temperature ranges of largemouth bass, 29.2°–32.0°C (Coutant 1974, Fry 1950, and Neill 1971), and of carp, 28.3°–32.0°C (Neill 1971 and Pitt et al. 1956). On 10 June, the range of available water temperatures was generally below those preferred temperatures at all three stations. However, most of the lake in the area of Station 4.5 was warmer than the preferred temperatures of both species on 3 July, 22 July, and 1 August. At Station 1.5 on 3 July and Station 5 on 22 July and 1 August, the water temperature range overlapped the preferred temperature ranges of both largemouth bass and carp.

Body temperatures of largemouth bass and carp collected on 10 June at all three

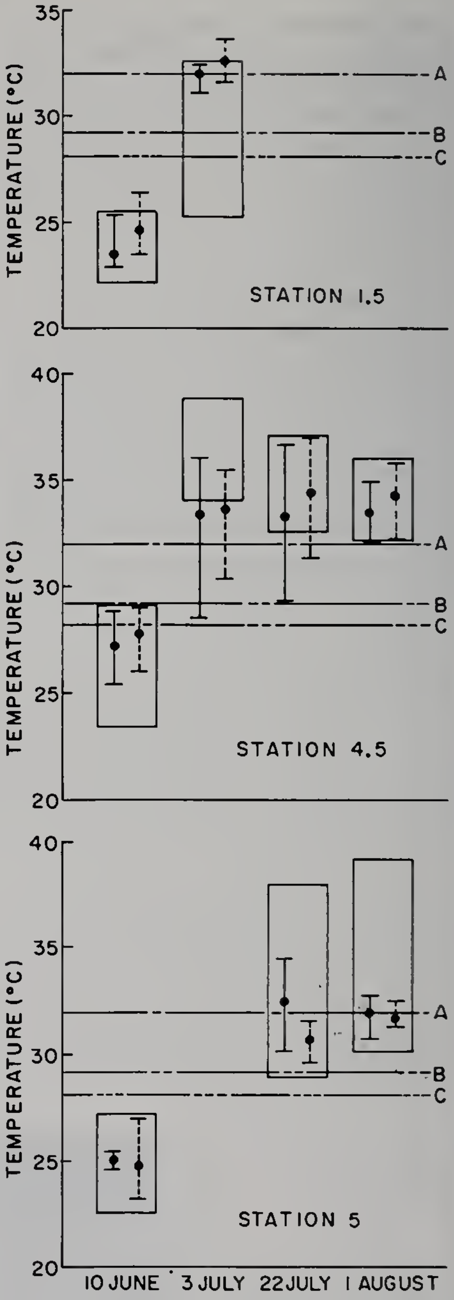


Fig 2 —The means (solid circles) and ranges of body temperatures of largemouth bass (solid vertical lines) and carp (broken vertical lines) measured at three Lake Sangchris sampling stations on four dates during 1975. The existing ranges of water temperature at each location on each date are indicated by the closed rectangles. The horizontal lines A, B, and C represent, respectively, the reported highest preferred temperature for both species (32.0°C), lowest preferred temperature for largemouth bass (29.2°C), and lowest preferred temperature for carp (28.3°C).

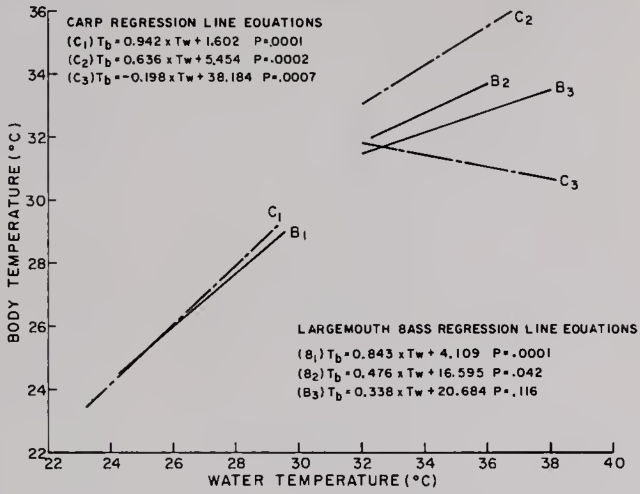


Fig. 3.—Regressions of deep body temperatures (T_b) of largemouth bass and carp from Lake Sangchris with the temperatures of the water (T_W) from which they were collected. Regression lines B_1 and C_1 represent the regression equations for largemouth bass and carp, respectively, at stations 1.5, 4.5, and 5 on 10 June. Regression lines B_2 and C_2 represent the regression equations for largemouth bass and carp, respectively, at Station 4.5 on 3 July, 22 July, and 1 August. Regression lines B_3 and C_3 represent the regression equations for largemouth bass and carp, respectively, at Station 5 on 22 July and 1 August.

stations indicated that neither had a particular temperature preference within the range of available temperature (22.0°–29.5°C) (Fig. 2). Internal body temperatures were widely distributed at each station.

The slopes of lines B_1 and C_1 (Fig. 3) (regressions of body temperature with respect to water temperature at the point of collection for largemouth bass and carp, respectively) were near 1.0, indicating a close correlation between body temperatures and surrounding water temperatures over the entire temperature range. Mean body temperature was not significantly different ($P < 0.05$) from the mean water temperature at any station on 10 June (Table 1).

Nearly the entire water volume at Station 4.5 on all sampling dates after 10 June was above the highest reported preferred temperature for both test species. Groundwater that entered coves at Station 4.5 formed pockets of water much cooler than the majority of the water volume in the area. Those pockets acted as refuges from the thermal discharge and were often too small to find with the temperature probe. Their presence was, however, indicated by body temperatures of fish captured on 3 July which were well below the lowest recorded water temperatures (Fig. 2). When the refuge areas were relatively large and numerous on 3 July, they were used by some of the carp and largemouth bass at Station 4.5 (Fig. 2). The water table fell as the summer progressed, reducing groundwater discharges and, therefore, the size and number of refuge areas. As the refuges were reduced (22 July) and finally eliminated (1 August), fewer fish were able to use thermoregulatory behavior to escape the high temperatures. This fact was indicated by the more restricted ranges of body temperatures on those dates and by regression lines B_2 and C_2 (Fig.3), which indicate some thermoregulation because their slopes are much less than 1.0. By 1 August, there was no evidence of temperature selection by either species at Station 4.5; all body temperatures were within the range of water temperatures measured, and the mean temperatures of fish and the water where they were collected were not significantly different (Table 1).

Some carp were found in water of unusually high temperature in the discharge arm of Lake Sangchris during periods when cooler water was available. Several carp that were collected at Station 4.5 on the last two collecting dates had body temperatures of up to 36.9°C, well in excess of the upper lethal temperature of 35°–36°C reported for carp 2–4 years old (Meuwis & Heuts 1957). Although Horoszewicz (1973) determined a higher upper lethal temperature of 40.6° ± 0.55°C for carp from a heated lake subjected to a slow temperature increase of 0.03°C/min

Table 1.—Mean preferred temperatures (Celsius) of largemouth bass and carp, determined by deep body measurements of fish, and mean surface water temperatures at three sampling stations in Lake Sangchris in 1975.

	10 June			3 July			22 July			1 August		
	Number	Mean	SD	Number	Mean	SD	Number	Mean	SD	Number	Mean	SD
Station 1.5												
Largemouth Bass	10	23.6	0.77	6	32.1	0.47	. . .	. . .	. . .	. . .	. . .	. . .
Carp	26	24.7	0.79	13	32.5	0.47	. . .	. . .	. . .	. . .	. . .	. . .
Surface Water	34	24.3	0.80	19	32.2	0.13	. . .	. . .	. . .	. . .	. . .	. . .
Station 4.5												
Largemouth Bass	23	27.2	1.12	28	33.3	1.94	12	33.2	1.81	7	33.5	0.92
Carp	39	27.8	0.61	3	33.6	2.81	5	34.5	2.22	8	34.4	0.94
Surface Water	62	27.5	1.00	29	35.3	0.60	17	35.2	1.30	15	34.0	1.15
Station 5												
Largemouth Bass	2	25.1	0.28	. . .	. . .	. . .	5	32.9	1.62	6	32.0	0.74
Carp	16	24.8	1.23	. . .	. . .	. . .	10	30.9	0.50	11	31.8	0.30
Surface Water	18	25.2	0.75	. . .	. . .	. . .	15	36.4	0.78	17	32.9	0.79

his test fish became obviously disturbed at 34.8°C.

The maximum body temperature recorded for largemouth bass from Lake Sangchris was 36.7°C at Station 4.5 on 22 July. Several workers have estimated the upper lethal temperature that will kill 50 percent of the population (LT_{50}) for adult largemouth bass to be in the range of 37.2°–38.9°C (Hathaway 1927, Trembley 1960 and 1961). Although the body temperatures of Lake Sangchris largemouth bass did not indicate residence at near-lethal temperatures, some of the individuals captured in the coldest refuge areas would have been exposed to lethal temperature changes, from about 30°C to above 36°C (Hart 1952), by traveling only a few meters at Station 4.5 on 3 July or 22 July or at Station 5 on 22 July or 1 August.

Despite the fact that nearby inhabitable waters had temperatures as low as 25.4°C, nearly all the fish captured at Station 1.5 on 3 July had body temperatures near the maximum recorded water temperature of 32.5°C (Fig. 2). The mean body temperatures of largemouth bass and carp were, respectively, 32.1°C and 32.5°C (Table 1), indicating that the fish had selected those temperatures. Several carp captured at Station 1.5 had body temperatures above the highest water temperature measured during the collection. Those fish probably were individuals that had been observed in very shallow water, less than 0.25 m deep, where they may have encountered surface water warmer than any measured from the collecting boat.

Fish collected at Station 5 on 22 July and 1 August clearly demonstrated behavioral thermoregulation. At that station cool water was supplied by runoff into the southern end of the discharge arm and the volume was much larger than the small pockets of cool water formed at Station 4.5. The interface between the cool water and the thermal discharge formed a consistent temperature gradient. The mean body temperatures of largemouth bass and carp captured at Station 5 were consistently near 32°C on 22 July and 1 August, when most of the water at Station 5 was warmer that 35°C (Table 1). The range of body temperatures was small on both dates, especially in relation to the wide range of available water temperatures (Fig. 2). Line B_3 and C_3 of Fig. 3, the regression lines of bass and carp body temperatures with respect to the water temperatures at which they were captured, had the most gradual slopes of all of the regression lines, also indicating that the most successful thermoregulation by fishes occurred at Station 5.

During the summer of 1975 both largemouth bass and carp at Lake Sangchris used behavioral thermoregulations to avoid body temperatures that would have been physiologically inefficient and perhaps even lethal. When necessary, some individuals found and occupied very small volumes of water that had temperatures near the preferred temperatures of the fishes. Final preferred temperatures for adult carp and largemouth bass weighing at least 450 g were inferred from body temperatures of those fish collected when and where a wide range of water temperatures was available in sufficient volumes to permit individuals to thermoregulate freely by temperature selection. These criteria for successful thermoregulatory behavior were met at Station 1.5 on 3 July 1975 and at Station 5 on 22 July and 1 August 1975. The mean body temperature determined for 16 largemouth bass was 32.29° ± 1.04°C within a range of 30.3–34.5°C. The body temperatures of 34 carp collected under the same conditions ranged from 30.2° to 33.5°C with a mean of 31.79° ± 0.76°C. These values represent reliable *in vivo* estimates of the final preferred temperatures of largemouth bass and carp. Both are near the highest laboratory measurements of preferred temperature of 32°C for largemouth bass (Fry 1950) and of 32°C for carp (Pitt et al.1956). They also agree well with the upper range of the field measurements of Neill (1971) of 32.0°C for largemouth bass and 31.7°C for carp.

SUMMARY

1. — Based on a review of pertinent literature and laboratory experiments, physiological effects on the body temperatures of carp and largemouth bass were determined to be negligible. Body temperatures were, therefore, considered to be the result of conductive heat exchange between the fish and the surrounding water.

2. — Predictable rates of body temperature changes, based on temperature differences and physical attributes of the fish, were identified from sources in the literature.

3. — Body temperature measurements indicated the selection by the fishes of water of certain temperatures, resulting in behavioral thermoregulation by largemouth bass and carp when environmental conditions permitted.

4. — When water of preferred temperature was not readily available, carp and largemouth bass in Lake Sangchris were sometimes found to have body temperatures near the reported lethal water temperatures for each species.

5. — The final preferred temperature for largemouth bass weighing at least 450 g, as indicated by field measurements of body temperature, was 32.29° ± 1.04°C.

6. — The final preferred temperature for carp weighing at least 450 g, as indicated by field measurements of body temperature, was 31.79° ± 0.76°C.

REFERENCES CITED

Bardach, J. E., and R. J. Bjorklund. 1957. The temperature sensitivity of some American freshwater fishes. American Naturalist 91:233–251.

Bull, H. O. 1936. Studies on conditioned responses in fishes. VII. Temperature perception in teleosts. Marine Biological Association of the United Kingdom Journal 21:1–27.

Carey, F.G. 1973. Fishes with warm bodies. Scientific American 228 (2):36–44.

______, and J. M. Teal. 1969. Regulation of body temperature by the bluefin tuna. Comparative Biochemistry and Physiology 28:205–213.

Coutant, C. C. 1974. Temperature selection by fish — a factor in power plant impact assessments. Paper presented at I. A. E. A. symposium on the physical and biological effects on the environment of cooling systems and thermal discharges at nuclear power stations. Oslo, 26–30 August 1974, IAEA-SM-18/11.

Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. Canada Fisheries Research Board Journal 15(4):607–624.

Fry, F. E. J. 1937. The summer migration of the cisco, *Leucichthys artedi* (Le Sueur), in Lake Nipissing, Ontario. University of Toronto Studies, Biology Series 44. Ontario Fisheries Research Laboratory Publication 55. 91 p.

______. 1950. Temperature preferences and cruising speed of largemouth and smallmouth bass in relation to acclimation temperature. Unpublished manuscript.

______. 1967. Response of vertebrate poikilotherms to temperature. Pages 375–409 *in* A. H. Rose, ed., Thermobiology. Academic Press, Inc., New York.

Hart, J. S. 1952. Geographical variation of some physiological characters in certain freshwater fish. University of Toronto Studies, Biology Series 60. Ontario Fisheries Research Laboratory Publication 72. 79 p.

Hathaway, E. S. 1927. Quantitative study of the changes produced by acclimatization on the tolerance of high temperatures by fishes and amphibians. U. S. Bureau of Fisheries Bulletin 43:169–192.

Horoszewicz, L. 1973. Lethal and 'disturbing' temperatures in some fish species from lakes with normal and artificially elevated temperature. Journal of Fishery Biology 5:165–181.

Meuwis, A. L., and M. J. Heuts. 1957. Temperature dependence of breathing rate in carp. Biological Bulletin 112(1):97–107.

Morrow, J. E., Jr., and A. Mauro. 1950. Body temperature of some marine fishes. Copeia 1950:108–116.

Neill, W. H. 1971. Distributional ecology and behavioral thermoregulation of fishes in relation to heated effluent from a steam-electric power plant (Lake Monona, Wisconsin). Ph.D. Thesis. University of Wisconsin, Madison.

Pitt, T. K., E. T. Garside, and R. L. Hepburn. 1956. Temperature selection of the carp *(Cyprinus carpio* Linn.). Canadian Journal of Zoology 34:555–557.

Spigarelli, S. A., G. P. Romberg, W. Prepjchal, and M. M. Thommes. 1974. Body-temperature characteristics of fish at a thermal discharge on

Lake Michigan. Pages 119–132 *in* J. W. Gibbons and R. R. Sharitz, eds., Thermal ecology. AEC Symposium Series (CONF-730505), Augusta, GA.

TREMBLEY, F. J. 1960. Research project on effects of condenser discharge water on aquatic life. Progress report 1956–1959. Institute of Research, Lehigh University, Bethlehem, PA.

______. 1961. Research project on effects of condenser discharge on aquatic life. Progress report 1960. Institute of Research, Lehigh University, Bethlehem, PA.

ZAHN, M. 1963. Jahreszeitliche veranderungender vorzugstemperaturen von scholle (*Pleuronectes platessa* Linne) und bitterling (*Rhodeus sericeus* Pallas). Verhandlungen der Deutschen Zoologischen Gesellschaft 562–580.

Lake Sangchris Creel Survey: 1973–1975

John M. McNurney and Herbert Dreier

ABSTRACT

For the 2-year period from April 1973 to April 1975, a year-round creel survey was conducted at Lake Sangchris, a cooling lake located in central Illinois, to determine the effects of a thermal discharge on the quantity and quality of sport fishing. Annual fishing pressure (93 man-hours per acre) was higher than usual for midwestern reservoirs of similar size. During all seasons of the year, fishing effort was concentrated in heated areas of the lake. The species most actively sought by fishermen were largemouth bass and channel catfish. Six species (largemouth bass, channel catfish, white bass, carp, white crappie, and bluegill) comprised 78 percent of the number and 91 percent of the weight of fish harvested. The catch rate and harvest of channel catfish were very high in comparison with those of other lakes.

INTRODUCTION

A recreational creel survey was begun on Lake Sangchris, a cooling lake in central Illinois, on 15 April 1973. The work was jointly supported by Commonwealth Edison Company and the Illinois Department of Conservation during the first year. From 15 April 1974 to 15 April 1975, the survey was funded by Commonwealth Edison Company and supervised by the Illinois Natural History Survey. Although not included in this report, the creel survey was continued through the summer of 1976 (McNurney & Frakes 1979).

The creel surveys at Lake Sangchris served several purposes. The primary objectives were to measure the public use of the cooling lake as a recreational resource, to determine the sport fishing harvest as a component of a complete study of the dynamics of the fish community, and to ascertain the effect of elevated water temperatures in the heated arm of the lake on the quantity and quality of sport fishing.

Fishing regulations may limit catch. Several specific regulations affected Lake Sangchris during the 1973–1975 creel period. Fishing effort was limited to pole-and-line fishing with no more than two poles per angler and no more than two hooks per pole. Effort was further restricted by the closure of the east and west arms of the lake (Fig. 1) to fishing during the waterfowl hunting season from about 20 October to about 5 December. The harvest of largemouth bass was restricted to no more than six fish per angler per day.

DESCRIPTION OF THE STUDY AREA

Lake Sangchris is a 2,165-acre (876-ha) cooling lake approximately 16 miles (25 km) southeast of Springfield, Illinois. The lake consists of three long, narrow arms with highly irregular shorelines (Fig. 1). The middle arm of the lake receives the heated discharge from Kincaid Generating Station, a 1,232-megawatt coal-fired generating facility of Commonwealth Edison Company. Water temperatures in the discharge canal are generally 7°–9°C above those in the other arms. A more complete description of Kincaid Generating Station and of the physical and chemical characteristics of Lake Sangchris is given by Larimore & Tranquilli (1981).

METHODS

The survey technique employed was a modification of the methods outlined by Starrett et al. (1963). It consisted of three parts: fast counts, fisherman contacts, and data compilation. Fast counts entail-

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ed cruising a lake area by boat at high speed while counting boat and shore fishermen. The clerk worked a total of about 270, 8-hour days in the 1973–1974 period by working 6 days followed by 2 days off. During the 1974–1975 period the clerk worked 4 days and then was off for 4 consecutive days. Schedules were designed to divide counts in each area equally among days of the week and hours of the day in each 3-month creel period. The months were grouped for seasonal summaries so that December, January, and February represented winter; March, April, and May represented spring; June, July, and August represented summer; and September, October, and November represented autumn. The logic and acceptability of such seasonal divisions is supported by the findings of Malvestuto et al. (1978).

Fisherman contacts included interviews with the fishermen and examinations of their catches. During each interview the creel clerk recorded the type of fishing, the principal species sought, the distance traveled to the lake, as well as background data detailing date and location in the lake. The catch was examined and the number and (in 1974 only) total weight of each species were reported. The data were processed on an IBM 360/75 computer using SAS 76.5 procedures (Barr et al. 1976). Seasonal summaries were produced.

Fishing effort in the seasonal summaries was calculated entirely from fast counts. The predicted fishing effort in man-hours was defined as the average number of fishermen in each hourly count in a particular category multiplied by the number of fishable hours per day, then multiplied by the number of days in a particular month. Fishable hours used in this study were 12 h/day during spring, 15 h/day during summer, 12 h/day during autumn, and 9 h/day during winter. The result was a compilation of fishing

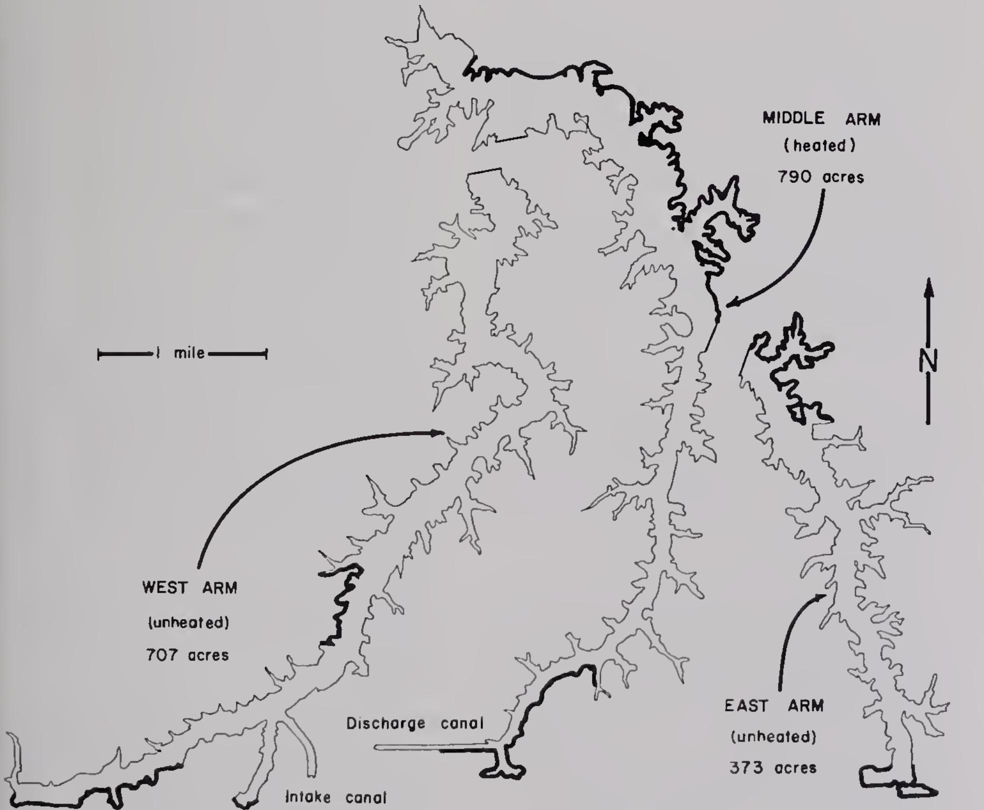

Fig. 1.—The three creel areas of Lake Sangchris, with accessible shorelines indicated by heavy lines.

Taylorville Bass Club member with the day's catch of largemouth bass from Lake Sangchris.

effort in each lake area by fishing type (boat or shore fishing) for each 3-month season. Each creel period, 1973–1975, was defined as extending from 15 April of one year to 15 April of the next. Bass tournament fishing efforts were handled somewhat differently, since the tournaments were closely controlled by the sponsoring bass clubs. Those efforts were calculated from observations of the tournament conclusion (weigh-in) by the creel clerk. Since the various sections of Lake Sangchris have different areas, the effort per unit area (man-hours/acre) was determined for each area, fishing type, and season. All data are presented in English units to facilitate comparisons with other published data, which have been customarily expressed in such units.

Projected catch data were calculated by multiplying the actual catch data by an expansion factor individually calculated for boat and shore fishermen from each area in each creel period. The expansion factors used in this study were calculated by dividing the projected fishing effort in a particular category by the effort (man-hours) expended by contacted fishermen in that category. Bass tournament data were usually complete, since the fishermen were censused at the required tournament check-in. Catch rates (fish/h) were determined by dividing the catch by the effort. Catch per unit area (fish/acre) was used for the comparison of harvests from the three arms of Lake Sangchris and with data from other lakes.

The species sought by fishermen were determined during the interview period. Those people who were not trying to catch a particular species were included in a "no preference" category. Predicted effort expended on each species in each arm by boat and shore fishermen was calculated by multiplying the effort of interviewed fishermen by the expansion factor.

Several frequency distributions of fishing party contacts were also created. These included separation by distance traveled to the lake, time of day, and habitat fished.

The three arms of Lake Sangchris were surveyed as if they were separate bodies of water (Fig. 1). The middle arm of the lake from the power plant discharge to the dam area was considered the heated area. It had a surface area of

790 acres. The west and east arms, which have areas of 707 and 373 acres, respectively, were designated unheated areas. Both unheated areas had similar temperature regimes and were only slightly influenced by the heated discharge.

RESULTS AND DISCUSSION

FISHING EFFORT

Since this study was based on a creel survey rather than a complete census, many fishermen were neither contacted nor counted on the lake. An estimate of the effectiveness of the methods used and, consequently, an evaluation of the reliability of the projected data, were made by determining what portion of the projected total effort was expended by fishermen actually contacted by the creel clerk. The contact ratio, or percentage contacted, varied between seasons, areas, and fishing types (Table 1).

The possibility of contacting a particular fisherman is proportional to the length of his stay on the lake and the amount of time available for the creel clerk to contact fishermen. It is inversely proportional to the total number of fishermen on the lake at one time. These generalizations apply within certain limits. Since shore fishing trips are usually shorter than boat trips, the contact ratio for shore fishermen is usually lower (5–56 percent; mean = 12.8 percent) than for boat fishermen (10–83 percent; mean = 29.4 percent). The highest contact ratios occurred during winter and early spring, the periods of lowest use, and the lowest ratios occurred during late spring and summer, the periods of highest use. The usage and contact ratios measured during the autumn periods were intermediate. The contacts in all arms of the lake varied similarly within seasons.

Between 15 April 1973 and 15 April 1974, an estimated 191,680 man-hours were spent fishing at Lake Sangchris. In the 1974–1975 creel period, 147,524 man-hours were spent there. More than 46 percent (88,903 man-hours) of the 1973–1974 total was expended during the summer months of June, July, and August. Similarly, a total of 70,597 man-hours (47.9 percent) was estimated for the summer of 1974. Such a seasonal use pattern (Fig. 2) is typical for midwestern lakes (Kathrein 1953, Snow 1971). The annual fishing pressure of about 93 man-hours per acre is higher than the range reported for reservoirs of similar size (Kathrein 1953, Rawstron & Hashagen 1972) and higher than values reported for Thomas Hill Reservoir (7.0–28.4 man-hours/acre), another heated midwestern reservoir (Hanson 1974). It is similar to the effort recorded for lakes of less than 500 acres (Snow 1971, Mraz & Threinen 1957).

Most of the fishing pressure was concentrated in the heated area of the lake, the middle arm, during all seasons (Fig. 2). In fact, 58.4 percent of the fishing effort during the 1973–1975 creel period was expended in the middle arm, which comprises only 42.2 percent of the area. Hanson (1974) observed similar use patterns in Thomas Hill Reservoir, a cooling lake in Missouri. During winter, early spring, and late autumn fishermen were attracted to the heated areas of the lake because the higher temperatures were expected to keep fish active and feeding. During the summer, anglers seemed to be drawn to the discharge arm merely because it was the single unusual character of the lake. The use rate of the northern half of the middle arm was increased by shore fishermen, who used it heavily, owing to the large amount of accessible shoreline in that lake area (Fig. 1).

Fisherman use varied daily and seasonally. During spring, summer, and autumn, people fished the lake at relatively even levels of effort between 0800 and 1900 hours. (Fig. 3). Fishing was concentrated during the warmest part of the day in winter. Most fishing occurred at Lake Sangchris in May, June, and July in the 1974–1975 period (Fig.4). The lowest monthly totals occurred during December and January. Monthly data breakdowns were not available for the 1973–1974 period.

The distance traveled by fishermen to use Lake Sangchris was documented in an effort to produce an economic evaluation of the resource by a method similar

Table 1.—Seasonal summary, by types of fishing, fishing effort (man-hours and man-hours/acre) and percentage of fishermen contacted for the three creel areas at Lake Sangchris during the 1973–1975 creel period.

		Control Arm			Discharge Arm			Intake Arm		
Creel Period	Fishing Type	Man-hours	Man-hours per acre	% Contacted	Man-hours	Man-hours per acre	% Contacted	Man-hours	Man-hours per acre	% Contacted
Spring 1973	Boat	2,227	5.97	17	5,900	8.35	12	2,194	2.78	13
	Shore	2,969	7.96	14	11,742	1.66	7	2,326	2.94	8
	Combined	5,196	13.93	15	17,642	24.95	9	4,520	5.72	10
Summer	Boat	6,932	18.58	15	14,667	20.75	10	12,274	15.54	12
	Shore	13,329	35.73	7	33,890	47.93	8	7,811	9.89	6
	Combined	20,261	54.32	10	48,557	68.68	8	20,085	25.42	10
Autumn	Boat	3,661	9.82	19	6,903	9.76	18	4,760	6.03	17
	Shore	5,417	14.52	8	10,239	14.48	9	2,858	3.62	8
	Combined	9,078	24.34	13	17,142	24.25	13	7,618	9.64	14
Winter	Boat	312	0.84	70	2,992	4.23	70	137	0.17	31
	Shore	135	0.36	56	1,358	1.92	42	50	0.06	30
	Combined	447	1.20	66	4,350	6.15	61	187	0.24	31
Spring 1974	Boat	6,417	17.20	15	15,559	22.01	12	9,081	11.49	10
	Shore	7,077	18.97	9	29,571	41.83	5	6,088	7.71	6
	Combined	13,494	36.18	12	45,130	63.83	8	15,169	19.20	8
Summer	Boat	5,821	15.61	46	11,010	15.57	20	11,519	14.58	23
	Shore	6,195	16.61	12	27,057	38.27	8	8,995	11.39	7
	Combined	12,016	32.21	28	38,067	53.84	11	20,514	25.97	16
Autumn	Boat	1,875	5.03	35	7,151	10.11	24	3,339	4.23	20
	Shore	2,309	6.19	8	10,257	14.51	7	2,122	2.67	6
	Combined	4,184	11.22	20	17,408	24.62	14	5,461	6.91	14
Winter	Boat	0	0.0	0	1,523	2.15	29	0	0.0	0
	Shore	0	0.0	0	382	0.54	11	0	0.0	0
	Combined	0	0.0	0	1,905	2.69	26	0	0.0	0
Spring 1975	Boat	690	1.84	83	3,662	5.18	33	967	1.22	67
	Shore	825	2.21	25	4,496	6.36	16	732	0.93	21
	Combined	1,515	4.06	52	8,158	11.54	24	1,699	2.15	47

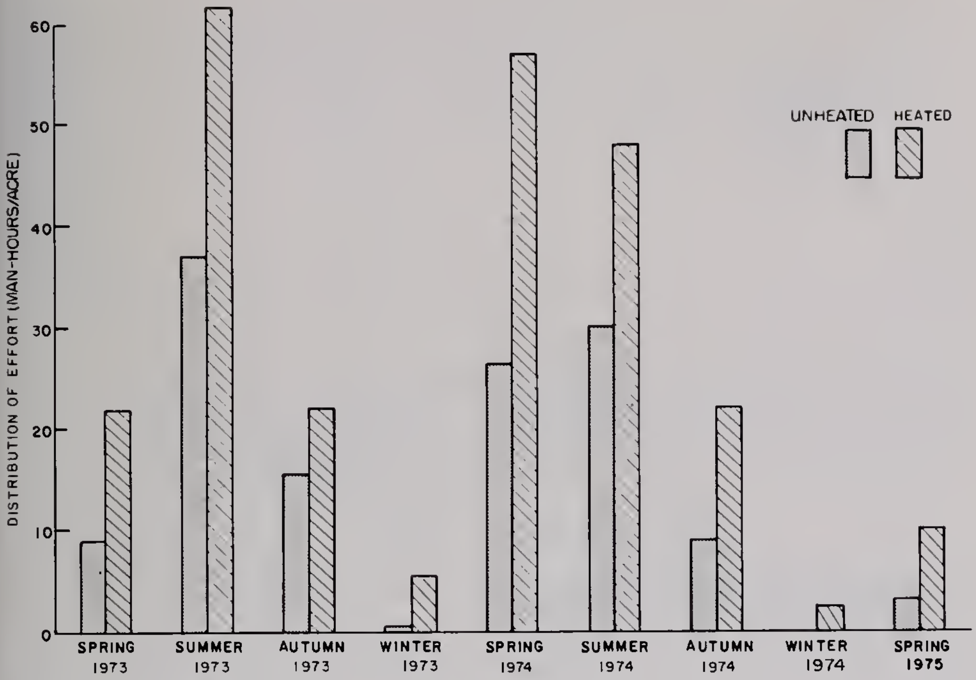

Fig. 2.—Seasonal distribution of fishing effort (man hours/acre) between unheated and heated areas of Lake Sangchris for the 1973–1975 creel period.

to that employed by Gordon et al. (1973). Because the vast majority of people fishing the lake lived within the nearest zone of record, such a graphical assessment was mathematically impossible. Between 66 and 79 percent of fishermen contacted each season lived less than 25 miles from Lake Sangchris (Table 2). Only 6–12 percent (mean = 9.4 percent) traveled 50 miles or more to the lake during spring, summer, and autumn. During winter, 23 percent of the fishermen were from 50 or more miles distant, indicating the attractiveness of the winter fishery. Many of those were bass club fishermen from Champaign, Peoria, Bloomington (75–99 miles distant), and Decatur (25–49 miles).

Data from interviews with fishermen were used to describe the fisherman population. The age composition of the fishing population remained relatively unchanged throughout the year (Table 3). The minor differences apparent in the winter were probably due to the occurrence, in that small sample, of bass club fishermen, generally middle-aged males. Most fishermen were males (78–96 percent). The lowest percentage of fishing females occurred in winter and the highest occurred in summer.

Most of the fishing effort at Lake Sangchris during the creel period was expended in search of largemouth bass and channel catfish (Table 4). The annual effort from June 1973 to June 1974 was 56,476 hours seeking largemouth bass and 19,134 hours for channel catfish. During that period the total time spent on the next four most desirable species (white bass, carp, white crappie, and bluegill) was only 25,700 hours. For each species, the fishing effort was distributed differently between lake areas and seasons.

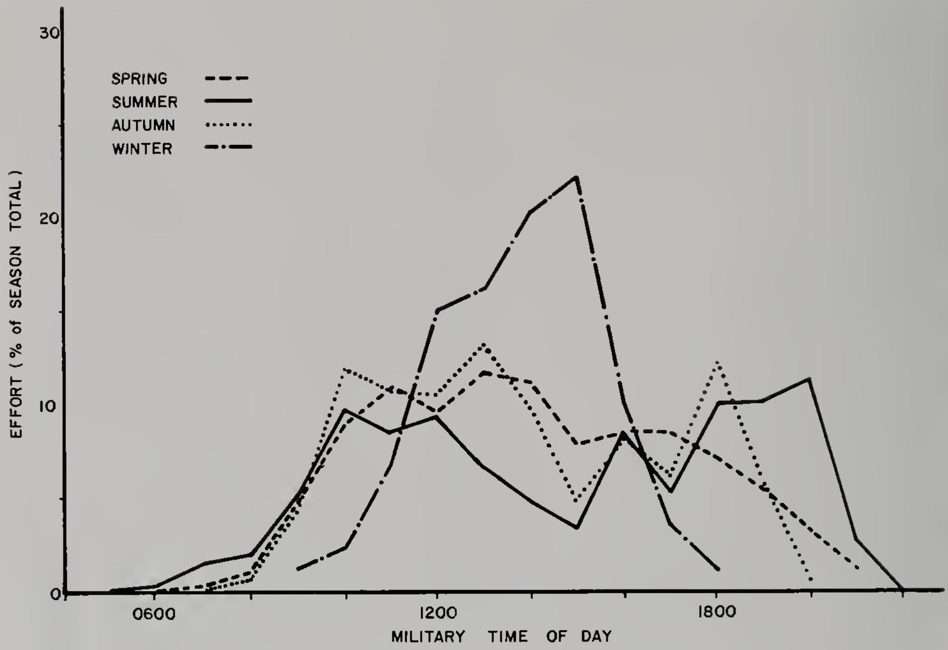

Fig. 3.—Hourly distribution of seasonal fishing effort (percentage of season total) for the 1973–1975 creel period.

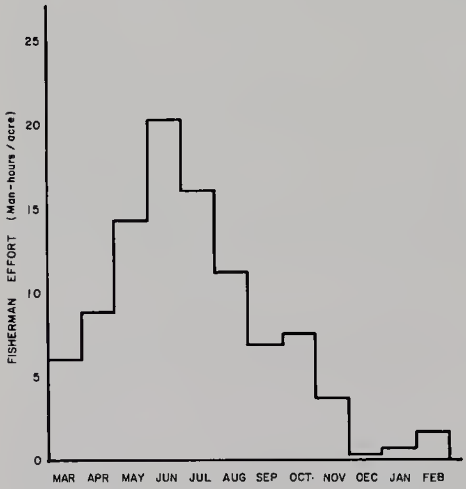

Fig. 4.—Monthly distribution of fishing effort (man-hours/acre) from March 1974 through February 1975.

Largemouth bass angling was concentrated in the spring and summer months. During the summer, it was relatively well distributed over the lake in effort per acre (Table 4). Largemouth bass fishing effort was clearly concentrated in the heated area of the lake during autumn, winter, and spring. Channel catfish effort was greatest during the summer (approximately 57 percent). Catfish angling was consistently highest in the heated area during all seasons except summer 1974. Most white bass fishing was associated with spawning activities in the heated discharge during the late winter and early spring. Carp fishing was most popular during the summer and was usually associated with the heated area of the lake. The angling effort associated with the white crappie was relatively strong, especially during the spring. This effort was probably the result of the reputation of Lake Sangchris as a good crappie lake. The crappie population was actually low at the time, consisting of about 1 percent of the total fish stock (Tranquilli et al. 1981). Although bluegill are usually a popular sport fish in midwestern reservoirs, bluegill fishing was unpopular at Lake Sangchris because the population was dominated by stunted and small individuals (Tranquilli et al. 1981) that were not desirable to most fishermen.

CATCH

Only 11 of the more than 20 fish species in Lake Sangchris were caught by sport fishermen in significant numbers

Table 2.—Seasonal summary of the distance traveled by fishermen to Lake Sangchris (percentage of season total) for the 1973–1975 creel period.

Distance in Miles	Spring 1973	Summer 1973	Autumn 1973	Winter 1973	Spring 1974	Summer 1974
< 25	66	77	79	66	73	79
25– 49	25	12	9	11	18	15
50– 74	2	2	2	3	2	1
75– 99	3	5	7	18	3	4
100–124	1	--[a]	--	1	1	--
125–149	--	--	--	--	0	0
>150	3	4	3	1	3	1

[a] Dashes indicate less than 1 percent.

during the 1973–1975 creel period. Six species comprised about 78 percent of the number of fish and 91 percent of the biomass captured annually by fishermen. These six species (largemouth bass, channel catfish, white bass, carp, white crappie, and bluegill) were considered the principal sport species in Lake Sangchris during the creel period.

Annual fish harvest figures were predicted by compiling the seasonal data from April 1973 through April 1975 for number and weight caught for each species (Tables 5 and 6). The numbers of fish harvested annually (41.79 and 30.21 per acre in 1973–1974 and 1974–1975, respectively) were similar to data for unheated Clearwater Lake (Kathrein 1953) and heated Thomas Hill Reservoir (Hanson 1974), Missouri lakes similar in size to Lake Sangchris. The biomasses harvested from Lake Sangchris in 1974 and 1975 (Tables 5 and 6) were similar to that reported by Hanson (1974) for Thomas Hill Reservoir.

Discussions of the projected harvest of each of the six principal sport species follow. Catch rates and harvest data were analyzed for each species by area and season.

Largemouth Bass

The projected harvest of largemouth bass by number and weight is presented in Table 7. Most of the catch came from the relatively large unheated areas of the lake. The harvest per unit area was, however, usually higher in the heated area during all seasons except summer. During the summer periods the catch was depressed in the discharge area, probably because largemouth bass avoided the heated water at that time (Tranquilli et al. 1981). The catch per area was higher in the heated area than it was in the unheated areas during autumn, winter, and spring, probably because higher water temperatures promoted active feeding for a longer period than in unheated areas. Although definitely a

Table 3.—Composition of the 1973 Lake Sangchris fishing population by age groups (percentage of total).

Age	Spring	Summer	Autumn	Winter	Entire Year
< 10	5	9	3	2	6
11–20	14	16	7	4	12
21–30	19	17	15	19	17
31–40	19	18	19	33	20
41–50	16	14	18	15	16
51–60	13	14	19	13	13
61–70	12	10	16	14	12
71–80	2	2	3	--[a]	2
81–90	--	--	--	--	--
>· 90	--	0	0	0	--
Sample Size	2,386	3,327	1,707	891	8.311

[a] Dashes indicate less than 1 percent

Table 4.—Seasonal distribution of fishing effort in man-hours and effort per acre, according to species caught, for heated and unheated arms of Lake Sangchris, spring 1973 through summer 1974.

		Spring 1973		Summer 1973		Autumn 1973		Winter 1973		Spring 1974		Summer 1974	
Species	Lake Arm	Total Effort	Effort per Acre	Total Effort	Effort per Acre	Total Effort	Effort per Acre	Total Effort	Effort per Acre	Total Effort	Effort per Acre	Total Effort	Effort per Acre
Largemouth bass	Heated	3,916	4.9570	7,940	10.0505	5,450	6.6449	2,118	2.6814	12,494	15.8146	8,031	10.1653
	Unheated	3,206	2.9681	13,820	12.7971	5,786	5.3572	186	0.1724	8,682	8.0391	9,125	8.4493
	Total	7,122	3.8086	21,760	11.6364	11,236	6.0086	2,304	1.2321	21,176	11.3241	17,156	9.1743
Channel catfish	Heated	1,668	2.1108	6,001	7.5968	1,622	2.0537	855	1.0817	1,940	2.4555	2,484	3.1447
	Unheated	341	0.3145	4,825	4.4677	1,705	1.5785	84	0.0778	2,102	1.9468	6,472	5.9930
	Total	2,009	1.0743	10,826	5.7893	3,327	1.7791	939	0.5021	4,042	2.1615	8,956	4.7893
White bass	Heated	0	0.0	13	0.0168	0	0.0	36	0.0458	0	0.0	30	0.0377
	Unheated	4	0.0034	0	0.0	0	0.0	6	0.0056	62	0.0577	0	0.0
	Total	4	0.0021	13	0.0070	0	0.0	42	0.0225	62	0.0332	30	0.0160
Carp	Heated	1,145	1.4494	4,534	0.0526	681	0.8626	129	0.1632	3,908	4.9472	3,359	4.2519
	Unheated	233	0.2156	1,377	1.2754	422	0.3904	0	0.0	910	0.8428	1,754	1.6244
	Total	1,378	0.7369	5,911	3.1610	1,103	0.5898	129	0.0690	4,818	2.5765	5,113	2.7342
Crappie	Heated	1,832	2.3184	702	0.8887	1,388	1.7569	448	0.5672	5,421	6.8614	209	0.2646
	Unheated	1,042	0.9644	756	0.7002	1,289	1.1939	587	0.5433	2,816	2.6074	375	0.3472
	Total	2,874	1.5369	1,458	0.7797	2,677	1.4316	1,035	0.5535	8,237	4.4048	584	0.3123
Bluegill	Heated	8	0.0101	83	0.1051	0	0.0	0	0.0	0	0.0	0	0.0
	Unheated	6	0.0058	132	0.1222	0	0.0	0	0.0	0	0.0	0	0.0
	Total	14	0.0075	215	0.1150	0	0.0	0	0.0	0	0.0	0	0.0

Table 5.—Predicted annual fish harvest data for Lake Sangchris for the 1973–1974 creel period (15 April 1973–15 April 1974).

Species	Number of Fish	Biomass of Fish in Pounds[a]	Number per Acre	Biomass per Acre	Number per Hour Fished	Biomass per Hour Fished
Carp	5,521	13,434	2.95	7.18	0.029	0.070
Channel catfish	10,702	5,689	5.72	3.04	0.056	0.030
Black bullhead	14,315	3,748	7.66	2.00	0.075	0.020
Yellow bullhead	0	0	0.0	0.0	0.0	0.0
White bass	2,048	1,274	1.10	0.68	0.011	0.007
Yellow bass	2,119	506	1.13	0.27	0.011	0.003
Bluegill	20,873	2,415	11.16	1.29	0.109	0.013
Green sunfish	1,076	148	0.58	0.08	0.006	0.001
Largemouth bass	15,039	22,430	8.04	11.99	0.078	0.117
White crappie	6,405	2,616	3.43	1.40	0.033	0.014
Freshwater drum	49	21	0.03	0.01	0.001	0.001
Total	*78,147*	*52,281*	*41.79*	*27.96*	*0.408*	*0.273*

[a] Calculated from average fish weights measured during the 1974–1975 creel period.

function of the distribution of fishing effort, the catch data did not fully parallel that effort.

The annual harvests of largemouth bass from Lake Sangchris in 1973 and 1974 (8.04 and 3.92 fish per acre) were comparable with those of Thomas Hill Reservoir (0.80–7.45; mean = 3.48 fish per acre) as reported by Hanson (1974) for 1968 through 1971. The harvest per unit area of large impoundments is generally much lower than the values for the small lakes. Values for Barren Reservoir (a 10,000-acre Kentucky lake) were 1.83 and 1.34 fish per acre during the first 2 years of impoundment (Carter 1969) and for Lake Shelbyville, an 11,100-acre impoundment 45 miles east of Lake Sangchris, the values for largemouth bass in 1976 and 1977 were only 0.31 and 0.26 fish per acre in the summer period (McNurney 1978).

The highest catches (numbers and biomass) of largemouth bass were consistently associated with boat fishermen in autumn, winter, and spring. The harvest by shore fishermen only approached the catch by boat fishermen during the summer periods. Bass tournament fishermen caught 6.7 percent of the number of largemouth bass caught.

The general catch rates for largemouth bass from various areas of Lake Sangchris were calculated by dividing catch by total effort (Fig. 5). The harvest rate generally decreased between 1973 and 1975. Catch rates were generally highest in the heated area in autumn and winter and highest in the unheated areas in spring and summer.

Channel Catfish

Channel catfish harvest figures, both number and biomass data, are presented in Table 8. Most of the catfish were caught in the summer seasons. The harvests were generally correlated with relative water temperature. For each area, the catches were best in the warm

Table 6.—Predicted annual fish harvest data for Lake Sangchris for the 1974–1975 creel period (15 April 1974–15 April 1975).

Species	Number of Fish	Biomass of Fish in Pounds[a]	Number per Acre	Biomass per Acre	Number per Hour Fished	Biomass per Hour Fished
Carp	3,763	9,156	2.01	4.90	0.026	0.062
Channel catfish	9,917	5,272	5.30	2.82	0.067	0.036
Black bullhead	7,434	1,875	3.98	1.00	0.050	0.013
Yellow bullhead	1,737	526	0.93	0.28	0.012	0.004
White bass	3,253	2,023	1.74	1.08	0.022	0.014
Yellow bass	1,520	363	0.81	0.19	0.010	0.002
Bluegill	14,752	1,707	7.89	0.91	0.100	0.012
Green sunfish	1,387	191	0.74	0.10	0.009	0.001
Largemouth bass	7,329	10,931	3.92	5.85	0.050	0.074
White crappie	5,145	2,101	2.75	1.12	0.035	0.014
Freshwater drum	261	113	0.14	0.06	0.002	0.001
Total	*56,498*	*34,258*	*30.21*	*18.32*	*0.383*	*0.232*

[a]Calculated from average fish weights measured during the 1974–1975 creel period.

seasons, spring and summer. During each season, the greatest harvest (numbers and biomass per unit area) was always in the heated area, and that catch was considerably better than in the unheated area.

Most of the channel catfish were caught by shore fishermen except during spring and summer of 1974, when catches by boat fishermen were slightly higher. In the unheated areas, where shore accessibility was low, shore fisherman caught less than 50 percent of the catfish. In the heated area, where much of the shoreline was accessible, shore fishermen accounted for 63 percent of the catch of catfish.

The annual harvest of channel catfish during the 1973–1975 creel period (5.72 and 5.30 fish per acre) was quite high in comparison with data from other lakes. Hanson (1974) reported 0.02–0.71 fish per acre in Thomas Hill Reservoir, a Missouri cooling lake. Carter (1969) calculated that the total catfish harvest from Barren Reservoir in Kentucky was 0.03–0.04 fish per acre, while McNurney (1978) reported 0.29 and 0.30 fish per acre for summer fishing only in Lake Shelbyville during 1976 and 1977. The abundance of catfish in Lake Sangchris was apparently due to the unusually successful spawning of channel catfish, attributed to the riverlike conditions prevalent as a result of the circulation of water through the power plant (Tranquilli et al. 1981).

The overall catch rates of channel catfish from this creel study at Lake Sangchris (harvest/total effort) are presented in Fig. 6. The catch rates have generally increased since 1973 in the area of the lake most influenced by the power plant discharge. Catch rates in the unheated areas have declined slightly. The catch rate in the discharge area was almost always (except spring 1974) higher than it was in the unheated areas.

White Bass

White bass harvests for various combinations of lake area, season, and fishing type are indicated in Table 9. The harvest was generally low and variable. Since white bass had only been introduced into Lake Sangchris in 1971, a consistent sport fishery had not yet developed. More white bass were caught in the heated area (68 percent of the total biomass) than in the unheated area. Summer harvests of white bass in 1973 and 1974 (0.32 and 0.13 fish per acre)

Table 7.—Projected harvest (number and biomass) of largemouth bass from unheated and heated areas of Lake Sangchris from April 1973 to April 1975 for boat and shore fishing. The biomass data for 1973 were calculated from average weight measured in 1974.

		Unheated Area				Heated Area			
Creel Period	Fishing Type	Number	Pounds	Fish per Acre	Pounds per Acre	Number	Pounds	Fish per Acre	Pounds per Acre
Spring 1973	Boat	891	1,319	0.8250	1.2213	684	1,012	0.8658	1.2810
	Shore	206	305	0.1907	0.2824	768	1,137	0.9722	1.4392
	Combined	1,097	1,624	1.0157	1.5037	1,452	2,149	1.8380	2.7202
Summer	Boat	2,969	4,394	2.7491	4.0685	1,546	2,288	1.9570	2.8962
	Shore	1,026	1,518	0.9500	1.4056	1,038	1,536	1.3139	1.9443
	Combined	3,995	5,912	3.6991	5.4741	2,584	3,824	3.2709	4.8405
Autumn	Boat	1,054	1,560	0.9759	1.4444	1,131	1,674	1.4316	2.1190
	Shore	336	497	0.3111	0.4609	605	895	0.7658	1.1329
	Combined	1,390	2,057	1.2870	1.9053	1,736	2,569	2.1974	3.2519
Winter	Boat	17	25	0.0157	0.0231	208	308	0.2633	0.3899
	Shore	0	0	0.0	0.0	10	15	0.0127	0.0190
	Combined	17	25	0.0157	0.0231	218	323	0.2760	0.4089
Spring 1974	Boat	1,962	2,904	1.8167	2.6889	825	1,221	1.0443	1.5456
	Shore	488	722	0.4519	0.6685	1,321	1,955	1.6722	2.4747
	Combined	2,450	3,626	2.2686	3.3574	2,146	3,176	2.7165	4.0203
Summer	Boat	1,533	2,269	1.4194	2.1009	876	1,296	1.1089	1.6405
	Shore	176	260	0.1630	0.2407	260	385	0.3291	0.4873
	Combined	1,709	2,529	1.5824	2.3416	1,136	1,581	1.4380	2.1278
Autumn	Boat	424	628	0.3926	0.5815	714	1,057	0.9038	1.3380
	Shore	85	126	0.0787	0.1167	176	260	0.2228	0.3291
	Combined	509	754	0.4713	0.6982	890	1,317	1.1266	1.6671
Winter	Boat	0	0	0.0	0.0	27	40	0.0342	0.0506
	Shore	0	0	0.0	0.0	0	0	0.0	0.0
	Combined	0	0	0.0	0.0	27	40	0.0342	0.0506
Spring 1975	Boat	179	265	0.1657	0.2454	41	61	0.0519	0.0772
	Shore	64	43	0.0593	0.0398	52	77	0.0658	0.0975
	Combined	243	308	0.2250	0.2752	93	138	0.1177	0.1747

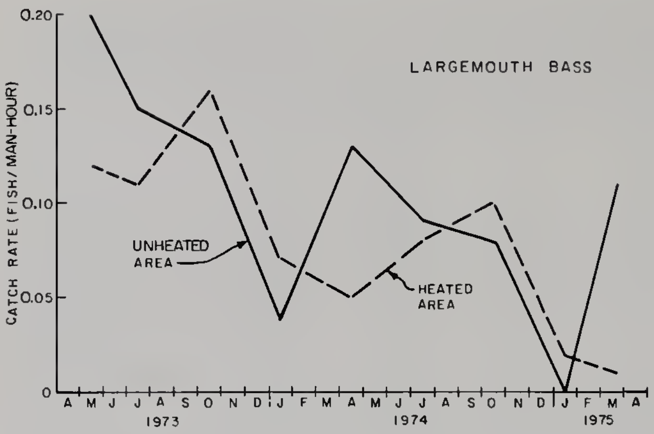

Fig. 5.—Total catch rates of largemouth bass at Lake Sangchris for unheated and heated areas from April 1973 through April 1975.

were somewhat lower than rates reported for Lake Shelbyville, a lake of much larger size (McNurney 1978).

Catch rates for white bass (fish per man-hour) were high in cold months and low in warm periods (Fig. 7). The highest catch rates occurred in the heated area of the lake. Catch rates improved at Lake Sangchris during 1976 and 1977 as the angling population became more accustomed to fishing for this recently introduced species (McNurney & Frakes 1979).

Carp

The number and biomass of carp harvested in various areas of Lake Sangchris between 15 April 1973 and 15 April 1975 are compiled in Table 10. In winter, carp were caught only in the heated area during 1973. Throughout the year the harvest in the heated area was consistently higher than that in the unheated areas. Since most carp were caught by shore fishermen, the reduced harvest in the unheated areas may be correlated to the minimal amount of shoreline accessible to anglers there. The annual harvests of 2.95 and 2.01 fish per acre in 1973 and 1974, respectively, were comparable to the 2.67 fish per acre reported for Thomas Hill Reservoir (Hanson 1974). Summer harvest values for the unheated areas of Lake Sangchris were 0.67 and 0.55 fish per acre for 1973 and 1974, respectively. McNurney (1978) reported summer harvests for Lake Shelbyville of 0.17 and 0.30 fish per acre in 1976 and 1977. Summer harvests of carp from the heated area of Lake

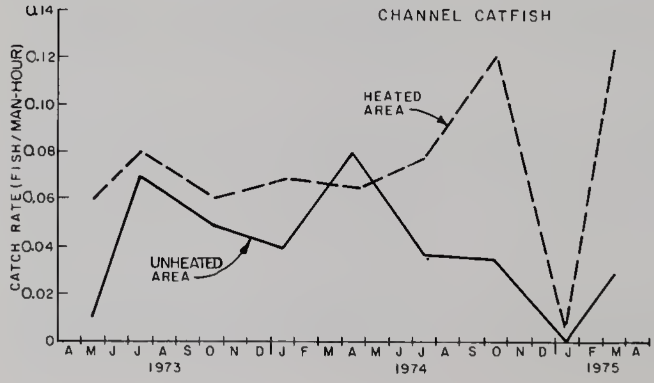

Fig. 6.—Total catch rates of channel catfish at Lake Sangchris for unheated and heated areas from April 1973 through April 1975.

Table 8.—Projected harvest (number and biomass) of channel catfish from unheated and heated areas of Lake Sangchris from April 1973 to April 1975 for boat and shore fishing. The biomass data for 1973 were calculated from average weight measured in 1974.

		Unheated Area				Heated Area			
Creel Period	Fishing Type	Number	Pounds	Fish per Acre	Pounds per Acre	Number	Pounds	Fish per Acre	Pounds per Acre
Spring 1973	Boat	56	30	0.0519	0.0278	301	160	0.3810	0.2025
	Shore	67	35	0.0620	0.0324	670	355	0.8481	0.4494
	Combined	123	65	0.1139	0.0602	971	515	1.2291	0.6519
Summer	Boat	800	424	0.7407	0.3926	893	473	1.1304	0.5987
	Shore	1,870	991	1.7315	0.9176	2,834	1,502	3.5873	1.9013
	Combined	2,670	1,415	2.4722	1.3102	3,727	1,975	4.7177	2.5000
Autumn	Boat	397	210	0.3676	0.1944	413	219	0.5228	0.2772
	Shore	394	209	0.3648	0.1935	594	315	0.7519	0.3987
	Combined	791	419	0.7234	0.3879	1,007	534	1.2747	0.6759
Winter	Boat	3	2	0.0028	0.0019	128	68	0.1620	0.0861
	Shore	13	7	0.0120	0.0065	175	93	0.2215	0.1177
	Combined	16	9	0.0148	0.0084	303	161	0.3835	0.2038
Spring 1974	Boat	1,638	868	1.5167	0.8037	1,054	559	1.3342	0.7076
	Shore	753	399	0.6972	0.3694	1,888	1,001	2.3899	1.2671
	Combined	2,391	1,267	2.2139	1.1731	2,942	1,560	3.7241	1.9747
Summer	Boat	702	372	0.6500	0.3444	1,405	745	1.7785	0.9430
	Shore	487	258	0.4509	0.2389	1,564	829	1.9797	1.0494
	Combined	1,189	630	1.1009	0.5833	2,969	1,574	2.7482	1.9924
Autumn	Boat	183	97	0.1694	0.0898	907	481	1.1481	0.6089
	Shore	151	80	0.1398	0.0741	1,231	652	1.5582	0.8253
	Combined	334	177	0.3092	0.1639	2,138	1,133	2.7063	1.4342
Winter	Boat	0	0	0.0	0.0	3	2	0.0038	0.0025
	Shore	0	0	0.0	0.0	9	5	0.0114	0.0063
	Combined	0	0	0.0	0.0	12	7	0.0152	0.0088
Spring 1975	Boat	55	29	0.0509	0.0269	535	284	0.6772	0.3595
	Shore	40	21	0.0370	0.0194	478	253	0.6051	0.3203
	Combined	95	50	0.0879	0.0463	1,013	537	1.2823	0.6798

Table 9.—Projected harvest (number and biomass) of white bass from unheated and heated areas of Lake Sangchris from April 1973 to April 1975 for boat and shore fishing. The biomass data for 1973 were calculated from average weight measured in 1974.

Creel Period	Fishing Type	Unheated Area				Heated Area			
		Number	Pounds	Fish per Acre	Pounds per Acre	Number	Pounds	Fish per Acre	Pounds per Acre
Spring 1973	Boat	10	6	0.0093	0.0056	49	30	0.0620	0.0380
	Shore	51	32	0.0472	0.0296	173	107	0.2190	0.1354
	Combined	61	38	0.0565	0.0252	222	137	0.2810	0.1734
Summer	Boat	344	213	0.3185	0.1972	31	19	0.0392	0.0241
	Shore	125	78	0.1157	0.0722	106	66	0.1342	0.0835
	Combined	469	291	0.4342	0.2694	137	85	0.1734	0.1076
Autumn	Boat	108	67	0.1000	0.0620	113	70	0.1430	0.0886
	Shore	167	104	0.1546	0.0963	363	225	0.4595	0.2848
	Combined	275	171	0.2546	0.1583	476	295	0.6025	0.3734
Winter	Boat	10	6	0.0093	0.0056	83	51	0.1051	0.0646
	Shore	0	0	0.0	0.0	22	14	0.0278	0.0178
	Combined	10	6	0.0093	0.0056	105	65	0.1329	0.0824
Spring 1974	Boat	297	184	0.2750	0.1704	103	64	0.1304	0.0810
	Shore	57	35	0.0528	0.0324	173	107	0.2190	0.1354
	Combined	354	219	0.3278	0.2028	276	171	0.3494	0.2264
Summer	Boat	98	61	0.0907	0.0565	51	32	0.0646	0.0405
	Shore	0	0	0.0	0.0	86	53	0.1089	0.0671
	Combined	98	61	0.9097	0.0565	137	85	0.1735	0.1076
Autumn	Boat	18	11	0.0167	0.0102	43	27	0.0544	0.0342
	Shore	12	7	0.0111	0.0065	14	9	0.0177	0.0114
	Combined	30	18	0.0278	0.0167	57	36	0.0721	0.0456
Winter	Boat	0	0	0.0	0.0	190	118	0.2406	0.1494
	Shore	0	0	0.0	0.0	90	56	0.1139	0.0709
	Combined	0	0	0.0	0.0	280	174	0.3635	0.2203
Spring 1975	Boat	3	2	0.0028	0.0019	435	270	0.5506	0.3418
	Shore	0	0	0.0	0.0	643	399	0.8139	0.5051
	Combined	3	2	0.0028	0.0019	1,078	669	1.3745	0.8469

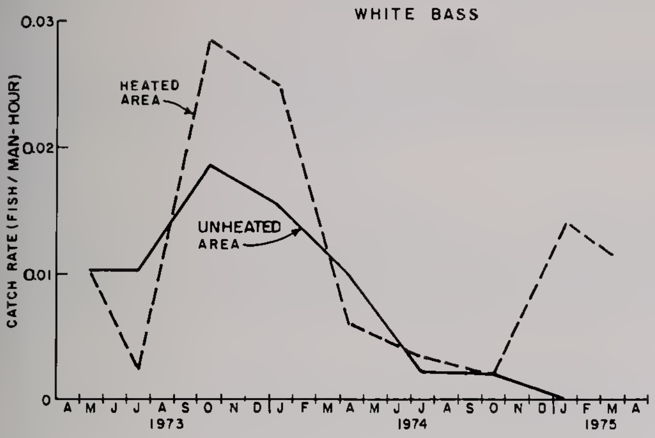

Fig. 7.—Total catch rates of white bass at Lake Sangchris for unheated and heated areas from April 1973 through April 1975.

Sangchris during the 1973–1975 creel period were much higher at 2.40 and 1.33 fish per acre.

Catch rates for carp were generally variable in 1973 and 1974 in the heated and unheated sections of Lake Sangchris (Fig. 8). They were highest in spring and summer and usually very low in winter. The catch rate in the heated area was consistently greater than or equal to the rate in the unheated area.

White Crappie

The sport fishing harvest projections for white crappie in various areas of Lake Sangchris are shown in Table 11. These data were included because crappie frequently constitute an important part of the sport fishery of a midwestern reservoir and because this species was apparently once an important game fish in Lake Sangchris.

In the 1973 and 1974 creel periods, respectively, 6,405 and 5,145 crappie were caught in Lake Sangchris (Tables 5 and 6). These figures correspond to harvest rates of 3.43 and 2.75 fish per acre, values comparable to the 2.53–4.57 fish per acre reported for Barren Reservoir, Kentucky (Carter 1969) and well below the 5-year mean for Thomas Hill Reservoir of 10.09 fish per acre (Hanson 1974). Crappie populations notoriously vary from year to year, as evidenced by the range of values from Thomas Hill Reservoir of 0.34–26.75 fish per acre in a 5-year period. The white crappie harvest at Lake Sangchris was well distributed between the heated and unheated areas in all seasons.

White crappie catch rates varied considerably between years, seasons, and areas (Fig. 9). No trends could be confidently identified because the occurrence of crappie catches was low and the sizes of those catches were highly variable.

Bluegill

Harvest projections for bluegill, a popular sport fish in many Illinois lakes, are described in Table 12 for various areas and seasons. The number harvested per acre (7.89–11.16) (Tables 5 and 6), was much higher than that recorded for Thomas Hill Reservoir (0–0.83 fish per acre with a mean of 0.26 fish per acre) by Hanson (1974) or for Lake Shelbyville (summer only, 0.35–0.50 fish per acre) by McNurney (1978). The catch at Lake Sangchris was, however, composed of small individuals (0.91–1.29 pounds per acre) (Tables 5 and 6) averaging less than 0.12 pound per fish. Most of the bluegill harvest was taken during the spring and summer months and was divided nearly equally between the heated and unheated

Table 10.—Projected harvest (number and biomass) of carp from unheated and heated areas of Lake Sangchris from April 1973 to April 1975 for boat and shore fishing. The biomass data for 1973 were calculated from average weight measured in 1974.

		Unheated Area				Heated Area			
Creel Period	Fishing Type	Number	Pounds	Fish per Acre	Pounds per Acre	Number	Pounds	Fish per Acre	Pounds per Acre
Spring 1973	Boat	10	25	0.0093	0.0231	191	472	0.2418	0.5975
	Shore	127	314	0.1176	0.2907	663	1,638	0.8392	2.0734
	Combined	137	339	0.1269	0.2905	854	2,110	1.0810	2.5709
Summer	Boat	194	479	0.1796	0.4437	218	538	0.2759	0.6810
	Shore	586	1,447	0.5426	1.3402	1,677	4,142	2.1228	5.2430
	Combined	726	1,793	0.6722	1.6604	1,895	4,680	2.3987	5.9240
Autumn	Boat	18	44	0.0167	0.0407	96	237	0.1215	0.3000
	Shore	92	227	0.0852	0.2102	352	869	0.4456	1.1000
	Combined	110	271	0.1019	0.2509	448	1,106	0.5671	1.4000
Winter	Boat	0	0	0.0	0.0	58	143	0.0734	0.1810
	Shore	0	0	0.0	0.0	96	237	0.1215	0.3000
	Combined	0	0	0.0	0.0	154	380	0.1949	0.4810
Spring 1974	Boat	193	477	0.1787	0.4139	191	472	0.2418	0.5975
	Shore	737	1,820	0.6824	1.6852	2,072	5,118	2.6228	6.4785
	Combined	930	2,297	0.8611	2.0991	2,263	5,690	2.8646	7.0760
Summer	Boat	50	124	0.0463	0.1148	81	200	0.1025	0.2532
	Shore	545	1,346	0.5046	1.2463	969	2,393	1.2266	3.0291
	Combined	595	1,470	0.5509	1.3611	1,050	2,593	1.3291	3.2823
Autumn	Boat	18	44	0.0167	0.0407	26	64	0.0329	0.0810
	Shore	42	104	0.0389	0.0963	337	832	0.4266	1.0532
	Combined	60	144	0.0556	0.1370	363	896	0.4595	1.1342
Winter	Boat	0	0	0.0	0.0	0	0	0.0	0.0
	Shore	0	0	0.0	0.0	0	0	0.0	0.0
	Combined	0	0	0.0	0.0	0	0	0.0	0.0
Spring 1975	Boat	2	5	0.0019	0.0046	98	242	0.1241	0.3063
	Shore	46	114	0.0426	0.1056	310	766	0.3924	0.9696
	Combined	48	119	0.0445	0.1102	408	1,008	0.5165	1.2759

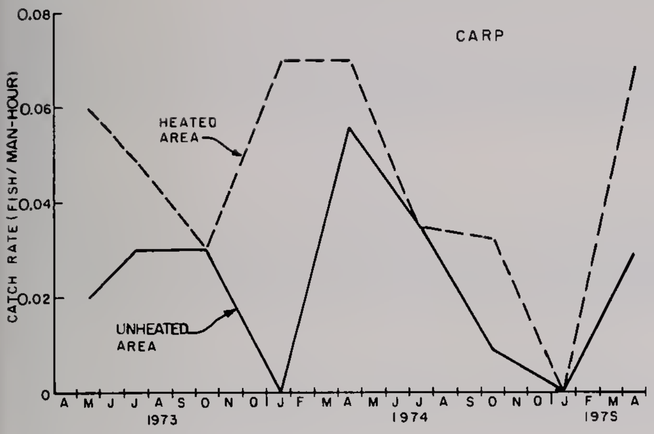

Fig. 8.—Total catch rates of carp at Lake Sangchris for unheated and heated areas from April 1973 through April 1975.

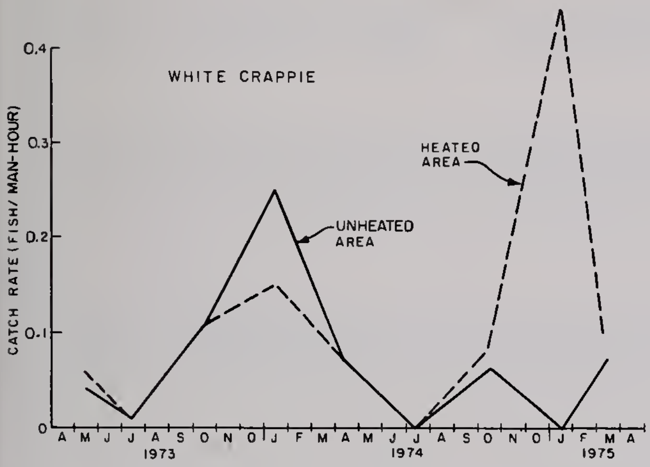

Fig. 9.—Total catch rates of white crappie at Lake Sangchris for unheated and heated areas from April 1973 through April 1975.

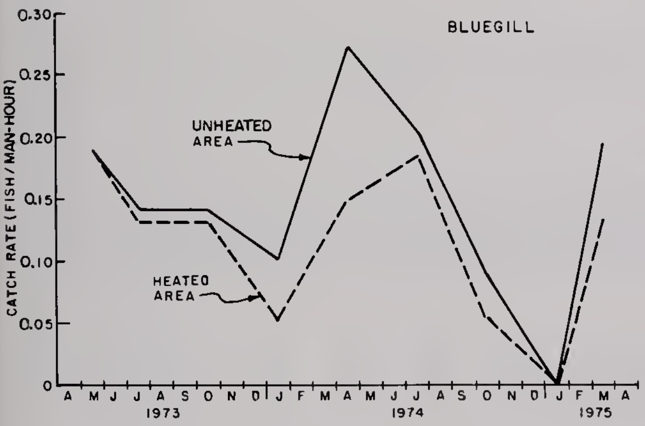

Fig. 10.—Total catch rates of bluegill at Lake Sangchris for unheated and heated areas from April 1973 through April 1975.

Table 11.—Projected harvest (number and biomass) of white crappie from unheated and heated areas of Lake Sangchris from April 1973 to April 1975 for boat and shore fishing. The biomass data for 1973 were calculated from average weight measured in 1974.

Creel Period	Fishing Type	Unheated Area				Heated Area			
		Number	Pounds	Fish per Acre	Pounds per Acre	Number	Pounds	Fish per Acre	Pounds per Acre
Spring 1973	Boat	158	65	0.1463	0.0602	362	148	0.4582	0.1873
	Shore	94	39	0.0870	0.0361	324	133	0.4101	0.1684
	Combined	252	104	0.2333	0.0963	686	281	0.8683	0.2557
Summer	Boat	186	76	0.1722	0.0704	218	89	0.2759	0.1127
	Shore	70	29	0.0648	0.0269	705	289	0.8924	0.3658
	Combined	256	105	0.2470	0.0973	923	278	1.1783	0.4785
Autumn	Boat	885	363	0.8194	0.3361	927	380	1.1734	0.4810
	Shore	589	241	0.5454	0.2231	440	180	0.5570	0.2278
	Combined	1,474	604	1.3648	0.5592	1,367	560	1.7304	0.7088
Winter	Boat	112	46	0.1037	0.0426	440	180	0.5570	0.2278
	Shore	17	7	0.0157	0.0065	12	5	0.0152	0.0063
	Combined	129	53	0.1194	0.0491	452	185	0.5722	0.2341
Spring 1974	Boat	1,083	444	1.0028	0.4111	1,156	474	1.4633	0.6000
	Shore	584	239	0.5407	0.2213	877	360	1.1101	0.4557
	Combined	1,667	683	1.5435	0.6324	2,033	830	2.5734	1.0557
Summer	Boat	9	4	0.0083	0.0037	46	19	0.0582	0.0241
	Shore	0	0	0.0	0.0	24	10	0.0304	0.0127
	Combined	9	4	0.0083	0.0037	70	29	0.0886	0.0368
Autumn	Boat	337	138	0.3120	0.1278	628	258	0.7949	0.3266
	Shore	78	32	0.0722	0.0296	29	12	0.0367	0.0152
	Combined	415	170	0.3842	0.1574	657	270	0.8316	0.3418
Winter	Boat	0	0	0.0	0.0	678	278	0.8582	0.3519
	Shore	0	0	0.0	0.0	36	15	0.0456	0.0190
	Combined	0	0	0.0	0.0	714	293	0.9038	0.3709
Spring 1975	Boat	124	51	0.1148	0.0472	360	148	0.4557	0.1873
	Shore	92	38	0.0852	0.0352	312	128	0.3949	0.1620
	Combined	216	89	0.2000	0.0824	672	276	0.8506	0.3593

Table 12.—Projected harvest (number and biomass) of bluegill from unheated and heated areas of Lake Sangchris from April 1973 to April 1975 for boat and shore fishing. The biomass data for 1973 were calculated from average weight measured in 1974.

Creel Period	Fishing Type	Unheated Area				Heated Area			
		Number	Pounds	Fish per Acre	Pounds per Acre	Number	Pounds	Fish per Acre	Pounds per Acre
Spring 1973	Boat	157	19	0.1454	0.0176	305	37	0.3861	0.0468
	Shore	954	114	0.8833	0.1056	2,071	249	2.6215	0.3152
	Combined	1,111	133	1.0387	0.1232	2,376	286	3.0076	0.3620
Summer	Boat	1,172	141	1.0852	0.1306	1,411	169	1.7861	0.2139
	Shore	2,991	359	2.1213	0.3324	5,296	636	6.7038	0.8051
	Combined	4,163	500	3.2065	0.4630	6,707	805	8.4899	1.0190
Autumn	Boat	209	25	0.1935	0.0231	164	20	0.2076	0.0253
	Shore	1,203	144	1.1139	0.1333	1,342	161	1.6987	0.2038
	Combined	1,412	169	1.3074	0.1564	1,506	181	1.9063	0.2291
Winter	Boat	12	2	0.0111	0.0019	24	3	0.0304	0.0038
	Shore	2	. . .	0.0019	. . .	74	9	0.0937	0.0114
	Combined	14	2	0.0130	0.0019	98	12	0.1241	0.0152
Spring 1974	Boat	1,307	157	1.2102	0.1454	798	96	1.0101	0.1215
	Shore	3,591	431	3.3250	0.3991	4,508	541	5.7063	0.6848
	Combined	4,898	588	4.5352	0.5445	5,306	637	6.7164	0.8063
Summer	Boat	73	9	0.0676	0.0083	195	23	0.2468	0.0291
	Shore	3,097	372	2.8676	0.3444	4,865	584	6.1582	0.7392
	Combined	3,170	381	2.8352	0.3527	5,060	607	6.4050	0.7683
Autumn	Boat	5	1	0.0046	0.0009	34	4	0.0430	0.0051
	Shore	369	44	0.3417	0.0407	576	69	0.7291	0.0873
	Combined	374	45	0.3463	0.0416	606	73	0.7721	0.0924
Winter	Boat	0	0	0.0	0.0	7	1	0.0089	0.0013
	Shore	0	0	0.0	0.0	0	0	0.0	0.0
	Combined	0	0	0.0	0.0	7	1	0.0089	0.0013
Spring 1975	Boat	47	6	0.0435	0.0056	386	46	0.4658	0.0582
	Shore	300	36	0.2778	0.0333	576	69	0.7291	0.0873
	Combined	347	42	0.3213	0.0389	962	115	1.2177	0.1455

areas. Since shore fishermen were responsible for most of the catch, most bluegill were caught in the heated area because of the considerable amount of fishable shoreline there.

Catch rates for bluegills generally declined from 1973 to 1975 (Fig. 10). Very few fishermen actively sought bluegill; most were caught while anglers were fishing for other species. The catch rate in unheated areas was consistently somewhat higher than in the heated area. Catch rates were generally higher than the 0.022–0.025 bluegill per hour reported for summer periods at Lake Shelbyville (McNurney 1978).

SUMMARY AND CONCLUSIONS

1.—During 1973 and 1974, annual fishing pressure at Lake Sangchris was higher than typical fishing-pressure levels for midwestern reservoirs of similar size.

2.—Fishing efforts were consistently concentrated in the heated area of the lake in all seasons.

3.—Largemouth bass and channel catfish were the most sought-after species in the lake.

4.—Most of the total sport fishing harvest (78 percent by number and 91 percent by weight) was composed of largemouth bass, channel catfish, white bass, carp, white crappie, and bluegill.

5.—Channel catfish harvests and catch rates in 1973 and 1974 were very high in comparison with those of other lakes.

6.—White bass harvests were low, probably because white bass had only recently been introduced in Lake Sangchris.

REFERENCES CITED

BARR, A. J., J. H. GOODNIGHT, J. P. SALL, and J. T. HELWIG. 1976. A user's guide to SAS 76. Statistical Analysis System Institute, Inc., Raleigh, NC. 329 p.

CARTER, J. P. 1969. Pre- and post-impoundment surveys on Barren River. Kentucky Fisheries Bulletin 50. 33 p.

GORDON, D., D.W. CHAPMAN, and T.C. BJORN. 1973. Economic evaluation of sport fisheries—what do they mean? American Fisheries Society Transactions 102(2): 293–311.

HANSON, W. D. 1974. The fishery of a Missouri reservoir receiving thermal effluent. Southeastern Association of Game and Fish Commissioners Proceedings for 1973, 27: 722–734.

KATHREIN, J.W. 1953. An intensive creel census on Clearwater Lake, Missouri, during its first four years of impoundment, 1949–1952. North American Wildlife Conference Transactions 18:282–295.

LARIMORE, R. W., and J. A. TRANQUILLI. 1981. The Lake Sangchris project. Pages 279–289 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32 (4).

MALVESTUTO, S.P., W.D. DAVIES, and W.L. SHELTON. 1978. An evaluation of the roving creel survey with nonuniform probability sampling. American Fisheries Society Transactions 107(2):255–262.

MCNURNEY, J.M. 1978. Survey of fishing and other water based recreation at Lake Shelbyville. Unpublished report to the Institute for Environmental Studies, University of Illinois, Urbana.

———, and M. FRAKES. 1979. Recreational creel survey at Lake Sangchris: a midwestern cooling lake, 1975–1976. Pages 6-1 –6-39 *in* Evaluation of a cooling lake fishery. Vol. III. Prepared by Illinois Natural History Survey for Electric Power Research Institute, Palo Alto, CA.

MRAZ, D., and C.W. THREINEN. 1957. Angler's harvest, growth rate and population estimate of the largemouth bass of Browns Lake, Wisconsin. American Fisheries Society Transactions 85:241–256.

RAWSTRON, R. R., and K. A. HASHAGEN. 1972. Mortality and survival rates of tagged largemouth bass (*Micropterus salmoides*) at Merle Collins reservoir. California Fish and Game 58(3):221–230.

SNOW, H. E. 1971. Harvest and feeding habits of largemouth bass in Murphy Flowage, Wisconsin. Department of Natural Resources Technical Bulletin 50. 25 p.

STARRETT, W.C., A.C. LOPINOT, and L. ROCK. 1963. 1962 Mississippi River sport fishing creel census procedures. Illinois Department of Conservation. Division of Fisheries. 90 p.

TRANQUILLI, J.A., R. KOCHER, and J.M. MCNURNEY. 1981. Population dynamics of the Lake Sangchris fishery. Pages 413–499 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

Distribution and Abundance of Larval Fishes in Lake Sangchris (1976)

Harry Bergmann

ABSTRACT

The distribution and abundance of larval fishes were studied in Lake Sangchris during the spring and summer of 1976. Gizzard shad *(Dorosoma cepedianum)* and *Lepomis* spp. were the only two taxonomic groups captured in adequate numbers for statistical analysis. *Morone* spp. were also collected but accounted for only 1.6 percent of the total catch. Gizzard shad densities were highest in similar habitats (coves and mouths of creeks) from both the discharge and intake arms. Densities of *Lepomis* larvae were highest in the discharge arm. For gizzard shad and *Morone* larvae, little difference was observed in the temporal appearance of larvae in the discharge and intake arms. In the discharge arm a peak in the numbers of *Lepomis* larvae occurred 1 week earlier than in the intake arm. Low numbers of gizzard shad and *Lepomis* larvae were found in deep water in the intake canal and indicated that few larvae were vulnerable to entrainment during the daytime. Gizzard shad larvae were collected during a 24-hour vertical migration study by taking tows at the surface, 1-, 2-, and 3-meter depths at 3-hour intervals. Gizzard shad densities were highest near the surface during daylight and highest near the bottom at night.

INTRODUCTION

A larval fishes study was conducted in Lake Sangchris during the spring and summer of 1976. The objectives of the study were: (1) to evaluate the impact of the heated effluent from the power plant upon fish reproduction by describing the spatial and temporal distribution of larval fishes within the cooling loop and (2) to compare the relative abundance of larval fishes in the intake and discharge canals.

DESCRIPTION OF THE STUDY AREA

Lake Sangchris is an 876-ha impoundment located in central Illinois and provides cooling water to a 1,232-MW coal-fired electrical generating plant. Water that passes through the plant's condensers is discharged into the middle branch (discharge arm) of the lake (Fig. 1). Water circulates around a 16-km "cooling loop" and re-enters the plant via the west branch (intake arm). The east branch (control arm) is not part of the cooling loop. A more detailed description of Lake Sangchris can be found in the introductory chapter of this monograph.

MATERIALS AND METHODS

Larval fishes were collected at weekly intervals during daylight hours from 19 March to 5 August 1976 from 10 stations in Lake Sangchris (Fig. 1). The stations used in this larval fish study do not correspond with collecting stations used in other Lake Sangchris studies. Stations 1–5 were located in the discharge arm and stations 6–10 were located in the intake arm. Larval fishes were not collected from the control arm because water temperatures there are similar to those in the intake arm. Stations were selected primarily according to habitat types which might be utilized as nursery areas. Comparable stations were selected from the discharge and intake arms and included coves, midchannel areas, mouths

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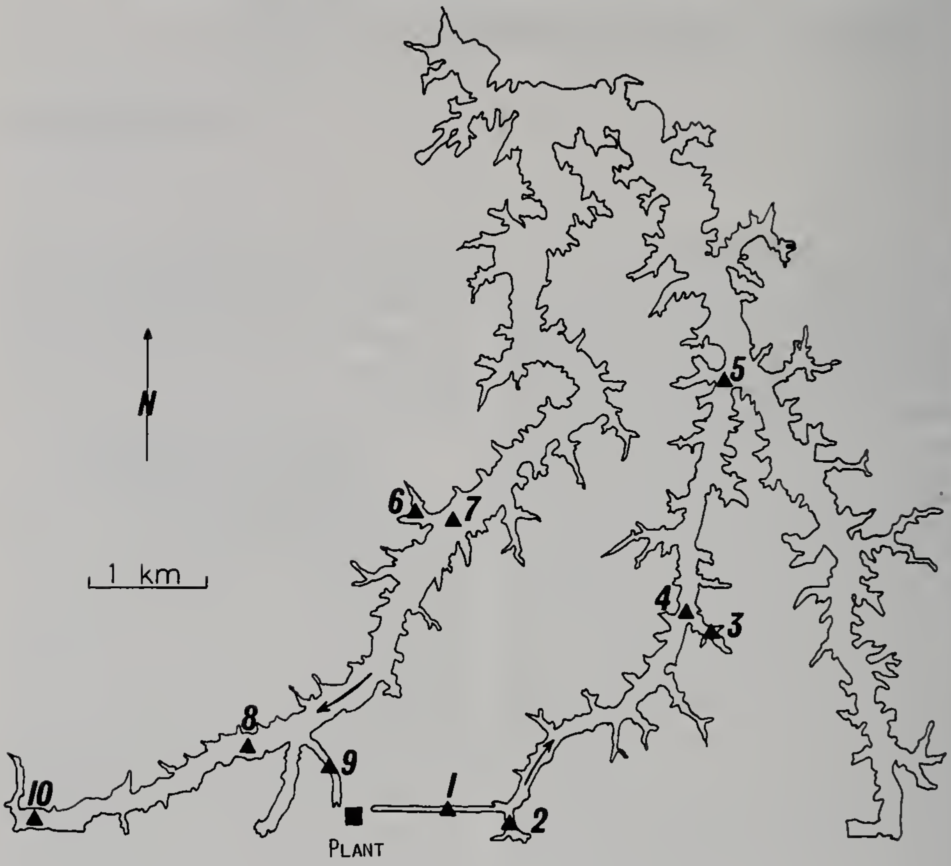

Fig. 1.—Larval fishes sampling stations at Lake Sangchris (1976).

of tributaries, and intake and discharge canals.

Tows were taken at the surface and at 2 and 4 m where there was sufficient depth. Stations where only one surface tow was taken are designated by the station number alone. Where more than one surface tow was taken, the letter m designates a midchannel sample. The letters e, w, and s designate tows along the east, west, and south shorelines, respectively. Deepwater tows of 2 and 4 m are designated by the superscript 2 or 4.

Supplementary tows were taken on 28 May to study vertical migration. A sampling site was selected near Station 8 because the water was uniformly 4 m deep. Samples were collected over a 24-hour period at 3-hour intervals at the surface, 1-, 2-, and 3-m depths.

Larval fishes were collected by towing paired No. 00 mesh (0.75 mm) conical plankton nets from the bow of a boat. The nets were 3.5 m in length with an opening diameter of 0.5 m. At the cod end, a modified plankton bucket with aperture screen of No. 0 mesh (0.571 mm) was attached. A General Oceanics model 2030 flowmeter was placed in the mouth of one of the paired nets. All nets were towed for 3 minutes at a boat speed of approximately 1.3 m/sec.

Samples were preserved in a buffered 5-percent solution of formalin and returned to the lab to be counted and identified. In samples where 30 or more larvae were collected, a representative subsample of 30 larvae was obtained for length determination and enumeration of pro- or postlarvae. All identifications and terminologies follow the key of May & Gasaway (1967).

Data were expressed as the number of fish per 10 m^3 of water filtered, and were transformed into logarithms to stabilize the variance for statistical analysis. One unit was added to all data before transformation so that zero values could be included and to eliminate negative logarithms. A two-way analysis of variance (ANOVA) was performed on the number of larvae collected and the least significant difference (LSD) used as the test for significance between station means (Snedecor & Cochran 1967).

RESULTS AND DISCUSSION

During the weekly larval fishes collections, 35,007 larvae were captured, representing five taxonomic groups. The most abundant species collected was gizzard shad, constituting 89.4 percent of the total catch. *Lepomis* spp. and *Morone* spp. accounted for 9.1 and 1.5 percent of the catch, respectively. One freshwater drum (*Aplodinotus grunniens),* one carp *(Cyprinus carpio),* and one unidentified cyprinid were also captured. During the vertical migration study totals of 6,684 gizzard shad and 26 *Morone* larvae were captured.

Power production (gross generation of electricity) by the Kincaid Generating Station was abnormally low during the spring of 1976 (Larimore & Tranquilli 1981). In more normal years, increased power production could elevate water temperatures in the spring above those observed in this study, thus having a greater effect on the time of spawning.

GIZZARD SHAD

Gizzard shad larvae were captured from 22 April to 30 July (Table 1), and ranged in total length from 3 to 37 mm. Of the 30,615 gizzard shad larvae collected, 74 percent were captured between 27 May and 10 June.

Larval gizzard shad were most abundant at Station 10 in the intake arm near the mouth of a tributary (Table 2). On 4 June, 10,673 gizzard shad (35 percent of the total collected) were collected in one 3-minute tow at this station. There was no significant difference between the number of larval shad collected at Station 2, in the discharge arm near the mouth of the middle branch of Clear Creek, and the two cove stations 3 and 6. The relatively high density of larvae at these four stations in coves and mouths of creeks from both the discharge and intake arms indicated that the thermal effluent had little influence on their spatial distribution, and that habitat preference may have been the dominant factor in gizzard shad reproduction in 1976.

Little difference was observed in the temporal distribution of gizzard shad between the discharge and intake arms (Fig. 2). Nelson & Cole (1976) estimated that increased water temperatures within the discharge system at Monroe, Michigan, may have extended the spawning period of gizzard shad by 2 months. However, in Lake Sangchris an extended spawning period was not evident. Larval gizzard shad first appeared on 22 April at 4 stations in the discharge arm (stations 1, 2, 3, and 4) where water temperatures ranged from 20.4° to 23.7°C and at Station 9 located in the intake canal where the water temperature was only 17.8°C (Table 3). Bodola (1966) reported that in western Lake Erie gizzard shad spawn between 17° and 23°C. The highest densities of gizzard shad larvae in both arms were found from 27 May to 10 June. The mean catch in the intake arm during this period was heavily influenced by the large number of larvae collected at Station 10. Prolarvae were last captured in the intake arm on 10 June and 1 week later in the discharge arm. Low numbers of gizzard shad larvae were collected from both arms on 7 July. Numbers remained low in the next three weekly collections until 5 August when no larval shad were collected in either arm.

At the three stations where 4-m tows were taken, densities of gizzard shad larvae were lower at the 4-m depth than at the surface or the 2-m depth (Table 2). Of all stations sampled, the density of larval shad was lowest at the 4-m depth in the intake canal (Station 9[4]). Within the intake canal, the number of larval shad

Table 1.—Number of gizzard shad larvae (per 10 cubic meters of water) in the intake and discharge arms of Lake Sangchris (1976). The dots indicate that no larvae were found.

Date	Net	Discharge Arm Stations										
		1	1s	2	3	4e	4w	4m	4^2	5	5^2	5^4
April 22	A	...	...	...	0.35	...	...	...	...	...	..	...
	B	0.35	...	0.76	0.35	0.32	0.35	...	...	...	...	...
29	A	...	1.00	5.31	3.67	...	...	...	3.73	0.60	12.79	...
	B	1.96	0.33	4.49	3.33	1.68	1.57	1.59	2.21	0.90	12.59	...
May 6	A	2.52	0.65	8.06	4.39	0.62	1.48	0.98	0.54	0.36	0.33	...
	B	3.79	1.94	4.18	7.77	1.24	2.96	0.98	0.62	0.73	1.29	0.96
13	A	1.89	5.69	8.70	13.36	7.36	13.41	8.43	7.00	3.45	5.25	2.33
	B	4.55	4.88	9.09	16.60	2.33	9.76	2.81	3.36	3.07	4.67	6.25
20	A	1.37	2.32	22.12	45.37	9.82	5.02	22.04	12.67	2.55	5.61	4.21
	B	2.41	2.98	10.00	23.64	12.63	14.38	13.73	5.92	2.55	17.23	2.53
27	A	6.06	8.10	17.95	56.16	5.75	1.95	1.78	5.86	3.69	7.71	4.73
	B	12.35	8.66	16.24	33.97	40.00	21.17	13.95	14.33	12.77	11.53	5.21
June 4	A	10.28	6.59	31.46	17.03	5.47	41.78	26.72	8.68	11.89	4.15	5.54
	B	6.52	7.74	23.88	7.57	7.81	30.36	13.22	2.24	10.23	15.13	15.14
10	A	0.76	1.04	67.94	58.35	3.96	6.27	8.63	7.35	9.84	7.33	6.17
	B	1.52	1.56	30.29	27.53	2.11	8.62	7.82	1.60	13.57	7.67	6.17
17	A	...	...	14.38	12.21	1.10	2.51	0.82	3.28	0.82	3.51	0.48
	B	...	...	10.00	7.89	18.51	32.16	10.90	2.19	1.92	2.11	1.93
24	A	0.22	...	2.27	5.34	4.83	3.64	4.06	0.70	0.58	3.00	0.53
	B	0.45	0.27	3.13	5.34	16.09	5.04	2.61	1.05	0.87	1.87	...
30	A	0.54	0.25	5.88	9.12	3.09	2.17	6.70	1.59	2.76	2.64	0.83
	B	1.09	3.00	17.14	52.99	31.46	22.76	44.91	...	11.06	1.13	2.08
July 7	A	...	...	...	0.27	...	...	...	0.34	...	...	0.36
	B	...	0.26	...	1.91	...	...	0.65	...	0.30	...	...
15	A	...	...	...	0.93	0.30	...	...	...	...	...	...
	B	..	...	...	1.25	0.90	0.30	...	...	0.31	...	...
22	A	...	...	...	...	...	...	...	...	...	...	...
	B	...	...	...	...	...	16.45	...	...	...	...	...
30	A	...	...	...	0.28	...	...	...	...	...	...	...
	B	...	...	...	...	...	...	...	...	...	...	...
August 5	A	...	...	...	...	...	...	...	...	...	...	...
	B	...	...	...	...	...	...	...	...	...	...	...

Table 1.—Continued.

Date		Net	Intake Arm Stations												
			6	7e	7w	7m	7^2	7^4	8	8^2	9	9s	9^2	9^4	10
April	22	A	...	...	...	...	...	...	...	...	...	...	...	...	...
		B	...	...	...	...	...	...	...	...	...	...	0.31	...	...
	29	A	14.80	0.33	0.39	...	2.56	0.40	0.28	17.87	...	...	7.30	1.31	0.70
		B	27.30	0.33	5.05	13.06	3.48	5.06	1.42	21.43	0.31	0.33	9.85	...	1.04
May	6	A	3.15	2.89	1.47	...	3.61	1.79	4.04	19.23	...	...	2.28	1.49	16.88
		B	5.35	2.60	1.18	0.68	2.54	1.42	2.60	6.85	...	0.62	4.96	1.02	44.88
	13	A	15.16	5.93	18.69	11.66	11.34	2.41	6.50	45.53	6.08	1.31	6.73	0.32	24.72
		B	8.20	4.44	17.20	8.74	9.28	4.24	5.78	21.70	4.56	0.87	7.43	0.33	32.47
	20	A	4.20	7.75	4.42	4.73	38.83	8.32	1.74	9.65	31.19	12.29	33.91	2.99	21.23
		B	7.36	7.44	23.77	10.41	26.05	2.72	6.97	7.49	22.08	16.49	20.89	2.16	13.39
	27	A	36.81	25.58	8.49	6.06	37.65	5.77	39.64	18.03	30.89	25.69	20.40	21.34	56.16
		B	99.69	7.46	69.23	29.13	17.75	7.31	47.62	17.22	39.56	61.88	57.43	...	21.41
June	4	A	14.90	10.47	8.85	4.10	33.36	1.00	41.32	36.80	6.20	6.28	32.28	4.80	1,718.57
		B	33.33	2.33	4.28	1.46	35.01	2.67	10.78	122.56	40.03	31.42	45.05	7.02	1,008.08
	10	A	15.41	12.70	13.98	18.11	11.19	7.52	21.03	6.68	1.68	4.75	6.27	1.34	151.24
		B	131.40	82.65	74.88	91.04	4.41	7.52	54.85	11.84	15.60	7.91	7.38	6.37	146.82
	17	A	3.26	...	...	2.34	1.90	2.04	4.62	1.07	21.14	44.54	3.12	...	57.97
		B	4.35	31.16	4.83	9.89	1.90	1.02	36.72	1.78	17.23	16.20	4.51	1.54	28.88
	24	A	17.58	14.53	2.81	7.17	...	...	10.76	0.65	11.91	15.97	0.42	...	18.00
		B	8.79	6.98	1.13	5.24	...	0.41	12.41	...	5.14	9.02	...	0.45	27.00
	30	A	1.49	0.52	1.58	0.54	0.66	0.80	1.88	0.69	0.61	1.12	...	...	39.54
		B	2.48	0.52	2.11	0.27	1.97	0.40	6.72	0.34	2.45	5.04	...	...	21.59
July	7	A	0.26	...	0.30	...	0.35	0.42	0.31	0.35	...	...	0.35	...	1.64
		B	...	0.28	0.60	0.30	0.35	...	0.61	...	0.29	0.86	0.35	...	1.64
	15	A	0.30	...	...	...	...	...	...	...	0.30	1.52	...	...	2.98
		B	...	...	...	...	...	...	...	...	...	0.30	...	...	4.77
	22	A	...	...	...	...	...	...	...	...	...	0.29	...	...	...
		B	...	...	...	...	...	...	0.30	...	...	...	...	...	0.88
	30	A	...	...	...	...	...	...	...	...	...	...	...	...	...
		B	...	...	...	...	...	...	...	...	...	...	...	...	2.43
August	5	A	...	...	...	...	...	...	...	...	...	...	...	...	...
		B	...	...	...	...	...	...	...	...	...	...	...	...	...

Table 2.—Analysis of variance and least significant difference for gizzard shad larvae collected in Lake Sangchris (1976).

Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Station (s)	23	29.651	1.289	7.34[a]
Date (d)	12	101.040	8.420	158.27[a]
Interaction (s x d)	276	48.473	0.176	3.301[a]
Error	312	16.600	0.053	

Least Significant Difference[b] Between Station Means

Station	10	3	6	2	8	8^2	4w	9^2	9s	9	7^2	7w	4m	4e	7e	7m	5^2	5	4^2	7^4	5^4	1	1s	9^4
Mean	1.3	.96	.86	.85	.77	.75	.69	.69	.68	.67	66	.65	.64	.62	.61	.60	.59	.48	.47	.40	.38	.36	.35	.28

[a] Significant at $P < 0.01$ level.

[b] Means underscored by the same line are not significantly different at the 0.05 level.

collected at the 4-m depth (Station 9^4) was significantly lower than the number collected at the surface (Station 9), along the shore (Station 9s), and at the 2-m depth (Station 9^2). This difference is particularly important because when Lake Sangchris is at normal pool, the cooling water is drawn from 6 m below the surface. If the larvae maintained this vertical distribution at the intake structure, few larvae would be vulnerable to entrainment

There were no significant differences in the number of larval shad collected at the 4-m depth in the intake canal and the number collected from the discharge canal stations. However, the relationship between the numbers of larvae collected at those locations and entrainment is not well understood. Marcy (1973) observed that dead entrained larvae at a nuclear power plant in Connecticut began settling out in the discharge canal. Fewer dead larvae were collected at his lower discharge station than at his upper discharge station. Similar results were reported by Nelson & Cole (1975), who found yellow perch were most abundant near the surface at lake and intake stations, but in the discharge canal the majority of larvae were collected near the bottom. In Lake Sangchris, irregularities in the bottom contour prevented subsurface collections in the discharge canal. The relationship was further complicated by an inability to separate entrained from non-entrained larvae. Water velocities at the mouth of the discharge canal were considered strong enough to prevent recruitment of the smaller larvae from outside the discharge canal; however, some spawning may have occurred along the shore within the canal.

During the vertical migration study, 6,684 gizzard shad larvae were captured ranging in size from 4 to 21 mm in total length. Four collections during the 24-hour study were made during daylight, three at night, and one at dusk (1900 h) (Fig. 3). The mean catch from

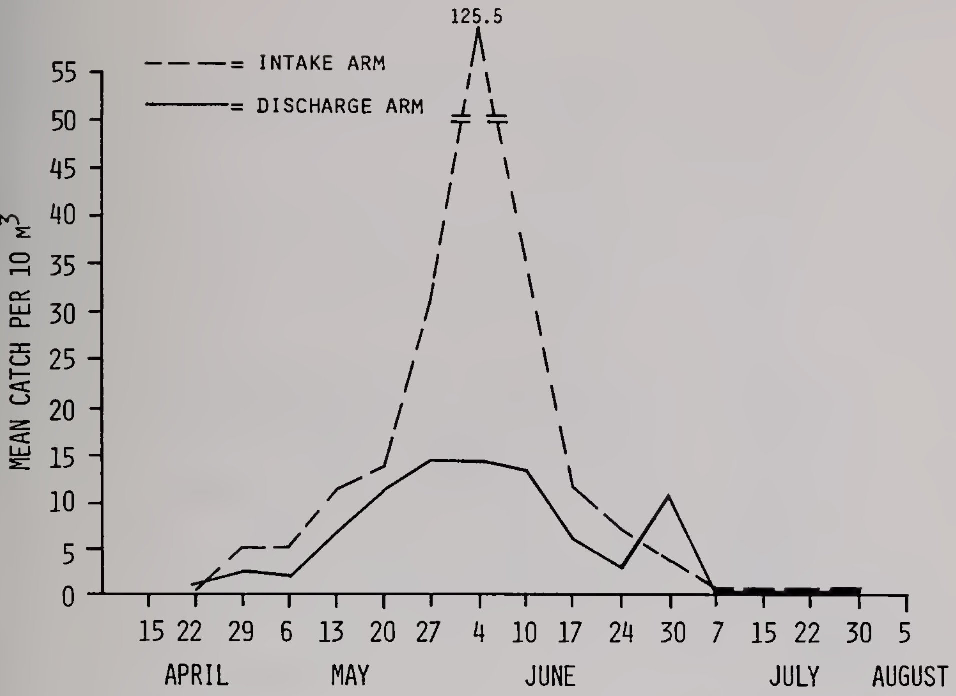

Fig. 2.—Mean catch of gizzard shad larvae in the discharge and intake arms of Lake Sangchris (1976).

the night collections was higher (51.3/10 m^3) than the mean catch from the day and dusk collections (31.4/10 m^3 and 8.9/10 m^3, respectively). The collection at dusk was considered to be a transition period and not included in further day/night comparisons. The mean length of larvae from the night collections was also greater (10.0 mm) than the day collections (9.5 mm). During daylight the highest number of gizzard shad larvae was captured at the surface, while at night, the highest number was collected near the bottom. The high densities found near the bottom at night suggested that this would be the period of highest entrainment of gizzard shad larvae in the intake canal.

The increased numbers of larvae collected at night are apparently due to reduced avoidance of sampling gear (Bridger 1956). This avoidance is dependent in part on a visual stimulus (Noble 1970) as well as variables such as type of sampling gear, net speed, and the size or stage of development of the species being collected (Bridger 1956, Aron & Collard 1969). Larger larvae are more developed and mobile and are less vulnerable to capture than smaller larvae. The relationship between the size of gizzard shad larvae and avoidance was more thoroughly examined by separating larvae into 2-mm size groups (Table 4). The mean density of each size group from day and night samples was compared. Smallest gizzard shad larvae (4–5 mm) were captured with greater efficiency during the day while larvae larger than 8 mm were captured with greater efficiency during the night. This indicated that the larger larvae were probably avoiding the sampling gear during the day; therefore, densities calculated from week-

Table 3.—Surface water temperatures (°c) at larval fish stations in Lake Sangchris (1976).

	Station									
Date	1	2	3	4	5	6	7	8	9	10
March 19	15.8	11.5	12.8	14.6	...	...	...	...	...	...
25	9.9	9.8	9.8	...	...	12.5	10.8	10.5	10.5	10.6
April 1	18.0	15.9	15.4	16.9	...	11.2	11.8	11.2	11.2	10.8
8	13.6	11.5	10.7	13.1	14.1	13.1	14.0	12.8	14.0	12.2
15	21.6	19.1	19.0	19.5	17.8	17.8	14.9	15.2	15.1	16.7
22	23.7	22.5	20.4	22.2	20.5	19.1	17.2	16.8	17.8	17.0
29	20.8	18.8	16.4	19.5	16.5	16.0	17.0	17.1	16.1	16.1
May 6	19.8	18.5	18.3	19.8	18.9	16.2	16.1	15.5	15.7	15.5
13	17.0	15.9	15.6	16.7	17.8	17.0	17.4	17.0	17.2	16.7
20	25.8	23.5	22.3	23.2	22.7	18.9	18.6	18.8	19.0	19.1
27	26.8	23.0	23.0	24.5	24.4	20.8	20.2	20.6	19.8	21.2
June 4	28.7	26.3	23.5	23.8	25.0	21.7	21.3	21.6	21.9	21.7
10	30.5	28.8	28.0	25.1	27.0	24.4	24.9	24.0	24.8	24.7
17	32.0	28.1	28.1	29.4	28.6	25.5	25.2	24.6	25.1	24.4
24	30.8	27.2	26.8	28.5	26.3	23.7	23.5	24.0	23.2	23.1
30	25.1	24.3	26.7	26.4	27.6	23.4	25.8	24.3	24.9	23.3
July 7	31.5	30.3	29.5	29.4	29.5	25.4	25.3	25.8	25.8	26.8
15	35.1	34.9	33.3	33.7	33.0	29.1	29.2	28.4	28.5	28.6
22	33.8	33.0	31.2	31.8	30.7	27.2	27.5	27.2	27.2	27.0
30	29.0	28.8	29.4	29.2	31.1	29.0	29.1	28.8	29.2	28.7
August 5	32.7	30.3	29.1	29.2	28.5	25.8	26.2	25.6	26.1	25.0

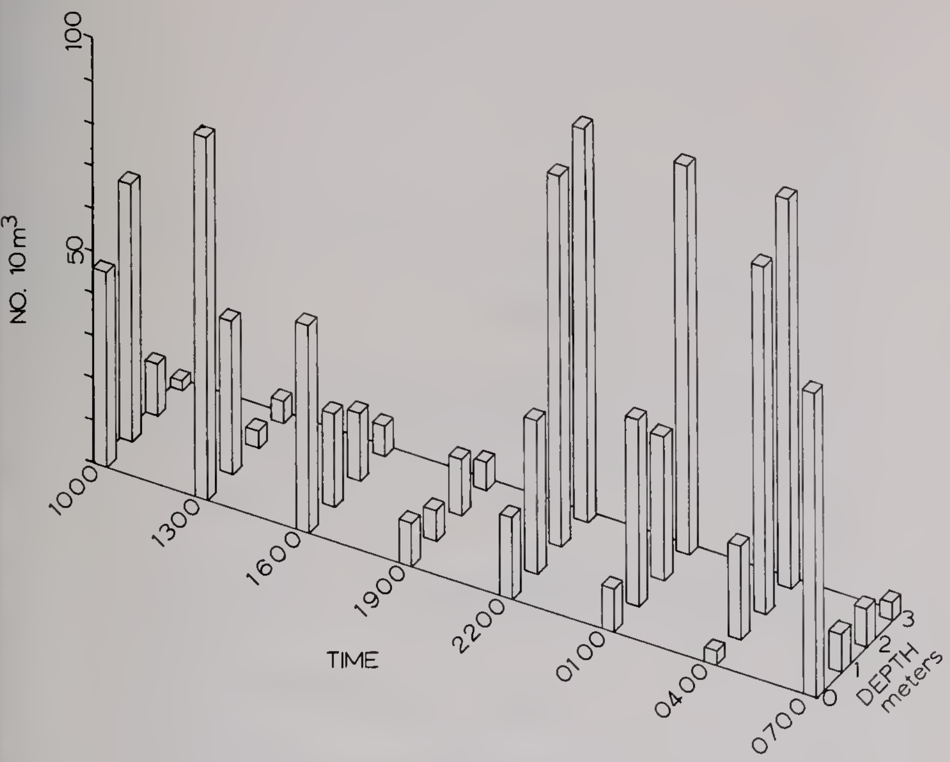

Fig. 3.—Vertical distribution of gizzard shad larvae in Lake Sangchris on 28 May 1976.

Table 4.—Length-frequency distribution of gizzard shad larvae collected during the day and night on 28 May 1976.

Total Length (mm)	Density/10 m^3 Day	Density/10 m^3 Night	Night:Day Ratio
4–5	0.3	0.01	0.03
6–7	2.4	2.5	1.04
8–9	10.5	17.1	1.63
10–11	15.1	23.6	1.56
12–13	3.0	6.3	2.10
14–15	0.1	1.1	11.0
16–17	...	0.4	...
18–19	...	0.2	...
20–21	...	0.1	...
Total	*31.4*	*51.3*	

ly collections should be considered an underestimate of actual larval shad densities.

During the weekly collections there were consistent differences in the size of gizzard shad larvae at different depths. For 16 of the 18 occasions when samples contained at least 30 larvae, the mean length of the larvae decreased with increasing depth. The decrease in size of larvae with increasing depth can be largely attributed to the abundance of prolarvae (3–5 mm) in deep water. Subsurface tows accounted for 68 percent of the pro-

Table 5.—Mean total length (TL) of gizzard shad larvae collected at different depths during day and night collections on 28 May 1976.

Depth (m)	Day TL (mm)	Day No. Measured	Night TL (mm)	Night No. Measured
0	9.8 (1.6)	407	9.4 (1.6)	182
1	9.6 (1.6)	289	10.1 (1.8)	198
2	9.0 (1.7)	203	10.5 (1.7)	286
3	9.0 (2.0)	92	9.9 (1.8)	270
Total	*9.5*	*991*	*10.0*	*936*

Table 6.—Number of *Lepomis* larvae (per 10 cubic meters of water) in the intake and discharge arms of Lake Sangchris (1976). Dots indicate that no larvae were found.

Date	Net	Discharge Arm Stations										
		1	1s	2	3	4e	4w	4m	4^2	5	5^2	5^4
May 27	A	...	...	...	...	...	3.06	0.59	...	0.85	...	...
	B	...	...	0.28	...	1.11	2.23	...	...	0.85	...	...
June 4	A	...	...	0.28	...	0.26	...	...	...	...	...	...
	B	...	...	...	...	...	...	...	...	...	...	...
10	A	...	...	36.79	174.48	8.97	9.14	11.05	0.96	10.64	0.33	...
	B	...	...	23.84	93.71	4.22	12.53	16.17	0.96	16.49	0.33	...
17	A	...	...	13.15	20.36	3.87	6.29	0.54	1.82	1.92	...	...
	B	...	...	8.76	43.51	1.94	10.06	...	0.36	0.55	...	0.48
24	A	...	...	6.53	2.81	5.63	7.84	1.45	...	0.87	...	...
	B	...	...	6.81	3.37	4.55	7.56	2.23	...	1.17	...	...
30	A	0.27	2.00	21.98	20.23	...	1.08	2.73	...	0.75	...	...
	B	...	1.25	17.89	21.94	0.84	0.27	1.49	...	0.75	...	...
July 7	A	...	0.26	8.51	7.09	7.07	...	...	...	...	...	...
	B	...	...	3.50	0.82	...	0.31	0.33	...	0.30	...	...
15	A	...	0.29	5.61	1.87	...	0.30	...	...	0.31	...	...
	B	...	...	12.71	2.49	...	...	...	...	...	...	...
22	A	...	0.33	2.21	6.91	0.91	1.61	...	...	0.28	...	...
	B	...	...	4.74	3.45	0.30	0.32	0.29	...	0.28	...	...
30	A	...	...	6.57	1.66	0.54	2.57	0.58	...	1.36	...	...
	B	...	...	7.66	1.10	1.34	2.00	0.86	...	0.81	...	...
August 5	A	...	...	1.18	0.27	0.59	0.83	0.90	...	0.29	...	...
	B	...	...	5.61	0.54	0.30	1.10	0.30	...	0.29	...	...

Table 6.—Continued.

Date	Net	Intake Arm Stations												
		6	7e	7w	7m	7^2	7^4	8	8^2	9	9s	9^2	9^4	10
May 27	A	...	...	...	...	...	...	...	...	...	...	...	...	...
	B	...	...	...	...	...	...	...	...	...	...	...	...	...
June 4	A	...	...	...	...	...	...	...	...	...	...	...	...	...
	B	...	...	...	0.29	...	...	...	...	...	...	...	...	...
10	A	0.45	...	...	...	...	...	...	...	...	...	...	...	0.80
	B	...	0.24	...	...	...	...	...	...	0.24	...	...	...	0.60
17	A	9.79	1.43	2.54	3.12	0.32	...	0.27	...	2.61	9.90	...	0.39	0.65
	B	5.16	0.74	5.08	2.34	0.63	...	0.27	...	1.83	1.57	...	...	0.65
24	A	...	0.28	1.69	0.83	...	...	1.38	...	4.88	5.41	...	...	4.63
	B	0.27	...	2.81	2.20	...	...	0.83	...	2.71	5.15	...	0.45	3.00
30	A	...	1.55	...	0.54	...	...	2.15	...	1.53	2.24	...	...	1.40
	B	...	1.04	0.26	0.27	...	...	0.54	...	0.92	1.68	...	...	0.56
July 7	A	0.79	0.28	1.21	0.89	...	...	0.61	...	0.29	0.29	...	...	1.64
	B	...	0.28	0.30	...	...	...	0.61	...	0.58	0.57	...	...	0.82
15	A	0.60	0.32	0.31	...	...	...	0.65	...	...	0.91	...	...	2.69
	B	1.19	1.89	0.62	0.32	...	...	1.31	...	...	0.91	...	...	4.18
22	A	1.47	1.38	6.10	0.29	...	...	1.21	...	0.32	0.88	...	...	0.29
	B	6.76	...	12.50	0.57	...	...	2.12	...	...	0.59	...	...	1.17
30	A	1.29	1.11	2.61	0.28	...	...	0.27	...	1.10	2.23	...	...	...
	B	1.80	3.89	0.87	0.57	...	...	1.88	...	1.10	3.79	...	...	...
August 5	A	0.81	0.57	0.58	0.30	...	...	0.89	...	...	0.28	...	...	0.30
	B	2.15	0.28	0.29	0.30	...	...	0.30	...	...	...	...	...	...

larvae catch while only contributing 13 percent to the total number of larvae (3–37 mm) captured.

During the vertical migration study, the lengths of larval gizzard shad captured in daytime collections also decreased with depth (Table 5). However, during the nighttime collections, lengths increased with depth except near the bottom at 3 m. Apparently, large larvae were concentrated near the surface during the day and moved into deeper water at night.

LEPOMIS LARVAE

Bluegill (*Lepomis macrochirus*), green sunfish (*Lepomis cyanellus*) and their hybrid are the only three *Lepomis* species in Lake Sangchris (Tranquilli et al. 1981). Bluegill are by far the most abundant; however, because of the similarities of the *Lepomis* larvae, identification to species was not made.

Lepomis larvae were collected from 27 May until 5 August when sampling was terminated (Table 6). Of the 3,800 *Lepomis* larvae collected, only 20 were captured at depths of 2 and 4 m; consequently, the subsurface tows were disregarded in the statistical analysis. Apparently larval *Lepomis* remain near the surface during the day.

Total lengths of *Lepomis* larvae captured ranged from 4 to 14 mm. No prolarval *Lepomis* were captured during the study. Werner (1967) reported that bluegill larvae migrate from littoral to limnetic habitats soon after absorption of the yolk sac. The design of the sampling gear used in this study prevented effective sampling in littoral areas and may therefore be responsible for the absence of prolarvae in the collections.

Lepomis larvae were most abundant in the discharge arm at stations 2 and 3 (Table 7). The largest single collection was made at Station 3 on 10 June when 1,139 *Lepomis* larvae (30 percent of the total) were captured. *Lepomis* larvae were also abundant in tows taken along the

Table 7.—Analysis of variance and least significant difference for *Lepomis* larvae collected in Lake Sangchris (1976).

Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	*F*
Stations (s)	15	14.655	0.977	6.584a
Date (d)	10	9.431	0.943	56.813a
Interaction (s x d)	150	22.253	0.148	8.940a
Error	176	2.920	0.017	. . .

Least Significant Difference[b] Between Station Means

Station	2	3	4w	4e	9s	7w	5	6	4m	10	8	9	7e	7m	1s	1
Mean	.798	.721	.469	.332	.301	.289	.268	.261	.258	.243	.196	.191	.184	.161	.053	.005

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[a] Significant at $P < 0.01$.

west shoreline at Station 4. Collections from the discharge arm at stations 2, 3, and 4w were responsible for 69 percent of the total *Lepomis* catch.

At stations 4 and 7, significant differences were found between tows taken from the west shoreline and tows taken from the middle and east shoreline. In both instances, the west shoreline had significantly higher *Lepomis* densities. Although visual observations suggested no apparent difference between the east and west shorelines, the west bank might have provided some shelter from the predominantly southwest winds, preventing wind and wave dispersion.

The earliest date when *Lepomis* larvae were captured in the discharge arm was 27 May at stations 2, 4, and 5, when surface water temperatures ranged from 23.0° to 24.5°C (Table 3). Larval *Lepomis* were captured 1 week later in the intake arm (Station 7), when the surface water temperature was 21.3°C. Peak catches occurred on 10 June in the discharge arm and 17 June in the intake arm (Fig. 4), indicating a difference in spawning time of about 1 week between heated and unheated areas in 1976. *Lepomis* larvae were still being captured in small numbers when collections were terminated on 5 August.

MORONE LARVAE

Large populations of both white bass (*Morone chrysops*) and yellow bass (*Morone mississippiensis*) occur in Lake Sangchris. White bass are an important sportfish, whereas yellow bass are not. According to a recent larval fishes identification key (Hogue et al. 1976), no means have been devised for separation of the two species.

Between 15 April and 10 June, 589 *Morone* larvae were collected (Table 8). Total lengths of *Morone* larvae captured ranged from 3 to 20 mm. *Morone* larvae were first captured on 15 April in the discharge arm at Station 2 where the surface water temperature was 19.1°C. *Morone* larvae were captured in the intake arm 1 week later at stations 8, 9, and 10 where surface water temperatures ranged from 16.8° to 17.8°C (Table 3). *Morone* larvae were captured last on 10 June in both arms. Although there was a 1-week difference in the onset of spawning, the mean catches of *Morone* larvae in the discharge and intake arms (Fig. 5) indicated no apparent difference in the duration of spawning.

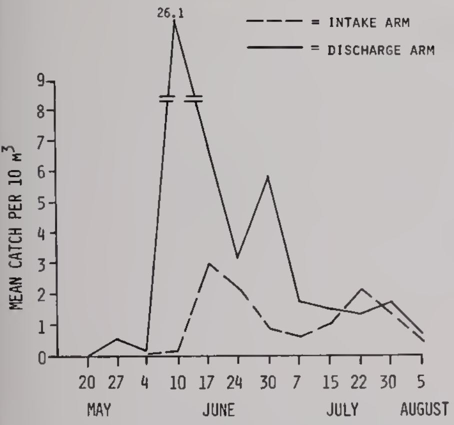

Fig. 4.—Mean catch of *Lepomis* larvae in the discharge and intake arms of Lake Sangchris (1976).

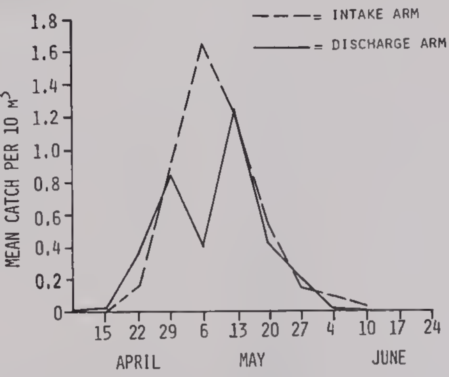

Fig. 5.—Mean catch of *Morone* larvae in the discharge and intake arms of Lake Sangchris (1976).

Table 8.—Number of *Morone* larvae (per 10 cubic meters of water) in the intake and discharge arms of Lake Sangchris (1976). Dots indicate that no larvae were found.

		Discharge Arm Stations										
Date	Net	1	1s	2	3	4e	4w	4m	4[2]	5	5[2]	5[4]
April 15	A	...	...	...	...	...	...	...	...	...	...	...
	B	...	...	0.36	...	...	...	...	...	...	...	...
22	A	0.35	...	3.05	1.38	...	...	...	...	...	...	...
	B	0.35	...	2.29	0.35	...	...	0.40	...	...	...	...
29	A	...	...	1.63	2.67	1.68	...	...	0.93	...	2.71	...
	B	0.65	...	1.22	1.00	1.68	...	0.32	1.58	...	2.38	...
May 6	A	0.32	0.32	2.99	...	...	...	...	0.82	...	0.33	...
	B	0.32	0.65	1.79	1.02	...	...	...	...	...	0.65	...
13	A	0.38	0.81	0.79	0.40	2.71	8.94	0.40	1.34	0.38	0.62	0.33
	B	...	...	1.19	0.40	0.39	6.91	0.40	...	0.38	0.62	0.33
20	A	...	..	0.91	2.88	1.06	...	0.96	0.45	...	...	...
	B	...	...	0.61	0.64	0.35	0.67	...	0.35	...	0.62	...
27	A	...	...	...	0.27	0.55	...	...	0.65	...	...	0.39
	B	...	...	1.14	...	0.27	...	...	0.33	...	0.75	...
June 4	A	...	...	...	0.27	...	...	...	0.28	...	...	...
	B	...	...	...	...	...	...	...	...	...	...	...
10	A	...	0.26	...	...	...	...	...	...	...	...	...
	B	...	...	...	...	...	...	...	...	...	...	...

Table 8.—Continued.

Date	Net	6	7e	7w	7m	7^2	7^4	8	8^2	9	9s	9^2	9^4	10
		Intake Arm Stations												
April 15	A	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	B	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
22	A	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	1.79	. . .	. . .
	B	. . .	. . .	. . .	. . .	. . .	. . .	0.48	. . .	. . .	. . .	1.88	. . .	0.34
29	A	2.63	. . .	. . .	. . .	0.43	0.40	. . .	0.31	. . .	. . .	2.34	0.87	. . .
	B	2.63	. . .	. . .	0.96	0.95	6.07	. . .	1.14	. . .	. . .	4.07	. . .	. . .
May 6	A	0.63	0.58	. . .	. . .	0.56	2.30	0.87	3.02	0.69	0.31	0.76	. . .	9.69
	B	0.63	0.29	. . .	. . .	1.13	1.98	0.87	3.27	0.69	. . .	0.83	. . .	13.64
13	A	1.23	0.74	4.49	2.19	0.30	. . .	1.08	2.88	0.38	. . .	2.56	0.32	1.85
	B	2.05	0.74	1.50	2.19	. . .	0.35	0.36	1.70	0.76	. . .	1.94	0.65	1.11
20	A	. . .	. . .	0.28	. . .	0.40	0.36	. . .	1.07	. . .	. . .	0.35	0.43	2.61
	B	. . .	. . .	. . .	0.32	1.86	. . .	. . .	1.50	. . .	. . .	0.42	1.80	2.61
27	A	. . .	. . .	. . .	0.29	0.31	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.28
	B	0.27	. . .	0.27	. . .	. . .	. . .	0.29	0.81	0.54	0.28	0.54	. . .	0.28
June 4	A	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.28	. . .	. . .	. . .	. . .	1.28
	B	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.35	. . .	. . .
10	A	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.20
	B	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

SUMMARY

1.—The most abundant larval fish was gizzard shad, which constituted 89.4 percent of the total catch. *Lepomis* and *Morone* larvae accounted for 9.1 and 1.5 percent of the catch, respectively.

2.—Gizzard shad densities were highest in coves and mouths of creeks from both the discharge and intake arms, indicating the thermal effluent had no influence on their spatial distribution.

3.—For gizzard shad and *Morone* larvae little difference was observed in the temporal appearance of larvae in the discharge and intake arms.

4.—*Lepomis* larvae were collected earlier and were more abundant in the discharge arm than in the intake arm.

5.—The low number of gizzard shad and *Lepomis* larvae found in deep water in the intake canal indicates that few larvae were vulnerable to entrainment during the daytime.

6.—The vertical migration study indicated that gizzard shad densities were highest at the surface during daylight, while at night, densities were highest near the bottom.

REFERENCES CITED

ARON, W., and S. COLLARD. 1969. A study of the influence of net speed on catch. Limnology and Oceanography 14(2): 242–249.

BODOLA, A. 1966. Life history of the gizzard shad *Dorosoma cepedianum* (LeSueur), in western Lake Erie. U.S. Fish and Wildlife Service Fishery Bulletin 65(2):391–425.

BRIDGER, J. P. 1956. On day and night variation in catches of fish larvae. International Council for the Study of the Sea. Journal du Conseil 22:42–57. Copenhagen, Denmark.

HOGUE, J. J., JR., R. WALLUS, and L. K. KAY. 1976. Preliminary guide to the identification of larval fishes in the Tennessee River. Technical Note B19, Tennessee Valley Authority, Division of Forestry, Fisheries, and Wildlife Development. Norris, TN. 67 p.

LARIMORE, R. W., and J. A. TRANQUILLI. 1981. The Lake Sangchris project. Pages 279–289 *in* R. W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32 (4).

MARCY, BARTON C., JR. 1973. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. Canada Fisheries Research Board Journal 30 (8): 1195–1203.

MAY, EDWIN B., and CHARLES R. GASAWAY. 1967. A preliminary key to the identification of larval fishes of Oklahoma, with particular reference to Canton Reservoir, including a selected bibliography. Oklahoma Fishery Research Laboratory. Bulletin Number 5. 44 p.

NELSON, D. D., and R. A. COLE. 1975. The distribution and abundance of larval fishes along the western shore of Lake Erie at Monroe, Michigan. Technical Report No. 32.4. Institute of Water Research, Michigan State University. East Lansing, MI. 66 p.

NOBLE, RICHARD L. 1970. Evaluation of the Miller high-speed sampler for sampling yellow perch and walleye fry. Canada Fisheries Research Board Journal 27(6):1033–1044.

SNEDECOR, GEORGE W., and WILLIAM G. COCHRAN. 1967. Statistical methods. The Iowa State University Press. Ames. 593 p.

TRANQUILLI, J. A., R. KOCHER, and J. M. MCNURNEY. 1981. Population dynamics of the Lake Sangchris fishery. Pages 413–499 *in* R.W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32 (4).

WERNER, R. G. 1967. Intralacustrine movements of bluegill fry in Crane Lake, Indiana. American Fisheries Society Transactions 96(4);416–420.

Impingement and Entrainment of Fishes at Kincaid Generating Station

Wesley Porak and John A. Tranquilli

ABSTRACT

A 1-year study was conducted to assess the effects of Kincaid Generating Station's cooling-water intake system on the Lake Sangchris fishery. The entrainment of fish eggs and larvae was investigated during the period of reproductive activity, and the impingement of juvenile and adult fishes on the traveling screens was studied throughout the year. The number and/or biomass of fishes impinged and entrained at Kincaid Generating Station were compared to standing crops and in some cases also to fecundities and natural mortality rates to determine the overall effect of the intake system on the fish community.

From December 1976 through March 1977, 94.16 percent of the estimated total impingement occurred. Gizzard shad (83.38 percent) and yellow bass (14.26 percent) accounted for 97.64 percent of the estimated 158,853 fish impinged on the screens. Small fishes were the most vulnerable to impingement; 93.8 percent of all the fish collected were less than 200 mm in total length. Mean condition factors of gizzard shad and yellow bass collected from the intake area by electrofishing were significantly higher ($P < 0.01$) than condition factors of these species collected from the traveling screens, indicating that stressed fishes were especially vulnerable to impingement. Numerically, impingement reduced the standing crop of gizzard shad and yellow bass by 1.82 and 7.86 percent, respectively.

Only 218 fish eggs were collected during entrainment sampling, accounting for a relatively low total estimate of 2.2 million eggs lost during the spawning season. Gizzard shad (85.61 percent), *Morone* spp. (4.03 percent), and *Lepomis* spp. (0.66 percent) accounted for most of the larval fish entrained. The entrainment of larval fishes during 1976 reduced the gizzard shad population by 4.74–5.48 percent and the *Lepomis* population by 0.33–0.59 percent. The numerical standing crop of unidentified *Morone* larvae, considered to be mostly yellow bass, was reduced 15.29 percent by entrainment.

During 1976 impingement and entrainment at Kincaid Generating Station's cooling-water intake system caused only relatively minor reductions in numbers of a few overabundant and/or undesirable species, and consequently was found to have no adverse impact on either the individual populations of those species or the sport fishery. Entrainment was affected by a 26-percent reduction in cooling-water use by the utility during the 1976 spawning season. Taking this factor into consideration did not change our evaluation of the potential impact of the intake system on the fishery.

INTRODUCTION

A 1-year study was conducted to assess the effects of the Kincaid Generating Station's intake system upon the fish population of Lake Sangchris. Entrained fish eggs, larvae, and small juveniles were collected quantitatively during the period of reproductive activity. Larger fishes were collected from the traveling screens throughout the year to determine the total number and biomass lost by impingement. The number and biomass of fishes impinged and entrained at the Kincaid Generating Station were used in conjunction with estimates of standing crops, fecundities, and natural mortality rates

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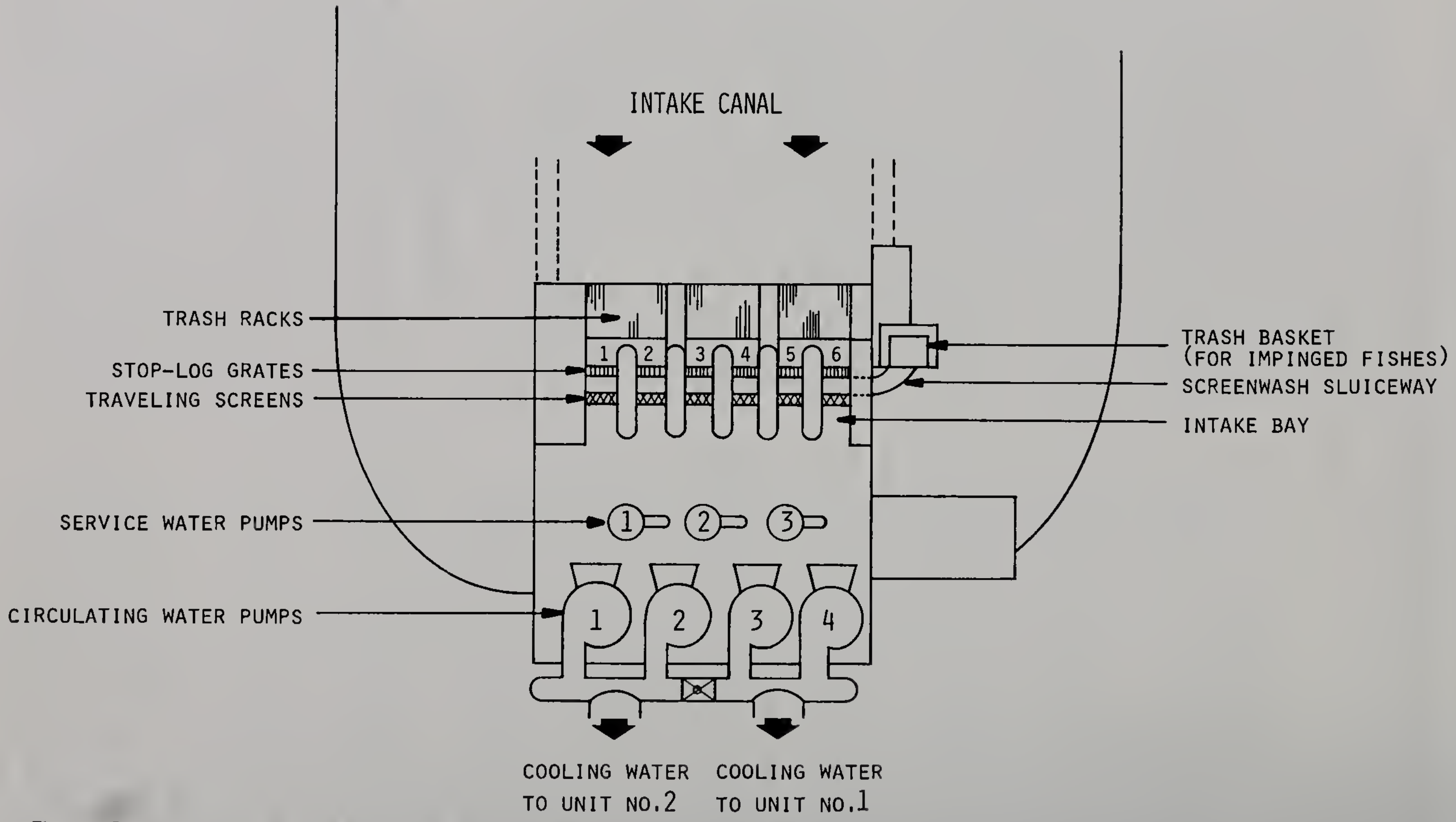


Fig. 1.—Schematic drawing (top view) of the intake structure at Kincaid Generating Station.

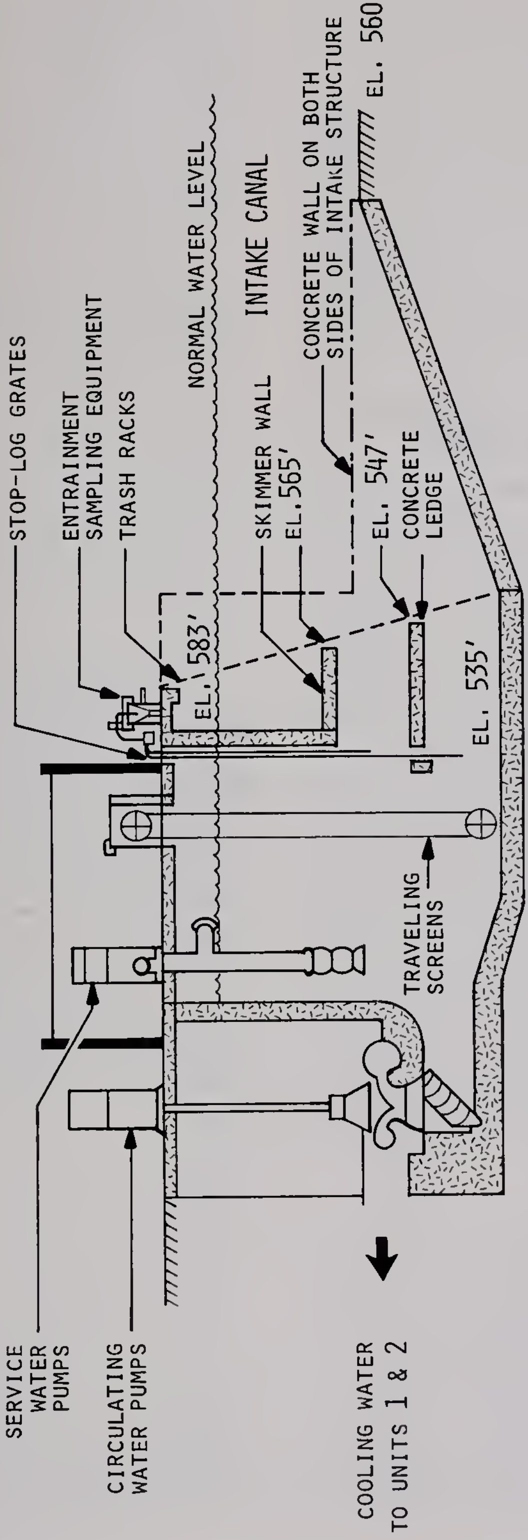


Fig. 2.—Schematic drawing (side view) of the intake structure at Kincaid Generating Station.

to determine the overall effect of the intake system upon the fish community of Lake Sangchris.

The impingement and entrainment sampling schedule was developed in cooperation with Commonwealth Edison Company (CeCo) and represents the level of sampling effort requested by the utility and agreed to by the Illinois Natural History Survey. The sampling program was presented to the U. S. Environmental Protection Agency by CeCo; however, no comments were received from the USEPA.

DESCRIPTION OF THE STUDY AREA

One intake structure, with six intake bays opening into a common pump well, services both generating units at the Kincaid Generating Station (Fig. 1). Vertical trash racks spaced 2.5 inches (6.35 cm) apart prevent large debris from entering the power plant. A skimmer wall directly behind the trash racks extends approximately 6 m below the water's surface (Fig. 2). Behind the skimmer wall are six traveling screens, consisting of panels of heavy steel mesh with 0.375-inch (0.95-cm) square openings, that further obstruct the passage of fish and debris through the intake bays. When the vertically revolving screens are operated, fish and debris are removed by water sprayed from high-pressure nozzles and are washed down a sluiceway into a permanent trash basket lined with 0.25-inch (0.64-cm) mesh hardware cloth. The trash basket outside the cribhouse can be emptied from the bottom for removal of its contents. Fish and debris are removed and transported to a disposal area.

A once-through cooling system is used by the Kincaid Generating Station at Lake Sangchris. Circulating water pumps withdraw water from the intake canal at the rate of 160,000 gpm (605.6 m^3/min) per pump for use as cooling water (Fig. 1 and 2). The number of pumps used depends upon the amount of cooling water needed. Only three of the four circulating pumps were used during the study period, and usually only one or two were in operation at any given time. In addition, three service water pumps are present to provide water for noncooling purposes, and their use is contingent upon the number of generating units in operation. Each service water pump has a maximum capacity of 24,000 gpm (90.8 m^3/min).

IMPINGEMENT

MATERIALS AND METHODS

One 24-hour sample was collected each week from the traveling screens at the intake of the power plant from 10 March 1976 through 13 February 1977. Collections were made twice each week from 21 February through 4 April 1977, when large numbers of fish were being impinged. Two final samples were taken 11 April and 19 April 1977.

Power plant personnel operated the traveling screens, emptied the trash basket, and logged the time of operation on the day preceeding each sampling date. The traveling screens were again operated 24 hours later in the presence of a biologist, who collected the fish from the trash basket. Since the spray nozzles may not always remove every fish from the traveling screens, the screens were observed as they were operated, and any remaining fish were collected and included in the sample. Freezing conditions prohibited use of the permanent trash basket for collecting fish on several winter sampling dates. When the trash basket was inoperable, a portable basket constructed of 0.25-inch (0.64-cm) mesh hardware cloth was used to collect fish. The portable basket was also used from mid-January to 8 February 1977 when the traveling screens were run continuously to alleviate icing problems.

Decayed fish that obviously had been dead for longer than 24 hours were excluded from the impingement sample. Each impinged fish was weighed and measured, and its condition was recorded if it was unusual. When large numbers of gizzard shad (*Dorosoma cepedianum*) and yellow bass (*Morone mississippiensis*) were collected, subsamples were measured to obtain a length frequency distribution and a group weight. For comparison with fishes captured from the intake area by electrofishing, a subsample of 25 fish of the same relative size (gizzard shad 160–200 mm and yellow bass 100–140 mm in total length) and of both sexes was selected from the total impingement sample for the calculation of condition factors. The coefficient of condition (K) was calculated according to the formula $K = W \times 10^5/L^3$, where W is the weight in grams and L is the total length in millimeters (Carlander 1969).

Velocity profiles (measured with a General Oceanics flowmeter, model 2035) and samples for the measurement of water-quality parameters (pH, conductivity, dissolved oxygen, and temperature) were taken through stoplog grates (Fig. 2) in front of the traveling screens.

RESULTS AND DISCUSSION

A total of 30,222 fish that weighed 534.3 kg (1,176.9 lb) were collected in 63 samples washed from the traveling screens from 10 March 1976 through 19 April 1977 (Table 1). Of all fish collected, 94.85 percent were impinged during the 4-month period from December 1976 through March 1977. Fourteen species representing six families were collected in the samples (Table 2). Gizzard shad (78.62 percent) and yellow bass (19.36 percent) constituted 97.98 percent of the total fish in the samples. The percentages of other fishes collected from the intake screens were bluegill, *Lepomis macrochirus,* 0.89 percent; white bass, *Morone chrysops,* 0.34 percent; channel catfish, *Ictalurus punctatus,* 0.23 percent; black bullhead, *Ictalurus melas,* 0.19 percent; and green sunfish, *Lepomis cyanellus,* 0.16 percent. White crappie, *Pomoxis annularis;* yellow bullhead, *Ictalurus natalis;* largemouth bass, *Micropterus salmoides;* freshwater drum, *Aplodinotus grunniens;* flathead catfish, *Pylodictis olivaris;* carp, *Cyprinus carpio;* and golden shiner, *Notemigonus crysoleucas,* comprised the remaining 0.21 percent of the total number of fish collected.

The volume of condenser cooling water used during each 24-hour sampling period from March 1976 through April 1977 was used to calculate monthly fish impingement rates per unit volume of water. Between 11.9 and 30.1 percent of the total condenser cooling water used by the station each month was sampled for fish impingement (Table 3). Since the

Table 1.—Total numbers, weights in grams, and monthly percentages of total numbers and weights of fish impinged on traveling screens at the Kincaid Generating Station from March 1976 through 19 April 1977.

Year and Month	Number of Sampling Dates	Fish Collected	Percent of Fish Collected	Weight of Fish	Percent of Weight
1976					
March	4	153	0.51	4,317	0.81
April	4	153	0.51	8,669	1.62
May	5	206	0.68	7,364	1.38
June	4	38	0.13	961	0.18
July	4	11	0.04	737	0.14
August	4	6	0.02	189	0.04
September	4	2	< 0.01	41	<0.01
October	4	2	< 0.01	533	0.10
November	5	256	0.85	10,875	2.04
December	4	2,764	9.15	97,014	18.16
1977					
January	4	3,222	10.66	93,341	17.47
February	5	11,437	37.84	123,024	23.02
March	8	11,243	37.20	165,899	31.05
April	4	729	2.41	21,334	3.99
Total	*63*	*30,222*	*100.00*	*534,298*	*100.00*

Table 2.—Numbers, weights in grams, average weights, lengths in millimeters, and percentage of fishes impinged on traveling screens at the Kincaid Generating Station each month from March 1976 through 19 April 1977.

	1976										1977					
Species	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April 1–19	Total	Percent of Total
Gizzard Shad																
Number	43	44	65	...	...	1	...	1	219	2,552	3,102	11,046	6,559	128	23,760	78.62
Weight	1,497	1,232	1,751	...	...	100	...	3	8,924	91,945	89,905	110,505	50,945	2,951	359,758	67.33
Avg. Weight	35	28	27	...	...	100	...	3	41	36	29	10	8	23	15	...
Length Range	101–240	91–200	91–200	...	...	254	...	73	61–280	61–290	61–280	71–290	71–250	71–240	61–290	...
Yellow Bass																
Number	103	74	111	31	1	...	1	...	15	57	61	300	4,566	530	5,850	19.36
Weight	2,019	1,877	3,715	478	17	...	40	...	471	2,180	2,251	9,674	106,516	13,270	142,497	26.67
Avg. Weight	20	25	33	15	17	...	40	...	31	38	37	32	23	25	24	...
Length Range	81–220	81–210	81–200	91–150	114	...	154	...	71–180	101–200	71–190	71–220	71–230	71–230	71–230	...
White Bass																
Number	2	15	1	1	...	...	...	...	...	22	2	14	33	14	104	0.34
Weight	47	3,587	13	233	...	...	...	...	...	431	14	228	6,111	1,893	12,557	2.35
Avg. Weight	24	239	13	233	...	...	...	...	...	20	7	16	185	135	121	...
Length Range	111–180	101–360	124	285	...	...	...	...	...	71–210	91–110	81–200	81–370	91–330	71–370	...
Bluegill																
Number	...	5	17	4	1	1	1	...	12	68	34	48	44	34	269	0.89
Weight	...	223	902	205	50	32	1	...	287	...	802	991	514	1,621	7,553	1.41
Avg. Weight	...	45	53	41	50	32	1	...	24	28	24	21	12	48	28	...
Length Range	...	121–160	101–170	131–170	146	125	43	...	41–170	31–180	41–190	41–190	31–170	91–180	31–190	...
Green Sunfish																
Number	...	...	1	...	...	...	...	...	...	18	3	9	15	3	49	0.16
Weight	...	...	14	...	...	...	...	...	...	229	24	32	154	28	481	0.09
Avg. Weight	...	...	14	...	...	...	...	...	...	13	8	4	10	9	10	...
Length Range	...	...	93	...	...	...	...	...	...	41–130	51–110	41–90	31–160	71–110	31–160	...
Largemouth Bass																
Number	...	...	...	...	1	...	...	...	1	6	1	...	...	1	10	0.03
Weight	...	...	...	...	366	...	...	...	2	21	4	...	...	146	539	0.10
Avg. Weight	...	...	...	...	366	...	...	...	2	4	4	...	...	146	54	...
Length Range	...	...	...	...	313	...	...	...	59	61–80	88	...	...	243	59–313	...
White Crappie																
Number	2	4	3	...	...	1	...	...	3	1	...	5	2	1	22	0.07
Weight	546	1,145	461	...	...	54	...	...	1,082	44	...	930	522	39	4,823	0.90
Avg. Weight	273	286	154	...	...	54	...	...	361	44	...	186	261	39	219	...
Length Range	261–300	261–300	111–260	...	...	168	...	...	261–330	185	...	151–300	251–280	168	111–330	...

Table 2.—Continued.

	1976										1977					
Species	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April 1-19	Total	Percent of Total
Channel Catfish																
Number	...	2	...	1	5	3	...	...	2	35	16	2	3	1	71	0.23
Weight	...	76	...	4	129	3	...	...	11	167	78	11	352	160	991	0.19
Avg. Weight	...	38	...	4	26	1	...	...	6	5	5	6	117	160	14	...
Length Range	...	161-200	...	85	71-210	41-60	...	...	81-110	61-120	71-100	81-90	71-340	251	41-340	...
Black Bullhead																
Number	3	8	6	1	3	...	...	...	2	1	...	6	11	16	57	0.19
Weight	208	519	418	41	175	...	...	...	52	53	...	430	653	1,168	3,717	0.70
Avg. Weight	69	65	70	41	59	...	...	...	26	53	...	72	59	73	65	...
Length Range	171-210	171-220	161-230	201	191-220	...	...	...	121-140	192	...	61-230	181-230	171-210	61-230	...
Yellow Bullhead																
Number	...	...	2	...	...	...	...	...	...	2	...	6	9	1	20	0.07
Weight	...	...	90	...	...	...	...	...	...	10	...	87	31	58	276	0.05
Avg. Weight	...	...	45	...	...	...	...	...	...	5	...	15	3	58	14	...
Length Range	...	...	131-200	...	...	...		...	...	61-90	...	71-190	61-80	168	61-200	...
Flathead Catfish																
Number	...	...	...	...	...	...	...	...	2	...	...	...	...	...	2	<0.01
Weight	...	...	...	...	...	...	...	...	46	...	...	...	...	...	46	<0.01
Avg. Weight	...	...	...	...	...	...	...	...	23	...	...	...	...	...	23	...
Length Range	...	...	...	...	...	...	...	...	61-190	...	...	...	...	...	61-190	...
Freshwater Drum																
Number	...	...	...	...	...	...	...	...	...	2	3	1	1	...	7	0.02
Weight	...	...	...	...	...	...	...	...	...	9	263	136	101	...	509	0.10
Avg. Weight	...	...	...	...	...	...	...	...	...	5	88	136	101	...	73	...
Length Range	...	...	...	...	...	...	...	...	...	61-90	51-270	268	217	...	51-270	...
Carp																
Number	...	...	...	...	...	...	...	1	...	...	...	...	...	...	1	<0.01
Weight	...	...	...	...	...	...	...	530	...	...	...	...	...	...	530	0.10
Avg. Weight	...	...	...	...	...	...	...	530	...	...	...	...	...	...	530	...
Length Range	...	...	...	...	...	...	...	385	...	...	...	...	...	...	385	...
Golden Shiner																
Number	...	1	...	...	...	...	...	...	...	...	...	...	...	...	1	<0.01
Weight	...	21	...	...	...	...	...	...	...	...	...	...	...	...	21	<0.01
Avg. Weight	...	21	...	...	...	...	...	...	...	...	...	...	...	...	21	...
Length Range	...	148	...	...	...	...	...	...	...	...	...	...	...	...	148	...

Table 3.—The volume of cooling water used by Kincaid Generating Station, the percentage sampled for fish impingement, the number of sampling dates, and the average number of fish impinged per unit volume of water from March 1976 through April 1977.

Month	Volume of Cooling Water (1×10^6 gal or $1 \times 3,785$ m^3)	Number of Sampling Dates	Percent of Cooling Water Sampled	Average Number of Fish Impinged per 1×10^9 gal or 3.785×10^6 m^3
1976				
March	12,442	4	15.3	80.5
April	12,902	4	13.2	89.5
May	15,898	5	12.9	100.4
June	13,594	4	13.8	20.2
July	15,667	4	11.9	5.9
August	5,591	4	23.8	4.5
September	5,904	4	17.2	2.0
October	13,363	4	12.1	1.2
November	13,363	5	14.0	136.4
December	21,427	4	13.0	989.4
1977				
January	21,427	4	13.2	1,141.6
February	17,510	5	17.2	3,800.2
March	20,275	8	30.1	1,842.9
April 1–19	11,981	4	22.2	274.1
Average	*14,382*	*4.5*	*16.4*	*606.3*

variability in cooling water use by the station affected the rate of fish impingement, the level of plant operation was accounted for in the projections. The number of fish collected per month was divided by the amount of condenser cooling water sampled per month to determine monthly impingement rates. For all fish species, the highest impingement rates occurred during the winter and early spring with a peak of 3,800 fish per billion gallons (0.001 fish/m^3) of cooling water in February 1977. Gizzard shad constituted 95.9 percent of the total number of fish collected from December 1976 through February 1977 (Table 2). The combined total of gizzard shad and yellow bass constituted 99.8 percent of the fish collected in March 1977 and 95.4 percent in March 1976. Very few fish were impinged on the intake screens during summer and early fall. All monthly impingement rates from June through October 1976 were less than 20 fish per billion gallons (5 x 10^{-6} fish/m^3) of cooling water (Table 3).

The monthly impingement rate and the volume of water used by the Kincaid Generating Station were used to estimate the total number and total weight of each species impinged per month. An estimated 158,853 fish that weighed 3,062.9 kg (6,752.4 lb) were impinged on the traveling screens from March 1976 through 19 April 1977 (Table 4).

Only yellow bass and gizzard shad were impinged in sufficient numbers to have a potential effect on the Lake Sangchris fishery. Since all impinged fish collected from the intake trash basket are disposed of, 100-percent mortality was assumed for the purpose of evaluation.

In six surveys Tranquilli et al. (1981) determined the average standing crop of gizzard shad in Lake Sangchris to be 275.3 kg/ha, or 8,309 fish per hectare. The total surface area of Lake Sangchris is 876 ha. During the study period an estimated 132,457 gizzard shad that weighed 2,309.9 kg were impinged by the power plant (Table 4). Thus, 1.82 percent of the lake area (15.9 of 876 ha) would be required to produce the number of impinged gizzard shad. However, only 0.96 percent of the lake area (8.4 ha) would produce the biomass of impinged shad. The difference estimated by biomass and number indicates that the average size of impinged gizzard shad was smaller than the average size of all gizzard shad present in the lake.

Gizzard shad, the major forage fish in Lake Sangchris, are overabundant, constituting 76.3 percent of the total biomass (Tranquilli et al. 1981). Although providing excellent forage when small, they quickly grow out of that size category, and the adults are considered rough fish that compete with sport fishes for food and space. Since a part of any sport fishery management plan for Lake Sangchris should include a recommendation to reduce the gizzard shad population drastically, the loss of shad through impingement should not be considered detrimental to the overall fishery.

The total number of yellow bass impinged during this study was estimated at 22,648 fish, weighing 567.2 kg (Table 4). The average standing crop of yellow bass in Lake Sangchris was determined to be 9.2 kg/ha, or 329 fish per hectare (Tranquilli et al. 1981). Thus, the yellow bass that were impinged on the traveling screen accounted for 7.86 percent by number and 7.04 percent by weight of the standing crop of yellow bass in Lake Sangchris. To produce this number of yellow bass requires 68.8 ha of the lake area, but production of this weight requires only 61.7 ha.

Yellow bass do not reach sizes of interest to most Lake Sangchris anglers and have almost no economic or sport fish value. They feed almost entirely on zooplankton and, in littoral areas, compete heavily with bluegills and young-of-the-year

Table 4.—Estimated numbers and weights in grams of fishes impinged on traveling screens at the Kincaid Generating Station from March 1976 to 19 April 1977, along with the percentages of the totals for the entire period.

	1976										1977						
Species	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April 1–19	Total	Pounds	Percent of Grand Total
Gizzard Shad																	
Number	281	332	504	...	...	4	...	8	1,559	19,574	23,550	64,269	21,799	577	132,457	...	83.38
Weight	9,799	9,302	13,574	...	...	419	...	25	63,534	705,228	682,544	642,938	169,321	13,295	2,309,979	(5,092.6)	75.42
Yellow Bass																	
Number	674	559	860	225	8	...	6	...	107	437	463	1,745	15,176	2,388	22,648	...	14.26
Weight	13,215	14,089	28,798	3,461	14°	...	233	...	3,353	16,720	17,089	56,285	354,017	59,787	567,190	(1,250.4)	18.52
White Bass																	
Number	13	113	8	7	...	...	6	...	...	169	15	81	110	63	585	...	0.37
Weight	308	27,084	101	1,688	...	...	6	...	...	3,306	106	1,327	20,311	8,529	62,766	(138.4)	2.05
Bluegill																	
Number	...	38	132	29	8	4	...	...	85	522	258	279	146	153	1,654	...	1.04
Weight	...	1,684	6,992	1,485	422	134	...	...	2,043	14,765	6,089	5,766	1,708	7,303	48,391	(106.7)	1.58
Green Sunfish																	
Number	...	...	8	...	...	...	...	...	...	138	23	52	50	14	285	...	0.18
Weight	...	...	109	...	...	...	...	...	...	1,756	182	186	512	126	2,871	(6.3)	0.09
Largemouth Bass																	
Number	...	...	...	...	8	...	...	...	7	46	8	...	...	5	74	...	0.05
Weight	...	...	...	...	3,086	...	...	...	14	161	30	...	...	658	3,949	(8.7)	0.13
White Crappie																	
Number	13	30	23	...	...	4	...	...	21	8	121	29	7	5	261	...	0.16
Weight	3,574	8,645	3,574	...	...	226	...	...	7,703	337	592	5,411	1,735	176	31,973	(70.5)	1.04
Channel Catfish																	
Number	...	15	...	7	42	13	...	...	14	268	...	12	10	5	386	...	0.24
Weight	...	574	...	29	1,088	13	...	...	78	1,281	...	64	1,170	721	5,018	(11.1)	0.16
Black Bullhead																	
Number	20	60	47	7	25	...	...	...	14	8	...	35	37	72	325	...	0.20
Weight	1,361	3,919	3,240	297	1,476	...	...	...	370	407	...	2,502	2,170	5,262	21,004	(46.3)	0.69

Table 4.—Continued.

	1976										1977						
Species	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April 1–19	Total	Pounds	Percent of Grand Total
Yellow Bullhead																	
Number	...	...	16	...	...	...	...	...	...	15	...	35	30	5	101	...	0.06
Weight	...	...	698	...	...	...	...	...	...	77	...	506	103	261	1,645	(3.6)	0.05
Flathead Catfish																	
Number	...	...	...	...	...	...	...	...	14	...	...	...	...	...	14	...	<0.01
Weight	...	...	...	...	...	...	...	...	327	...	...	...	...	...	327	(0.7)	<0.01
Freshwater Drum																	
Number	...	...	...	...	...	...	...	...	...	15	23	6	3	...	47	...	0.03
Weight	...	...	...	...	...	...	...	...	...	69	1,998	791	336	...	3,194	(7.0)	0.10
Carp																	
Number	...	...	...	...	...	...	...	8	...	...	...	...	...	...	8	...	<0.01
Weight	...	...	...	...	...	...	...	4,378	...	...	...	...	...	...	4,378	(9.7)	0.14
Golden Shiner																	
Number	...	8	...	...	...	...	...	...	...	...	...	...	...	...	8	...	<0.01
Weight	...	159	...	...	...	...	...	...	...	...	...	...	...	...	159	(0.4)	<0.01
Totals																	
Number	*1,001*	*1,155*	*1,598*	*275*	*91*	*25*	*12*	*16*	*1,821*	*21,200*	*24,461*	*66,543*	*37,368*	*3,287*	*158,853*	...	*100.00*
Weight	*28,257*	*65,456*	*57,086*	*6,960*	*6,215*	*792*	*239*	*4,403*	*77,422*	*744,107*	*708,630*	*715,776*	*551,383*	*96,118*	*3,062,844*	*(6,752.4)*	*100.00*

largemouth bass for this limited food resource. Although yellow bass in Lake Sangchris are relatively small, they are not preferred forage for other sport fishes. Thus, these yellow bass could best be described as undesirable rough fish. Since the Lake Sangchris fishery would probably be more productive of sport fishes if the yellow bass population were reduced or eliminated, the observed mortality of yellow bass by impingement is, like that of gizzard shad, not considered detrimental to the Lake Sangchris fishery.

Velocities of water currents were measured in front of the six intake screens of the Kincaid Generating Station under varying modes of operation when one to three circulating water pumps were running. A maximum velocity of 0.34 m/second (1.12 ft/second) was recorded when three pumps were running (Table 5). Water velocities were typically very low from the surface down to the 5-m depth due to the presence of the skimmer wall. The highest velocities were recorded at depths of 6–8 m. At 9 m a concrete brace partially blocked the flow (Fig. 2), but from 10 to 11.5 m the velocities were again relatively high. From our observations of the eddies between the skimmer wall and the traveling screens and the fluctuating values that we observed on the flowmeter, we concluded that the flow of water through the intake structure was turbulent. However, the intake velocities were not high enough to impinge all fish in the vicinity of the traveling screens, because congregations of fish were often observed swimming at the surface on the pump side of the skimmer wall.

Small fishes were most vulnerable to impingement. The average weight of impinged fish was only 19 g (Table 4). One largemouth bass, one carp, and several white crappies and white bass longer than 300 mm were found in the impingement samples, but 93.8 percent of all fishes collected from the intake screens were less than 200 mm in total length. Latvaitus (1976) attributed the large number of small fish impinged at the Quad Cities Nuclear Plant on the Mississippi River to the inability of smaller individuals to escape the turbulence and velocity of the intake currents. Length frequency distributions for gizzard shad, yellow bass, and 12 additional fish species impinged at the Kincaid Generating Station indicated that the majority were young-of-the-year individuals (Fig. 3).

On impingement and entrainment sampling dates, water temperature, dissolved oxygen, and conductivity were measured in profiles (1-m intervals) at the intake structure. The mean dissolved oxygen value ranged from 6.6 to 12.2 ppm, while the mean specific conductance (standardized to 25°C) ranged from 549 to 657 μmho/cm. Mean hydrogen ion concentration (pH) measured at the sur-

Table 5.—Velocities (cm/sec) measured in front of the intake screens at Kincaid Generating Station, 25 March 1977, when circulating water pumps 1, 2, and 3 (Fig. 1) were in operation[a]

	Screen Number					
Depth in Meters	1	2	3	4	5	6
Surface	0–8	0–7	0–6	0	0	0
1	0	2–10	0	0	0	0
2	5–7	4–8	0	0	0–6	0
3	4–8	0–8	0	0	0	0
4	0	0	0	0	0	0
5	24–26	0–6	0–6	0–8	0–10	0
6	26–30	28–34	24–30	22–30	22–25	22–26
7	14–20	24–26	16–20	17–21	14–20	12–16
8	16–20	28–30	16–18	18–20	12–14	10–14
9	0–6	6–10	0–8	0–6	4–9	0
10	22–24	20–26	11–15	10–16	8–12	14–16
11	14–18	16–18	10–12	12–14	6–10	7–11
11.5	18–21	12–15	14–16	12–14	8–12	4–10

[a] The lake level was 582.7 feet above sea level when these measurements were taken.

face ranged from 7.8 to 9.2. During the study period the only water quality parameter associated with high rates of fish impingement was water temperature.

Cold water temperatures are known to make fish sluggish during the winter and early spring. McConnell (1975) and Latvaitus (1976) suggested that the decreased

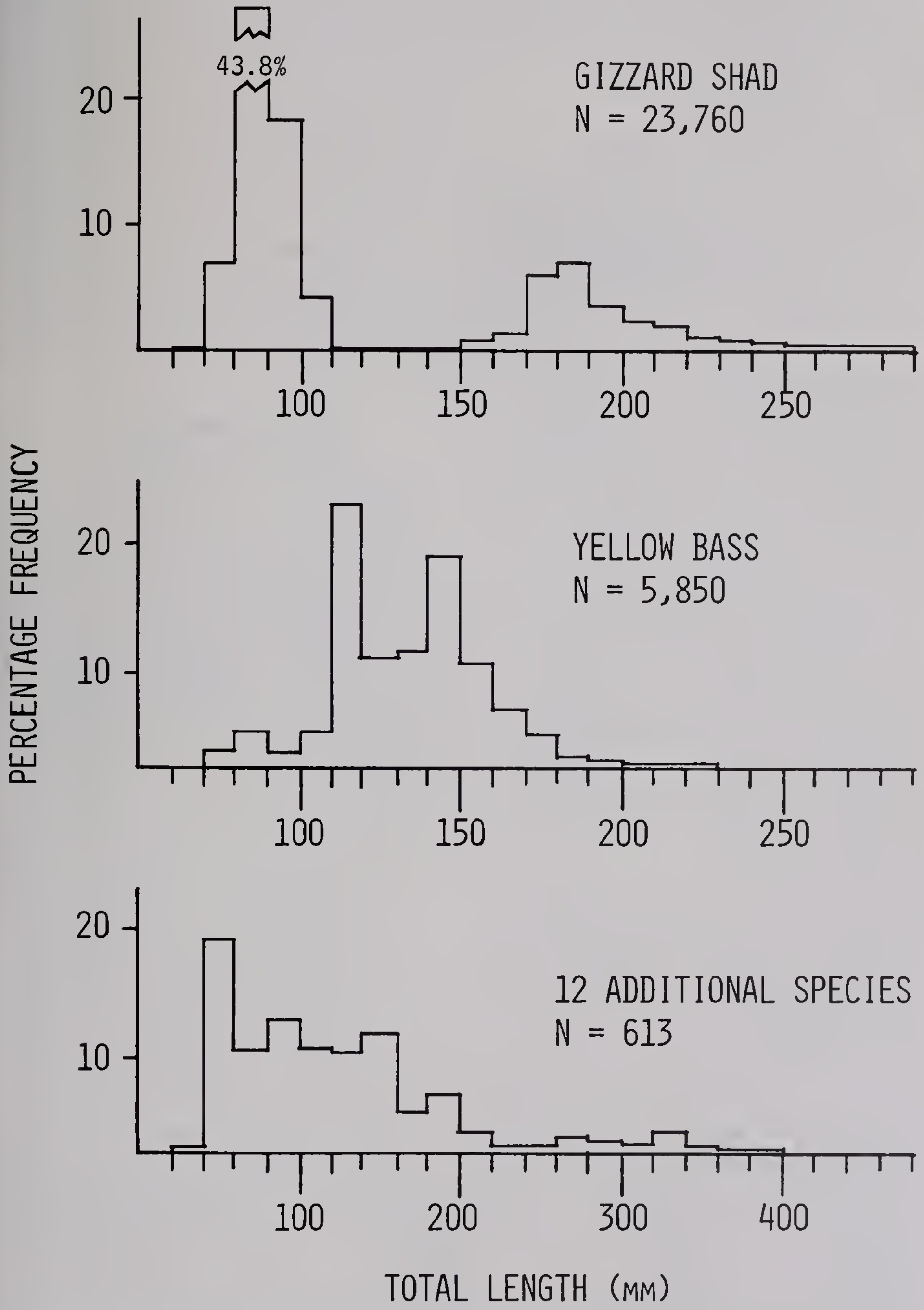


Fig. 3.—Length-frequency distribution of weekly samples of gizzard shad, yellow bass, and 12 additional fish species impinged on the intake screens of Kincaid Generating Station from March 1976 to April 1977.

mobility of fish during cold weather may not allow them to avoid the intake screens or to free themselves if they are impinged. A natural winter die-off of fishes could also affect the rate of impingement. Mass mortality of gizzard shad was observed during the winter in New Mexico, when water temperatures fell below 3.3°C (Jester & Jensen 1972).

During the springs of 1976 and 1977, a large number of impinged fish were infested with aquatic fungi. Bennett (1970) reported that condition to be associated with reduced resistance to infection as a result of winter conditions and rising water temperatures.

Emaciated fish were frequently found in impingement samples. A comparison of coefficients of condition (K) was made between gizzard shad impinged at Kincaid Generating Station and samples collected from the intake area of Lake Sangchris by electrofishing during March, May, and November 1976. A similar comparison was made for yellow bass during March (Table 6). Although fish from the two locations were of the same relative size, the samples collected from the lake consisted entirely of males, while the samples from the impingement collection were composed of fish of both sexes. Since ovaries usually are larger than testes, a larger mean condition value would be expected for the fish from the impingement sample as a result of the bias due to sex. In addition, Larimore (1952) showed that when temperatures were below 21°C, as in this comparison, fish gained weight immediately after death for a period of more than 24 hours due to absorption of water through the skin. In spite of such bias, the mean condition of impinged fish was significantly lower ($P < 0.01$) than the mean K value of fish from the intake area for all months in which comparisons could be made. These data indicate that the fish most vulnerable to entrainment by the power plant are individuals in poor body condition, weaker individuals that would be selected by natural predators in the lake itself.

The higher impingement rates observed during the winters and early springs of 1976 and 1977 may also have been associated with the greater use of cooling water by the Kincaid Generating Station at those times and by the attraction of fish to the intake area by the warm water recirculated into the intake canal by deicing pipes.

ENTRAINMENT

MATERIALS AND METHODS

From 25 March through 15 April 1976, entrainment samples were taken from a boat at the intake canal of the Kincaid Generating Station through a 1.5-inch (3.81-cm) diameter plastic hose and a centrifugal pump. Intake water was pumped through a No. 3 mesh (0.333-mm) plankton net suspended partially in the water from the boat. Nine 45-minute pump samples were taken over a 12-hour period at an average rate of 54 gpm (0.204 m^3/min). Three depths were individually sampled at three stations (one located in front of each of the three vertical trash racks) in random order.

From 22 April to 12 August 1976, 24-hour entrainment samples were taken twice each week through the stop-log grates on top of the intake structure (Fig. 2). Samples were taken at weekly intervals from 12 August through 4 October 1976.

Table 6.—Comparison of the mean coefficient of condition (K) between fish captured by electrofishing in the intake area of Lake Sangchris and fish impinged at Kincaid Generating Station in 1976.

		K Value	
Species	Month	Intake Area (N)	Impingement Sample (N)
Gizzard shad	March[a]	0.96 (12)	0.57 (25)
Gizzard shad	May[a]	0.94 (25)	0.56 (25)
Gizzard shad	Nov.[a]	0.88 (25)	0.57 (25)
Yellow bass	March[a]	1.15 (19)	1.05 (19)

[a] In these months means were significantly different ($P < 0.01$) by one-way analysis of variance.

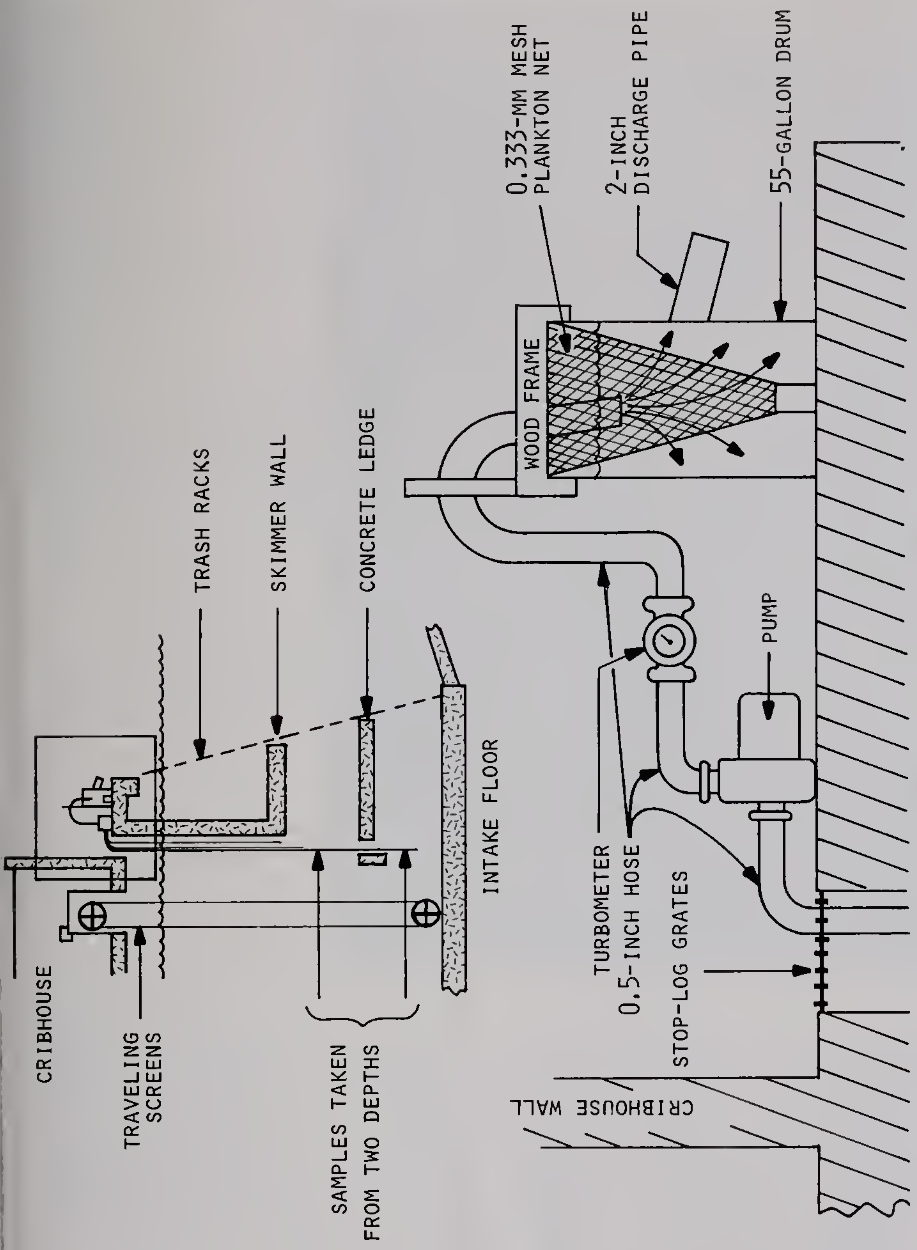
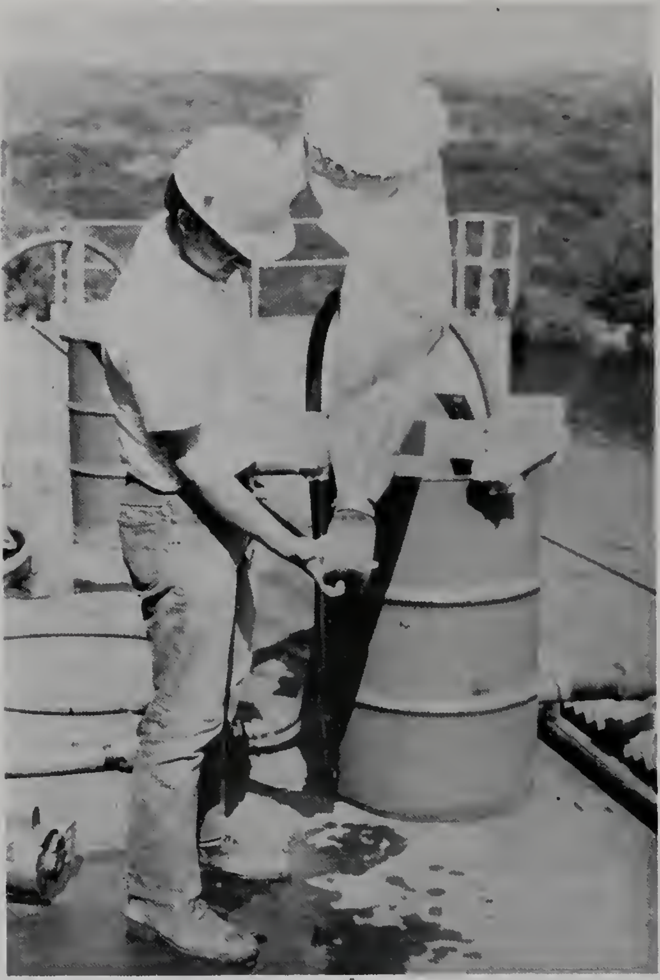


Fig. 4.—Diagram of fish egg and larvae sampling equipment. The area of the drawing at the top that is enclosed in a square is shown in greater detail below.

A Teel centrifugal pump (model 5K476C) with a 1.5-inch (3.81-cm) reinforced hose was used to pump intake water through a No. 3 mesh (0.333-mm) plankton net. The plankton net was suspended in a 55-gallon drum (Fig. 4). The discharge hose from the pump was placed in the net and submerged to reduce mechanical damage to the organisms. About two-thirds of the barrel remained full of water while the sample was taken, and the excess water drained out through a 2-inch (5.08-cm) discharge pipe.

Only one sample was taken at the intake structure from the 8-m depth until 6



Collecting an entrainment sample from the intake canal of the Kincaid Generating Station.

May, when a second pump was obtained. Throughout the remainder of the study period, two depths were sampled simultaneously from the same intake bay. An intake bay directly in front of one or between two operating circulating water pumps was chosen. The depths sampled at the intake were (1) between the bottom of the skimmer wall and a horizontal concrete ledge at approximately 8 m and (2) between the concrete ledge and the bottom of the intake structure at approximately 12.5 m (Fig. 2 and 4).

The total volume of individual pump samples was measured on one pump with a Rockwell turbometer (model W-160DR) connected between the pump and the plankton net (Fig. 4). Average pumping rates calculated from metered samples were used to determine the volumes of unmetered samples.

From June through October 1976, organisms were collected from the plankton nets at approximately 4-hour intervals to investigate diurnal differences in entrainment rates of fish eggs and larvae. That procedure also reduced the amount of damage to larval fish experienced during less frequent collecting prior to June.

All samples were preserved in 5-percent formalin. Samples were returned to the laboratory, where all fish eggs and larvae were sorted from other organisms captured by the plankton net. Fish eggs were counted but not identified. Larval fishes were counted and identified to the lowest possible taxonomic level, using keys and literature by Fish (1932), Mansueti & Hardy (1967), May & Gasaway (1967), Meyer (1970), and Hogue et al. (1976). Ichthyoplankton data were standardized into catch per unit effort and expressed as number of fish eggs (or larvae) per 10 m^3 of water.

Velocity profiles and water parameters were measured through the stop-log grates in front of the traveling screens. Pump data were obtained from power plant personnel.

RESULTS AND DISCUSSION

A total of 218 fish eggs was collected during the study period. Most of the eggs (99.5 percent) were collected from 31 May through 12 August (Fig. 5). The greatest number of fish eggs found in 1 day was collected on 1 July at a density of 0.895 fish eggs/10 m^3.

Fish eggs were collected in very low numbers at depths of 8 m and 12.5 m during the study period. A *t* test indicated no significant differences ($P < 0.05$) between the numbers of fish eggs collected at the two depths.

To estimate the total number of fish eggs entrained by the Kincaid Generating Station, the mean density of eggs was multiplied by the total flow of water through the plant during the major period of egg entrainment from 31 May through 12 August. An estimated 2.2 million eggs were entrained during the 1976 spawning season. Since so few eggs were collected, a rigorous evaluation of the impact of fish-egg entrainment was not made. However, the estimate of 2.2 million entrained eggs appears minimal when considering the prolific nature of most fish species. For example, data cited by Carlander (1969) showed fecundities for age II gizzard shad ranging from 211,378 to 543,912 eggs per female. Low fish-egg entrainment rates might have been expected, because all species of fish in Lake Sangchris, with the exception of freshwater drum, have demersal or semibouyant adhesive eggs.

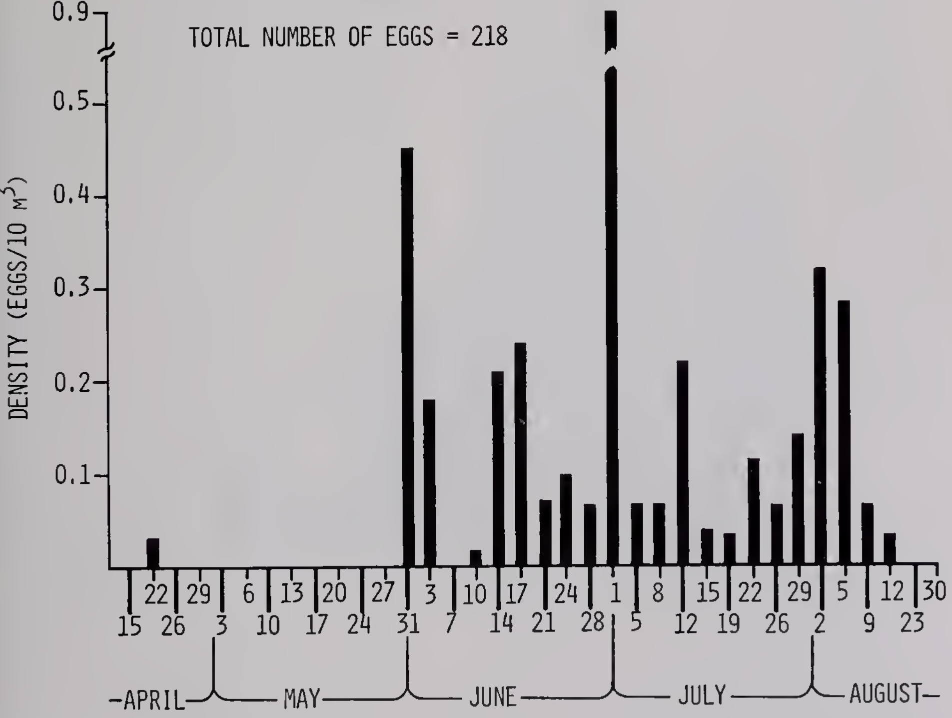


Fig. 5.—Density of fish eggs collected at the intake of Kincaid Generating Station during 24-hour pump samples taken from 15 April through 30 August 1976.

Table 7.—Total numbers, mean densities (larvae/10 m³), and percentages of fish larvae collected during 24-hour pump samples at the intake of the Kincaid Generating Station, 15 April through 7 September 1976.

Taxon	Larvae Collected	Mean Number per 10 m³	Percent of Larvae Collected
Gizzard shad	18,594	9.494	85.61
Morone	876	0.447	4.03
Lepomis	143	0.073	0.66
Freshwater drum	19	0.010	0.09
Flathead catfish	3	0.002	0.01
Channel catfish	2	0.001	0.01
Cyprinidae	1	0.001	<0.01
Unidentified larvae	2,082	1.063	9.59
Total	*21,720*	*11.091*	*100.00*

A total of 21,720 fish larvae, representing seven taxa, and 2,082 unidentified fish larvae were collected during the study period (Table 7). Larval fishes were collected on 35 of the 44 sampling dates from 25 March through 4 October 1976. Larvae first appeared in the samples on 15 April at a mean density of 0.348 larvae/10 m³ of water (Fig. 6) Catch per unit effort generally increased to a peak density of 44.674 larval fish/10 m³ of water on 24 May. Concentrations of fish larvae remained relatively high through the middle of June and gradually decreased until 7 September, when the last larval fish was collected.

Gizzard shad, the most abundant and most frequently occurring species in

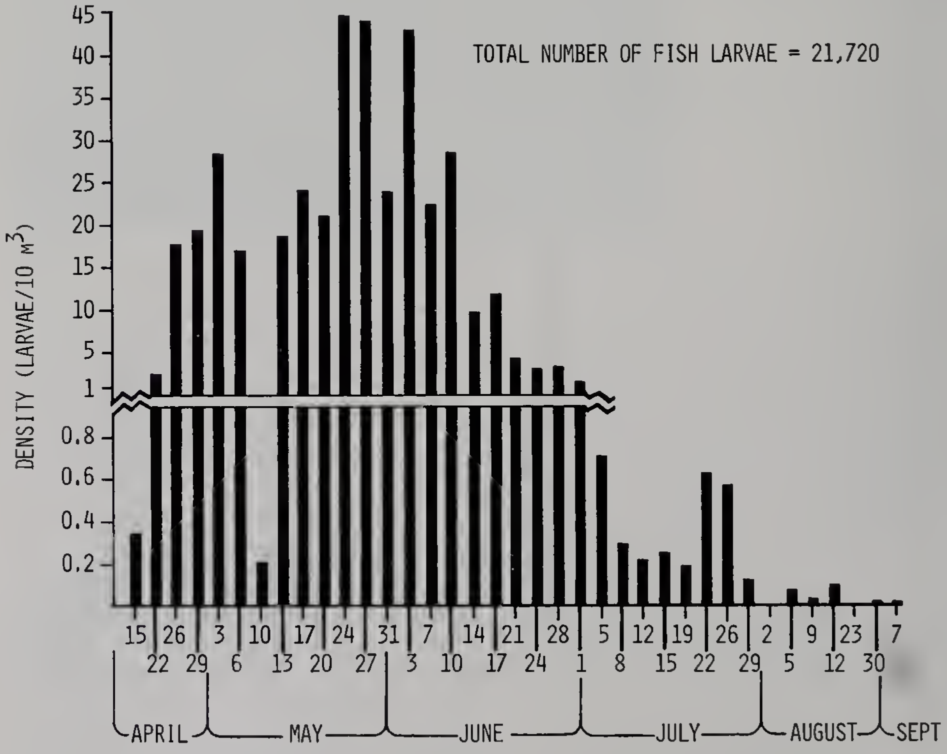


Fig. 6.—Density of fish larvae collected at the intake of Kincaid Generating Station during 24-hour pump samples, 15 April through 7 September 1976.

entrainment samples, constituted 85.6 percent of the larvae collected (Table 7). The percentage of other larval fishes in the samples was *Morone*, 4.03 percent; *Lepomis*, 0.66 percent; and freshwater drum, 0.09 percent. Three flathead catfish, two channel catfish, and one unidentified cyprinid were also collected. Due to mechanical damage caused by the sampling equipment, 9.6 percent of the larvae were decapitated or mutilated and could not be identified; however, we assumed that unidentified larvae occurred in the same proportions as those identified in the collection.

During the spawning season, fish larvae were collected regularly from both depths sampled at the intake structure. Mean densities of fish larvae were significantly higher (*t* test: $P < 0.05$) at 8 m than at 12.5 m. A greater abundance of fish larvae at 8 m may have been associated with the higher intake velocities observed between the skimmer wall (6 m) and a horizontal concrete ledge at 9 m (Table 5).

Diurnal differences in entrainment rates of larval gizzard shad were compared on 27 May and 10 June, when samples were collected at 4-hour intervals for 24 hours. Although densities were highest during hours of darkness, a one-way analysis of variance indicated that no significant diurnal differences ($P < 0.05$) existed during those two series. Higher gizzard shad entrainment rates during the night may have been associated with diurnal differences in the vertical distribution of larval gizzard shad. Bergmann (1981) found few gizzard shad larvae in deep water during daylight and high densities near the bottom of the lake at night. He suggested that the period of highest entrainment would be at night, since cooling water is drawn from 6 m below the surface at Kincaid Generating Station.

Fish larvae that pass through condensers may suffer direct or latent mortality from temperature shock, prolonged exposure to elevated temperatures, mechanical effects, and chemical effects. Although some larval fishes may survive after passing through condensers, Marcy (1974) observed that the percentage of survival may be very low. Consequently, to evaluate the "worst-case" effect of larval fish entrainment by the Kincaid Generating Station, we assumed that all were killed.

The very low numbers of freshwater drum, flathead catfish, channel catfish, and the unidentified cyprinid collected in the samples during the study period indicated that entrainment of those species was negligible. Therefore, an assessment of the impact of larval fish entrainment was only made for gizzard shad, *Morone*, and *Lepomis*.

Use of condenser cooling water at the Kincaid Generating Station during the 1976 spawning season was unusually low. Flow rates from 15 March through 30 August 1976 were compared to flow rates during the same time period in 1974, 1975, and 1977. The mean flow during the "spawning season" for those 3 years was approximately 26 percent greater than the flow during the 1976 season, partially because of a nonscheduled outage at the Kincaid Generating Station from the middle of August through the middle of September. Still, flow rates were lower during the other months as well. Since the amount of cooling water used affects the rate of ichthyoplankton entrainment, 1976 ichthyoplankton entrainment results should be considered lower than normal.

A total of 18,594 gizzard shad larvae was collected during the study period (Table 7). Larval gizzard shad densities were highest from 17 May through 10 June (Fig. 7), when mean water temperatures ranged from 18.4° to 24.2°C. A peak density of 39.14 gizzard shad larvae/10 m^3 was observed on 27 May.

An estimated 214.6 x 10^6 gizzard shad larvae were entrained from 22 April through 21 July 1976 (Table 8). The number was calculated from entrainment rates and cooling water use rates between consecutive sampling dates. The impact of gizzard shad entrainment was assessed by comparing that estimate with the standing crop of larval gizzard shad in Lake

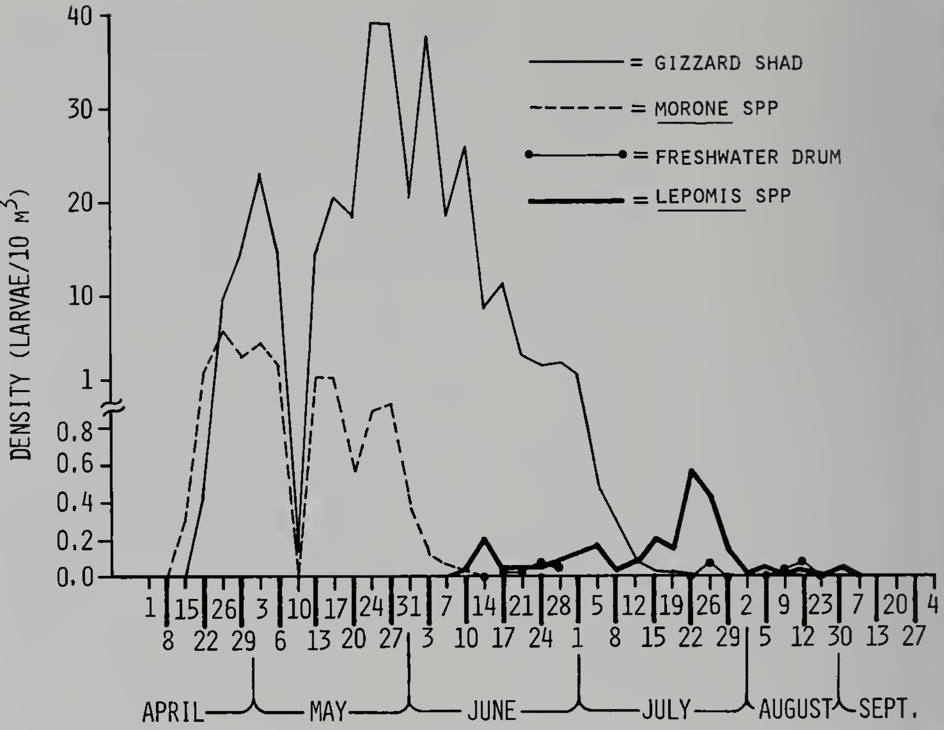


Fig. 7.—Density of major taxa of larval fishes collected at the intake of Kincaid Generating Station during 24-hour pump samples 1 April through 4 October 1976.

Sangchris during the same period (determined from data presented in Bergmann 1981). For that comparison , we assumed that the standing crop of gizzard shad larvae found in the intake and discharge arms of Lake Sangchris was representative of densities of larval shad in the entire lake. The total standing crop of larval gizzard shad in Lake Sangchris during the period of entrainment sampling was estimated to be 4,523.1 x 10^6 fish. This estimate was determined by multiplying the mean daily density of larvae (1,329/m^3) by the total volume of the lake at normal pool (37.4 x $10^6 m^3$) and multiplying the product by the days in the study period (91). The estimated number entrained thus represented 4.74 percent of the estimated standing crop of gizzard shad larvae in Lake Sangchris during 1976.

The impact of larval gizzard shad entrainment was also viewed from the aspect of recruitment. Ricker (1975) postulated that a stable population requires two adults to replace themselves via reproduction during their spawning lifetime. From data cited by Carlander (1969), the weighted mean fecundity of gizzard shad ranging in total length from 282 to 381 mm was determined to be 287,679 eggs per female. To maintain population stability, one egg would have to survive during each of the 2 expected spawning years, or a survival rate of 3.48 x 10^{-6}. Assuming equal rates of natural mortality for development of eggs to larvae and larvae to adults, a survival rate of 1.86 x 10^{-3} (0.19 percent) was calculated. Using that rate, the 214.605 x 10^6 gizzard shad larvae entrained, represent 399.165 x 10^3 potential adults lost to

Lepomis during 1976.

Sampling Date	Cooling Water Used Between Dates ($10\ m^3 \times 10^3$)	Entrainment Rate (Larvae/10 m^3)			Estimated Total Larval Entrainment ($\times 10^3$)		
		Gizzard Shad	*Morone*	*Lepomis*	Gizzard Shad	*Morone*	*Lepomis*
15 April	1,046.5	...	0.348	...	...	364.2	...
22 April	610.4	0.430	1.835	...	262.5	1,120.1	...
26 April	261.6	9.368	6.185	...	2,450.7	1,618.0	...
29 April	1,046.5	14.237	3.344	...	14,899.0	3,499.5	...
3 May	784.9	23.326	4.827	...	18,308.6	3,788.7	...
6 May	872.1	13.923	2.297	...	12,142.2	2,003.2	...
10 May	463.0	0.142	0.036	...	61.9	15.7	...
13 May	784.8	14.620	1.214	...	11,473.8	952.7	...
17 May	523.2	20.841	1.099	...	10,904.0	575.0	...
20 May	697.7	18.221	0.584	...	12,712.8	407.5	...
24 May	523.2	39.114	0.878	...	20,464.4	459.4	...
27 May	697.7	39.140	0.917	...	27,308.0	639.8	...
31 May	523.2	20.453	0.389	...	10,701.0	203.5	...
3 June	697.7	37.864	0.131	...	26,417.7	91.4	...
7 June	523.2	18.973	0.046	...	9,926.7	24.1	...
10 June	697.7	25.862	0.032	0.048	18,043.9	22.3	33.5
14 June	523.2	8.945	...	0.209	4,680.0	...	109.3
17 June	697.7	11.152	...	0.016	7,780.8	...	11.2
21 June	523.2	3.648	...	0.036	1,908.6	...	18.8
24 June	697.7	2.547	...	0.049	1,777.0	...	34.2
28 June	436.0	2.716	...	0.081	1,184.2	...	35.3
1 July	523.2	1.217	...	0.125	636.7	...	65.4
5 July	523.2	0.512	...	0.182	267.9	...	95.2
8 July	697.7	0.281	...	0.017	196.1	...	11.9
12 July	784.9	0.084	...	0.084	65.9	...	65.9
15 July	523.2	0.038	...	0.209	19.9	...	109.3
19 July	697.7	0.016	...	0.147	11.2	...	102.6
22 July	959.3	...	...	0.592	...	...	567.9
26 July	784.9	...	...	0.430	...	...	337.5
29 July	610.4	...	...	0.141	...	...	86.1
2 Aug.	523.2	...	...	...	...	...	...
5 Aug.	697.7	...	...	0.033	...	...	23.0
9 Aug.	261.6	...	...	...	...	...	...
12 Aug.	174.4	...	...	0.033	...	...	5.8
23 Aug.	126.3	...	...	...	...	...	...
30 Aug.	158.6	...	...	0.020	...	...	3.2
7 Sept.	141.7	...	...	...	...	...	...
Total					*214,605.5*	*15,785.1*	*1,716.1*

the population. The average standing crop of gizzard shad in Lake Sangchris was determined to be 8,309 fish per hectare (Tranquilli et al. 1981). Thus, from the aspect of recruitment, the total loss of larval shad in the 876-ha Lake Sangchris system represents 5.48 percent of the numerical standing crop of adults, a value slightly higher than the estimated loss of 4.74 percent obtained by calculation from the estimated standing crop of larval fish in Lake Sangchris. Such a loss appears negligible in light of the abundance of this species in the lake.

Only two members of the genus *Lepomis* are present in Lake Sangchris: bluegills (the more abundant species) and green sunfish. Entrained *Lepomis* larvae were not identified to species because of the difficulty in separating them.

A total of 143 *Lepomis* larvae was collected at the intake from 10 June through 30 August, when mean water temperatures ranged from 23.5° to 28.5°C. Entrainment rates of *Lepomis* larvae were low throughout that period with a peak density of only 0.592 larvae/10 m^3 of water on 22 July (Fig. 7).

The effect of larval *Lepomis* entrainment was assessed by comparing entrainment data with *Lepomis* standing crop estimates determined from 27 May through 5 August, the last date Bergmann (1981) collected larval fishes. During that period, an estimated 1,707,100 *Lepomis* larvae were entrained (Table 8). Assuming equal distribution of larvae throughout the lake, the estimated standing crop of *Lepomis* larvae was calculated to be 520.31 x 10^6 by multiplying the daily mean density of *Lepomis* larvae (0.188/m^3), calculated from Bergmann's data (1981), by the total volume of Lake Sangchris at normal pool and multiplying the product by the days in the study period (74). Thus, approximately 0.33 percent of the estimated numerical standing crop of *Lepomis* larvae were entrained at the Kincaid Generating Station.

The impact of *Lepomis* entrainment was also evaluated from the aspect of recruitment. By number, bluegills constituted 84 percent of the total standing crop of *Lepomis* in Lake Sangchris (Tranquilli et al. 1981). Using that figure and data cited in Carlander (1977), the weighted mean fecundity of bluegills and green sunfish ranging in total length from 102 mm to 177 mm was calculated to be 16,361 eggs per female. To maintain a stable population, a survival rate of 4.1 x 10^{-5} would be required for two eggs to survive to adults over 3 years of expected spawning activity. Assuming equal rates of natural mortality for the development of eggs to larvae and larvae to adults, the estimated entrainment of 1,716,100 *Lepomis* larvae would represent 10,983 potential adults lost to the population at a larval survival rate of 6.4 x 10^{-3} (0.64 percent). This estimate represents a loss of 12.5 fish/ha in Lake Sangchris or 0.59 percent of the total standing crop of 2,114 *Lepomis* /ha found by Tranquilli et al. (1981).

The two species of Percichthyidae in Lake Sangchris are white bass and yellow bass. From 15 April through 10 June 1976, a total of 876 percichthyid larvae were collected at the intake, but no means have been devised for differentiation between larvae of these species (Hogue et al. 1976). The highest entrainment rates occurred from 22 April through 6 May, when mean water temperatures ranged from 13.6° to 18.0°C. A peak density of 6 185 *Morone* larvae/10 m^3 of water sampled was observed on 26 April (Table 8).

The estimate of 15,785,100 *Morone* larvae entrained during 1976 was calculated from entrainment rates and cooling water use rates between consecutive sample dates (Table 8). To evaluate the impact of entrainment, that estimate was compared to numerical standing crop estimates of *Morone* larvae found in Lake Sangchris during the same period (determined from data presented in Bergmann 1981). Assuming equal distribution of larvae throughout the entire lake, the standing crop was calculated by multiplying the daily mean density of *Morone* larvae (0.046/m^3) by the total lake volume at normal pool and multiplying the product by the days in the study period (60). Thus, 15.29 percent of the estimated 103 million *Morone* larvae in Lake Sangchris during 1976 were entrained by the Kincaid Generating Station.

The impact of *Morone* entrainment was not evaluated from the aspect of recruitment because the fecundity of yellow bass of the size range present in Lake Sangchris was not known. Also, white bass have higher fecundities and reach a larger adult size than do yellow bass, and the proportion of the two species as larvae in the lake was not known.

For purposes of evaluation, we assumed 100 percent mortality for entrained fish eggs and larvae. Unlike impinged fishes, however, entrained organisms do not represent a complete loss of energy to the ecosystem because they are recycled to the discharge canal and used by animals in other trophic levels. The seasonal appearance of entrained fish eggs and larvae may serve as a food resource and be partially responsible for the seasonal aggregation of certain species of fishes in the discharge canal (Tranquilli et al. 1981).

Although our sampling schedule was not extensive, it provided useful estimates of the magnitude of fishes lost at the power plant intake, especially in a closed lake system where current population data were available for direct comparison.

ENVIRONMENTAL IMPACT OF THE INTAKE SYSTEM

Although 14 species of fishes were impinged on the traveling screens at Kincaid Generating Station, only gizzard shad and yellow bass were captured in sufficient numbers to have a potential effect on the fish population of the lake. A comparison of impingement losses of these species with their populations in Lake Sangchris indicated that their numbers were reduced by 1.82 and 7.85 percent, respectively, during a 415-day sampling period. Considering the abundance and relative importance of these species in Lake Sangchris, the observed reductions would have no discernible impact on the fishery. In addition, the impinged individuals were in significantly poorer body condition than those captured from the intake area by electrofishing, indicating that stressed individuals were being impinged selectively.

Entrainment of ichthyoplankton was primarily of gizzard shad, *Morone,* and *Lepomis.* When compared with standing crops of larval fishes in the lake at the same time, 4.74 percent of the gizzard shad larvae in Lake Sangchris were entrained during 1976. From the aspect of recruitment, the numerical loss in entrained gizzard shad was very nearly the same at 5.48 percent of the numerical standing crop of adults. The loss of that number of gizzard shad, the principal forage species, would not likely have an adverse impact on either the fishery or the individual population, because the species is already overabundant, constituting 76.3 percent by weight of the total fish biomass (Tranquilli et al. 1981).

Entrainment of *Morone* larvae was estimated to have reduced the numerical standing crop of white and yellow bass in Lake Sangchris by 15.29 percent. A loss of that magnitude would have a detrimental effect if it consisted entirely of white bass, a major sport fish. Most of the *Morone* larvae, however, were believed to be yellow bass, because standing crop surveys showed that the ratio of juvenile and adult yellow bass to white bass was 329:18/ha (Tranquilli et al. 1981). Since yellow bass are rough fish that compete with sport fishes for food and space, a reduction in their population would likely be considered beneficial to the fishery. Annual mortality of yellow bass at Kincaid Generating Station, including entrainment of 15.29 percent of the numerical standing crop of larvae and impingement of 7.86 percent of the juveniles and adults, would have a minimal effect on either the species population or the fish community.

During the 1976 spawning season, entrainment of bluegills and green sunfish reduced the larval *Lepomis* standing crop in the lake by 0.33 percent. Viewed from the aspect of recruitment, entrainment reduced the numerical standing crop of

Lepomis by 0.59 percent. The ratio of juvenile and adult bluegills to green sunfish in standing crop samples from coves was 1,899:213/ha (Tranquilli et al. 1981). Although bluegills represent an important part of the sport fish harvest in Lake Sangchris, their slow growth and stunted condition as a result of overabundance detract from their potential value. Thus, the loss of *Lepomis* larvae by entrainment had no adverse effect.

A discussion of the impact of impingement and entrainment would be incomplete without considering the compensatory response of fish populations to the predatory type of mortality induced by power plants. McFadden (1977) noted that the agent of mortality, whether it be predatory fish, fishermen, or power plants, is indifferent to the population. When the population is reduced, the survival rate or reproductive rate of the remaining members tends to increase; a compensating response is generated. McFadden also pointed out that when the mortality takes a form similar to natural predation, little harm results, because it is the kind of impact to which the population has adapted over millions of years of evolutionary experience.

In summary, on the basis of a 1-year monitoring study, it appears that the entrapment of fish eggs, larvae, juveniles, and adults at the Kincaid Generating Station's cooling water intake system has caused only relatively minor reductions in numbers of a few overabundant or undesirable species, and consequently has caused no adverse effect on either the individual populations of those species or on the Lake Sangchris sport fishery. Even considering a 26-percent reduction in plant cooling water flow during the 1976 spawning season and a likely 26-percent greater loss with normal flow, our evaluation of the overall impact on the fishery did not change. This study and that of Bergmann (1981) have demonstrated that the existing intake system is well located and well designed and results in a minimal impact on the surrounding environment.

SUMMARY

1.—The major period of fish impingement occurred from December 1976 through March 1977, when 94.16 percent of the estimated total impingement occurred.

2.—Gizzard shad constituted 83.38 percent and yellow bass 14.26 percent of the estimated 158,853 fish impinged from March 1976 to 19 April 1977. The remaining 2.36 percent of the total fish impingement comprised 12 additional species.

3.—Small fishes were highly vulnerable to impingement. The majority of the impinged fish were young-of-the-year individuals, and 93.8 percent of all the fish collected were less than 200 mm in total length.

4.—Gizzard shad and yellow bass collected from the traveling screens at Kincaid Generating Station had significantly lower ($P < 0.01$) mean body condition factors than individuals of the same species collected from the intake area by electrofishing, indicating that stressed fishes were being impinged selectively.

5.—Numerically, impingement reduced the standing crop of gizzard shad by 1.82 percent and the standing crop of yellow bass by 7.86 percent. The reductions in the standing crops of these species were considered to have no adverse effect on the sport fishery of Lake Sangchris.

6.—A total of 218 fish eggs collected during entrainment sampling accounted for a relatively low total estimate of 2.2 million eggs lost by entrainment during 1976. Since low numbers of fish eggs were collected, a rigorous evaluation of fish egg entrainment was not made.

7.—Gizzard shad (85.61 percent), *Morone* (4.03 percent), and *Lepomis* (0.66 percent) accounted for most of the larval fishes entrained at the Kincaid Generating Station. The species composition of fish larvae damaged by the pumps (9.6 percent), and consequently unidentifiable, was assumed to be similar to that of the identifiable fish larvae.

8.—Statistical tests provided no

evidence of diurnal differences in entrainment rates for gizzard shad larvae.

9.—Two methods of estimating the impact of larval fish entrainment on numerical standing crops revealed that gizzard shad and *Lepomis* populations were reduced by 4.74–5.48 percent and 0.33–0.59 percent, respectively. Entrainment of *Morone* was estimated to have reduced the numerical standing crop of white bass and yellow bass larvae by 15.29 percent.

10.—Impingement and entrainment of fishes at Kincaid Generating Station during 1976 resulted in relatively minor reductions in numbers of a few overabundant or undesirable species and caused no adverse effect on the sport fishery.

11.—Our evaluation of the overall impact on the fishery was not changed by taking into consideration a 26-percent reduction in cooling water use by the utility during the 1976 spawning season.

REFERENCES CITED

Bennett, G. W. 1970. Management of lakes and ponds. Van Nostrand Reinhold Co., New York. 375 p.

Bergmann, H. 1981. Distribution of larval fishes in Lake Sangchris (1976). Pages 615–630 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

Carlander, K. D. 1969. Handbook of freshwater fishery biology. Vol. 1. Iowa State University Press, Ames. 752 p.

______. 1977. Handbook of freshwater fishery biology. Vol. 2. Iowa State University Press, Ames. 431 p.

Fish, M. P. 1932. Contributions to the early life histories of sixty-two species of fishes from Lake Erie and its tributary waters. U. S. Bureau of Fisheries Bulletin 47:293–398.

Hogue, J.J., Jr., R. Wallus, and L. K. Kay. 1976. Preliminary guide to the identification of larval fishes in the Tennessee River. Tennessee Valley Authority, Norris, TN. 67 p.

Jester, D. B., and B. L. Jensen. 1972. Life history and ecology of gizzard shad, *Dorosoma cepedianum* (Le Sueur) with reference to Elephant Butte Lake. New Mexico State University Agricultural Experiment Station Research Report 218. 56 p.

Larimore, R. W. 1952. Weight changes in fish after death. Journal of Wildlife Management 16(2):131–138.

Latvaitis, B. P. 1976. Impingement investigation. Pages 125–168 *in* Operation environmental monitoring in the Mississippi River near Quad-Cities Station February 1975 through January 1976. Nalco Environmental Sciences Northbrook, IL.

Mansueti, A. J., and J. D. Hardy. 1967. Development of fishes of the Chesapeake Bay Region. An atlas of egg, larval, and juvenile stages. Part 1. University of Maryland, Baltimore. 202 p.

Marcy, B. C., Jr. 1974. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. Pages 281–288 *in* Entrainment and intake screening. Proceedings of the Second Entrainment and Intake Screening Workshop. Electric Power Research Institute, Palo Alto, CA.

May, E. B., and C. R. Gasaway. 1967. A preliminary key to the identification of larval fishes of Oklahoma, with particular reference to Canton Reservoir, including a selected bibliography. Oklahoma Fisheries Research Laboratory Bulletin 5. 42 p.

McConnell, G. R. 1975. Fishes section. Pages 80–102 *in* Studies on the effects of the Havana Power Station on the ecological balance of the Illinois River 1974 to 1975. Wapora, Inc., Charleston, IL.

McFadden, J. T. 1977. An argument supporting reality of compensation in fish populations and a plea to let them exercise it. Pages 153–183 *in* W. Van Winkle, ed., Proceedings of the Conference on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations. Pergamon Press, New York.

Meyer, F. A. 1970. Development of some larval centrarchids. Progressive Fish-Culturist 32:130–136.

Ricker, W. E.·1975. Computation and interpretation of biological statistics of fish populations. Canada Fisheries Research Board Bulletin 191. 382 p.

Tranquilli, J. A., R. Kocher, and J. M. McNurney. 1981. Population dynamics of the Lake Sangchris fishery. Pages 413–499 *in* R. W. Larimore and J. A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

Waterfowl Studies at Lake Sangchris, 1973–1977

Glen C. Sanderson and William L. Anderson

ABSTRACT

The highest single count of waterfowl on Lake Sangchris was always in November when counts were made in that month. However, mean monthly averages of total waterfowl increased from less than 8,000 in October to less than 64,000 in November and to 72,000 in December and then declined to approximately 27,000 in January, less than 12,000 in February, and about 6,000 in March. Mallards constituted from approximately 50 percent of the total population in October to more than 95 percent in December. Other species that comprised 10 percent or more of the population in one or more months were wigeons in October, Canada geese in February and March, and coots in October.

The chronology of abundance of mallards at Lake Sangchris and in the Illinois River valley exhibited similar patterns, but the fall buildup was 1–2 weeks later at Sangchris, which is about 100 km southeast of the Illinois Valley. In spring, relatively fewer mallards stopped at Sangchris.

Mallards were found in equal concentrations on the unheated and heated water in October, in higher concentrations on the heated water from November through January, in equal numbers in February, and in higher concentrations on the unheated water in March. Gadwalls, shovelers, and both species of teals were more abundant on the unheated water in October and March, had similar concentrations in November, and were virtually absent in other months. Coots were much more abundant on the heated water in November, slightly more concentrated on the unheated water in March, equally numerous on both areas in October, and were virtually absent during the other months. Mergansers and goldeneyes were present in low concentrations from December through March and were more abundant on the heated water except in March, when no difference was evident. Canada geese were present in relatively low concentrations in all months; their numbers were more concentrated on the heated water in December and on the unheated water in March but showed no differences in other months.

From 0.2 to 0.4 percent of the maximum number of waterfowl present at any one time was killed each fall by colliding with the transmission lines at Lake Sangchris. Blue-winged teals were the most vulnerable to collisions.

Mean weights of ducks bagged at Sangchris were within the range reported for each species; however, the mean weights of adult male and female mallards and adult female lesser scaups at Sangchris were heavier than a large series of mean weights reported in the literature. At the same time, mean weights of juvenile male and female mallards, wigeons, and lesser scaups; of adult male and female wigeons; and of adult male lesser scaups were lower at Sangchris than a large series of mean weights reported in the literature.

Nearly 60 percent of the gizzards and proventriculi of waterfowl shot at Lake Sangchris contained ingested slag. Studies with game farm mallards fed diets of corn, corn plus slag, commercial maintenance chow, and chow plus slag indicate that slag possibly has adverse effects on body weight and packed cell volume of the blood. However, all ducks

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dosed experimentally with slag survived the 8-week experiment.

Water areas heavily used by waterfowl at Lake Sangchris may receive as much as 65 kg of nitrogen and 36 kg of phosphorus per hectare in one season.

INTRODUCTION

The preference that waterfowl frequently exhibit for lakes used by power plants for cooling purposes is viewed with a mixture of pleasure and concern. Waterfowl thrill and delight thousands of people who visit cooling lakes and nearby areas, and the recreational opportunities provided in the form of waterfowl hunting are no less important. The concern of waterfowl biologists regarding the waterfowl at such lakes, and thus the reason for these studies, revolves around these questions: (1) Are the behavior and migration of the birds being altered? (2) Does the heated water adversely affect forage organisms? (3) Do the large transmission lines emanating from the power plants present hazards to flying birds? (4) Are birds that ingest slag at coal-fired plants adversely affected? (5) Do the birds add large amounts of nutrients to the lakes? (6) Are epidemics of botulism, duck plague, and other diseases increased? All of these concerns except the last were addressed during this study.

This investigation evaluates some of the benefits and disadvantages of large numbers (>100,000) of waterfowl that congregate each autumn at Lake Sangchris and in close proximity to the Kincaid Generating Station—a large (1,232 MW) coal-fired generating facility that is owned and operated by Commonwealth Edison Company. Approximately half of the waterfowl present at Lake Sangchris during October, November, and December are attracted to the slag pond, a diked area adjacent to the power plant.

STUDY AREA

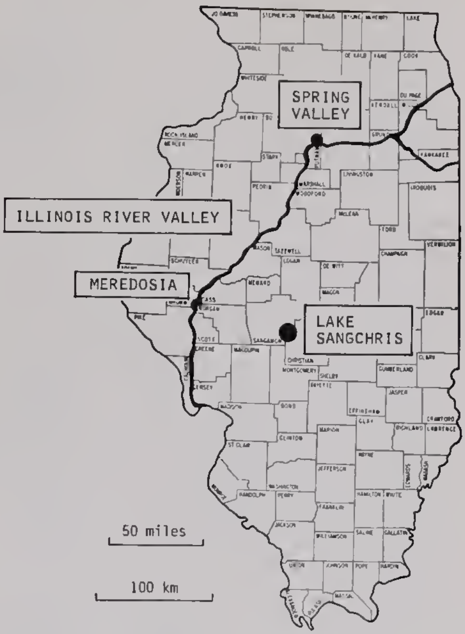

Fig. 1.—Locations of Lake Sangchris and the Illinois River valley.

Lake Sangchris is a man-made body of water in northwest Christian County, central Illinois (Fig. 1). The lake, formed in 1963–1966 by damming Clear Creek, consists of three long, relatively narrow arms that extend southward for a distance of 8–11 km from the dam (Fig. 2). For purposes of this study, the lake was segmented into four areas, hereafter referred to as the *discharge arm* (250 ha), *dam area* (79 ha), *intake arm* (315 ha), and *control arm* (227 ha) (Fig. 2 and Table 1). A fifth area, the *slag pond,* contains 32 ha of water. The land surrounding Lake Sangchris is intensively farmed for corn and soybeans.

The Kincaid Generating Station, which began generating electricity for commercial consumption in 1967, is between the discharge and intake arms of Lake Sangchris (Fig. 2). Water is taken from the intake arm, circulated through the plant, and returned to the discharge (warmwater) arm of the lake. The Kincaid plant consumed 2.7 million metric tons of coal in 1972 (National Coal Association 1974:9). When burned in this plant, coal is reduced to 15 percent of its original weight. About half of the residue is slag, which is slurried into the slag pond immediately northeast of the plant (Fig. 2). The slag pond serves as a settling

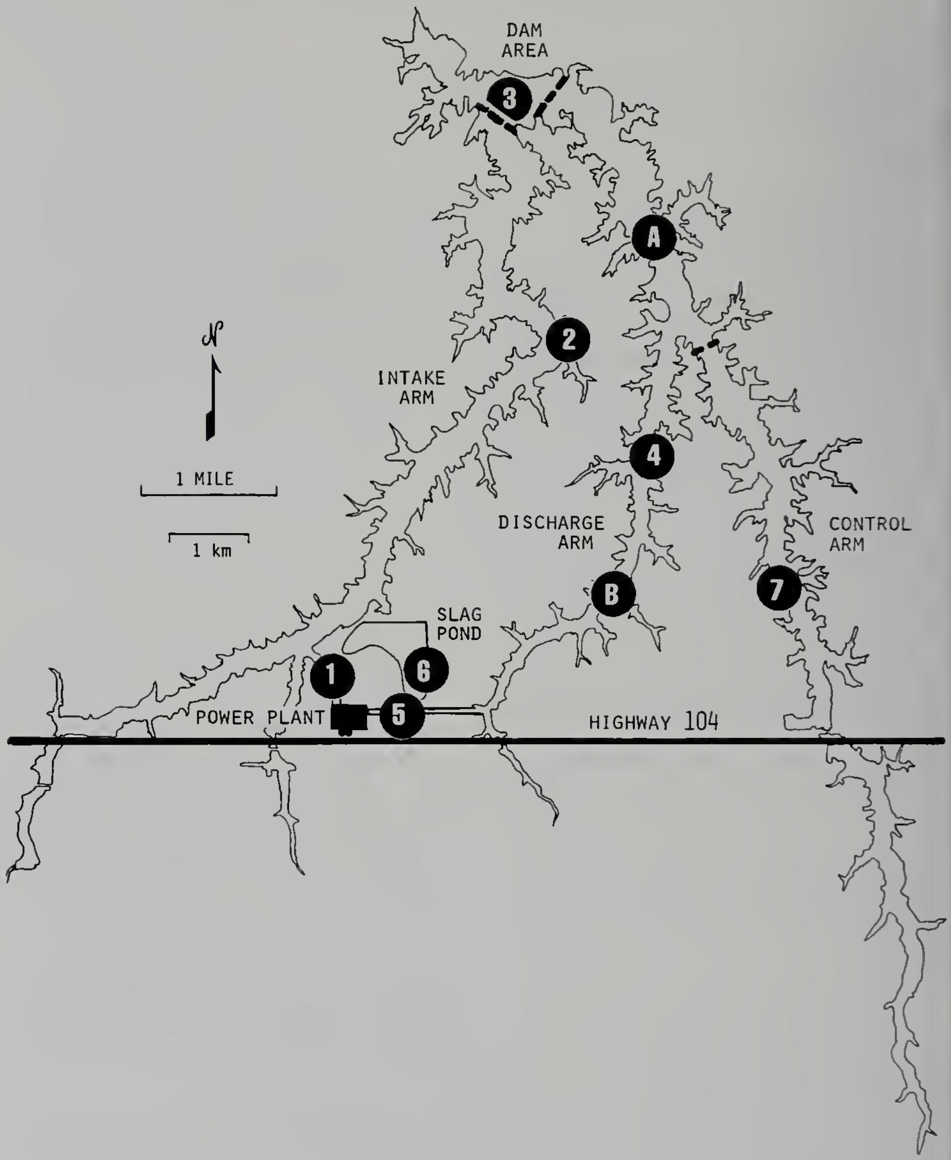

Fig. 2.—The Lake Sangchris-Kincaid Generating Station complex as segmented into areas for studying waterfowl. The five areas are the dam area and slag pond—no hunting, fishing, or trespassing; discharge arm—fishing permitted but no hunting; control arm and intake arm—hunting permitted but no fishing. The restrictions for the slag pond are permanent. Restrictions for the other areas were in effect during the waterfowl hunting seasons only, beginning in 1974. Stations where water temperatures were taken are indicated by circles.

Table 1.—Surface area of water and length of shoreline for the intake arm and for the discharge arm of Lake Sangchris.

Arm of Lake	Surface Area (ha)	Shoreline (km)
Discharge arm	250(44.2)[a]	49(48.5)
Intake arm	315(55.8)	52(51.5)

[a] Percentage of the total of these two areas.

basin; excess water is returned to the lake via a large (122-cm diameter) pipe that empties into the discharge canal. Thus, the water level in the slag pond is held relatively constant. The plant's twin smoke stacks are equipped with electrostatic precipitators that remove 99 percent of the fly ash from the atmospheric discharge.

METHODS

Water temperatures were taken at the surface at eight locations (stations 1, 2, 3, A, 4, B, 5, and 7) in Lake Sangchris (Fig. 2). These data were collected at approximately biweekly intervals from October 1974 to March 1977 under the supervision of John A. Tranquilli or Allison R. Brigham, Associate Aquatic Biologists, Illinois Natural History Survey.

Counts of the numbers and species of waterfowl at Lake Sangchris and on the slag pond were made primarily by Robert D. Crompton, Field Assistant, Illinois Natural History Survey, while riding in a small aircraft flying at about 122 m (400 feet) above mean ground level. The censuses were begun on 15 November 1972 as part of another study. At first, only the total number and species of waterfowl for the entire area were recorded. Counts were made 1 day each week, weather permitting, during fall and winter from 16 October 1974 to 13 April 1977. The numbers of birds present were recorded according to the portion of the lake they occupied—discharge arm, for example. These censuses were supplemented by counts made by observers located on the ground, particularly during September and October.

The methods used to investigate the impact of the power lines on waterfowl were previously described by Anderson (1978). Briefly, the slag pond was searched 1 day each week for dead and crippled birds, which were saved and autopsied, and observations were made to determine the flight patterns of birds relative to the slag pond and the power lines. The resulting data were integrated with the results of the weekly waterfowl censuses for purposes of analysis.

Because waterfowl hunting was permitted at Lake Sangchris on a controlled basis (hunters had to report to a check station both before and after hunting), beginning with the fall of 1974, it was possible to examine several hundred waterfowl shot by hunters. The species, sex, age, and body weight of each of those birds were determined, after which the gizzard (1974) or gizzard and proventriculus (1975) were removed and stored in a freezer. The contents of each gizzard and each proventriculus were screened (no. 35 mesh) and washed to divide them into two fractions: (1) plant and animal material (except for shells) and (2) grit, shells, slag, and lead pellets. The frequencies of occurrence and amounts of corn, soybeans, and other important foods were determined for mallards and wigeons; analyses of these materials collected in 1974 were limited to birds that had "appreciable amounts" (≥ 1 g for mallards and ≥ 0.25 g for wigeons, dry weight) of food in the gizzard. The frequencies of occurrence of *Corbicula* shells, slag, and lead pellets were determined for all species represented.

Mallards used for the slag-feeding study were juvenile males hatched and reared at the Max McGraw Wildlife Foundation, Dundee, Illinois. Those ducks were transported on 15 September 1976 to Urbana, where they were held in a 3.0- x 6.1-m pen 1.8 m high and equipped with a wire floor; they were fed commercial chow and whole kernel corn. On 30 September, 40 ducks were placed in eight 1.5- x 1.5-m pens (5 ducks per pen), also 1.8 m high, equipped with wire floors. They were fed a mixture of commercial maintenance chow and ground corn and given water via automatic watering devices.

Ten ducks (two pens) were placed on each of four experimental diets on 11 October. The diets, given ad libitum, were (1) ground corn, (2) ground corn to which slag had been added, (3) commercial maintenane chow, and (4) commercial maintenance chow to which slag had been added. The slag was added to the corn and chow at the rate of 2.5 percent of these diets (dry-weight basis), thoroughly mixed, and pelleted (4.5-mm diameter). The control diets were also pelleted. Unfortunately, it was discovered at the conclusion of the experiment that the diet consisting of ground corn was contaminated with slag at the rate of 0.42

Waterfowl in the refuge located near the dam at Lake Sangchris.

percent of the diet and, therefore, was not a true control.

The body weight and packed cell volume (PCV) were determined for each duck at the beginning of the study (11 October) and after 1, 2, 4, 6, and 8 weeks of being on the experimental diets. All ducks were killed (decapitated) at the end of the 8th week (6 December) and autopsied. The liver, both kidneys, the gizzard with proventriculus attached, and both adrenal glands were excised, freed of extraneous material, and weighed.

Calculations of nutrient loading—the amounts of total nitrogen (N_2) and available phosphorus (P_2O_5) that waterfowl add to Lake Sangchris—were made, using the formula:

$$N = \frac{W \times F \times P \times 0.8}{1,000}$$

where:

N = kg of nitrogen or phosphorus per day

W = number of waterfowl (all species combined) present

F = grams of fecal material excreted per bird per day

P = proportion of the fecal material that is nitrogen or phosphorus.

The 0.8 multiplier was used to correct for the fact that not all fecal material was excreted into the water. The 80-percent value was selected after considering the behavior and daily routine of mallards at Lake Sangchris.

In these calculations, $F = 16.7$, and $P = 0.0624$ for nitrogen and 0.0348 for phosphorus. These values are based on information obtained from mallards fed exclusively on shelled corn. That is, captive mallard hens fed only corn during winter consumed an average of 57 g per day and excreted an average of 8.0 g (dry weight) of feces per day, and the feces contained an average of 6.24 percent nitrogen and 3.48 percent phosphorus (Ronald F. Labisky, Illinois Natural History Survey, Urbana, unpublished data). Bossenmaier & Marshall (1958:24) estimated that wild mallards could consume as much as 197 g of wheat per day—a value that is reduced to 181 g when applied to corn. For lack of a better value, we selected 119 g (halfway between 57 and 181) as the average amount of corn eaten per mallard per day. The corresponding value for feces is 16.7 g ($F/8.0 = 119/57$). All of the weight data are given on a dry-weight basis.

The dry weight of feces excreted per day in relation to body weight was determined in several species of captive geese by Kear (1963) and in wild Canada geese by Manny et al. (1975). The average ratio of dry feces per day to body weight was 2.25 percent. The average weight of mallards of all ages and sexes bagged at Lake Sangchris was 1,135 g (Table 12). Thus, if we used these figures (1,135 g X 2.25 percent = 25.5 g), we would have 25.5 g of dry feces produced per duck per day instead of 16.7 g. Kear (1963) reported 2.2 percent nitrogen and 1.0 percent phosphorus and Manny et al. (1975) reported 4.38 percent nitrogen and 1.34 percent phosphorus in the dry feces of the geese they studied. Paloumpis & Starrett (1960) used data from Sanderson (1953), who reported that 1,000 domestic ducks produced an average of 5.7 lb of nitrogen and 7.6 lb of phosphorus per day. Paloumpis & Starrett arbitarily used 0.50 as a correction factor for the lower food intake and smaller size of wild ducks. If we used these figures, we would calculate that each wild mallard produced 1.29 g of nitrogen and 1.72 g of phosphorus per day. Thus, if the mallards at Sangchris excrete 25.5 g of dry feces each day, that amount would contain 5.0 percent nitrogen (1.29/25.5) and 6.7 percent total phosphorus (1.72/25.5). If we averaged the three sets of published figures for nitrogen and phosphorus, we would have 3.86 percent for the amount of nitrogen and 3.01 percent for the amount of phosphorus in the dry feces instead of 6.24 percent nitrogen and 3.48 percent phosphorus.

The studies of waterfowl-power line interactions were conducted intensively in 1973, 1974, and 1975. The other studies were begun in the fall of 1974 and continued through the spring of 1977.

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FINDINGS

WATER TEMPERATURES

The distribution of water temperatures at the surface of Lake Sangchris from October to March was much the same for each of the three seasons of our study (Table 2). Except in October 1976 when they were almost the same, mean monthly temperatures were always greater in the discharge arm (stations A, 4, B, and 5), which receives heated water from the power plant, than in the intake arm (stations 1 and 2). Temperatures in the dam area were generally intermediate between those in the discharge arm and the intake arm.

When tested by Wilcoxon's sign ranked test (Steel & Torrie 1960:402), all differences in mean surface-water temperatures from one portion of the lake to another were significant ($P < 0.05$) for 1974–1975. All differences in surface-water temperatures, except those from the intake arm and the control arm, were also significant in 1975–1976. In 1976–1977 all differences in surface-water temperatures were significantly dif-

Table 2.—Mean temperatures (C) of surface water and air at Lake Sangchris from October to March, 1974 –1977.

Season and Month	Slag Pond (Station 6)	Discharge Arm (Stations 4, B, 5)	Discharge Arm (Station A)	Dam Area (Station 3)	Intake Arm (Stations 1, 2)	Control Arm (Station 7)	Air[a]
1974–1975							
Oct.	. . .	22.6	19.5	18.5	16.9	16.3	13.2
Nov.	. . .	16.6	14.7	14.0	13.5	12.0	5.7
Dec.	. . .	9.9	6.3	5.5	4.5	3.0	0.4
Jan.	. . .	9.9	6.2	4.4	3.5	1.8	−0.5
Feb.	. . .	8.2	5.2	4.5	2.8	2.0	−1.4
Mar.	. . .	10.5	9.2	8.6	7.7	5.9	3.0
1975–1976							
Oct.	19.8	22.6	20.8	20.3	19.3	19.3	14.3
Nov.	14.8	19.2	17.2	16.2	15.1	13.7	8.4
Dec.	6.6	13.2	10.4	9.6	7.8	5.4	0.8
Jan.	. . .	11.1	7.3	5.5	3.9	1.7	−4.7
Feb.	7.9	9.8	9.2	8.7	7.0	5.8	4.2
Mar.	12.0	12.4	11.0	10.9	10.0	10.1	7.4
1976–1977							
Oct.	. . .	14.7	16.1	16.0	15.0	14.6	9.7
Nov.	. . .	10.7	9.3	8.6	7.4	6.8	1.4
Dec.	. . .	6.8	5.5	4.1	3.0	0.0	−4.4
Jan.[b]	. . .	8.9	6.6	4.0	2.3	1.4	−12.1
Feb.[b]	. . .	13.4	10.5	6.6	5.7	7.7	−1.4
Mar.[b]	. . .	18.8	14.9	13.2	11.1	11.9	8.7

[a] Recorded at Springfield, 30 km northwest of Lake Sangchris (National Oceanic and Atmospheric Administration 1974–1977).

[b] Data are a combination of surface data from the power plant, temperatures taken by John A. Tranquilli at the surface, and at the locations of radio-tagged bass, which were not at the surface.

ferent, except those from the discharge arm and the dam area and the intake arm in October, the dam area versus the control area in February, and the intake arm versus the control arm in February.

Temperatures of water in the slag pond were recorded only five times during this study. They were similar to the temperatures in the intake arm and control arm during October, November, and December 1975 (Table 2). However, temperatures recorded in the slag pond during February and March 1976 tended to be relatively warm—approaching those in the discharge arm. Because the amount of water in the slag pond is comparatively small, its temperature might be expected to decrease and increase at faster rates than the temperatures of the various arms of Lake Sangchris.

WATERFOWL POPULATIONS

Numbers

The highest count of waterfowl recorded for Lake Sangchris during the present study was 177,035 birds on 29 November 1972. Of those, 168,000 were mallards and 8,000 were black ducks. For the 1973–1974 season, censuses were not initiated until 6 December. There were more than twice as many waterfowl at Lake Sangchris during December, January, and February 1974–1975 as during the same months in 1973–1974 (Table 3).

Mean numbers of waterfowl at Lake Sangchris and on the slag pond increased from 6,667 during October to 76,154 in November and to 81,480 during December 1974 (Table 3). The maximum number counted in 1974 was approximately 111,500 on 26 November and again on 4 December. Waterfowl numbers decreased substantially during the latter half of December 1974 and the first part of January 1975. Mean numbers were 29,228 during January and 13,271 during February 1975. The population held steady during February and the first half of March, then decreased to only 2,432 birds on the 19th and 1,355 on the 26th of March.

During the 1975–1976 season, the October and November populations were substantially lower than the populations in the same months in the previous year (Table 3), but the mean populations for December and January were similar for the 2 years. The peak population (101,185) for the season was reached on 19 November 1975 and was somewhat lower than the peak population (111,496) for the 1974–1975 season reached 26 November 1974.

The peak population of the 1976–1977 season was only 72,868 birds counted on 27 November 1976. On the other hand, the mean number of birds present in October (11,432) was the highest recorded for this month. The dry fall of 1976–1977 resulted in much fall plowing of corn stubble. Thus, little food was available for mallards and geese, which feed on waste corn. The mean numbers of waterfowl present in November, December, and January were lower than average, whereas the numbers present in February 1977 (13,916) were slightly higher than average (11,736, Table 4).

Species Composition

Mallards were the most abundant waterfowl species—constituting from nearly 50 percent (October) to 95 percent (December) of the total population—during fall and winter from October 1974 through March 1977 (Table 5). From November through January, mallards constituted more than 90 percent of the total population. Black ducks made up a small but consistent portion (2.5–3.0 percent) of the population from October through March. Coots and wigeons made up sizable portions (23.4 and 12.6 percent, respectively) during October, as did Canada geese in October, January, February, and March (2.5, 3.9, 12.1, and

Table 3.—Numbers of waterfowl (ducks, geese, and coots) counted on Lake Sangchris and the slag pond from November 1972 to March 1977. The counts were made from small aircraft.[a]

Date	Dam Area	Remainder of Lake	Slag Pond	Total[b]
1972				
15 Nov.	...	...	...	64,420
29 Nov.	...	...	...	177,035
Mean	...	...	...	120,728
13 Dec.	...	...	...	38,890
1973				
9 Jan.	...	...	...	31,675
24 Jan.	...	...	...	23,700
Mean	...	...	...	27,688
8 Feb.	...	...	...	25,215
21 Feb.	...	...	...	43,510
Mean	...	...	...	34,362
7 Mar.	...	...	...	18,515
21 Mar.	...	...	...	560
Mean	...	...	...	9,538
6 Dec.	...	...	...	50,650
21 Dec.	...	...	...	22,560
Mean	...	...	...	36,605
1974				
9 Jan.	...	...	...	8,465
23 Jan.	...	...	...	2,020
Mean	...	...	...	5,242
7 Feb.	...	...	...	2,450
20 Feb.	...	...	...	5,713
Mean	...	...	...	4,082
7 Mar.	...	...	...	1,950
19 Mar.	...	...	...	1,548
Mean	...	...	...	1,749
2 Apr.	...	...	...	675
16 Oct.	287	615	1,106	2,008
23 Oct.	1,625	882	5,224	7,731
30 Oct.	2,373	288	7,600	10,261
Mean	...	...	...	6,667
7 Nov.	2,160	3,548	14,872	20,580
14 Nov.	25,266	32,187	19,353	76,806
20 Nov.	29,015	20,561	46,160	95,736
26 Nov.	11,053	16,028	84,415	111,496
Mean	...	...	...	76,154
4 Dec.	28,827	12,819	69,780	111,426
17 Dec.	16,031	37,466	21,228	74,725
23 Dec.	9,975	30,914	17,400	58,289
Mean	...	...	...	81,480
1975				
2 Jan.	9,519	36,972	18	46,509
9 Jan.	7,889	23,037	226	31,152
14 Jan.	8,812	15,409	19	24,240
22 Jan.	6,254	15,326	55	21,635
27 Jan.	6,393	16,120	90	22,603
Mean	...	...	...	29,228
6 Feb.	3,285	4,892	13	8,190
10 Feb.	5,908	5,901	37	11,846
19 Feb.	7,537	13,418	134	21,089
27 Feb.	6,450	5,432	76	11,958
Mean	...	...	...	13,271

Table 3.—Continued.

Date	Dam Area	Remainder of Lake	Slag Pond	Total
5 Mar.	1,858	10,202	154	12,214
11 Mar.	2,684	9,168	118	11,970
19 Mar.	508	1,797	127	2,432
26 Mar.	415	830	90	1,335
Mean	. . .	. . .	. . .	6,988
7 Oct.	170	589	1,484	2,243
15 Oct.	820	1,262	2,091	4,173
22 Oct.	615	1,188	2,502	4,305
28 Oct.	1,715	415	6,790	8,920
Mean	. . .	. . .	. . .	4,910
6 Nov.	17,145	3,356	6,345	26,846
12 Nov.	17,444	28,470	14,007	59,921
19 Nov.	42,840	6,795	51,550	101,185
Mean	. . .	. . .	. . .	62,651
2 Dec.	64,842	7,095	19,372	91,309
9 Dec.	65,051	15,529	9,928	90,508
17 Dec.	34,534	46,313	403	81,250
23 Dec.	46,311	29,627	735	76,663
Mean	. . .	. . .	. . .	84,932
1976				
6 Jan.	24,424	20,959	21	45,404
14 Jan.	16,057	13,051	27	29,135
21 Jan.	8,973	7,149	14	16,136
Mean	. . .	. . .	. . .	30,225
3 Feb.	8,504	4,574	20	13,098
18 Feb.	1,510	2,061	102	3,673
Mean	. . .	. . .	. . .	8,386
2 Mar.	351	2,902	134	3,387
18 Mar.	1,616	6,904	87	8,607
31 Mar.	588	1,673	128	2,389
Mean	. . .	. . .	. . .	4,794
6 Oct.[c]	52	814	4,400	5,266
14 Oct.[c]	254	682	6,000	6,936
21 Oct.[c]	1,900	800	6,460	9,160
28 Oct.	9,360	3,763	11,245	24,368
Mean	. . .	. . .	. . .	11,432
4 Nov.	12,183	2,503	10,465	25,151
12 Nov.	32,874	2,748	3,917	39,539
17 Nov.	39,565	5,626	25,265	70,456
27 Nov.	63,300	9,203	365	72,868
Mean	. . .	. . .	. . .	52,004
1 Dec.	42,022	13,021	2,885	57,928
8 Dec.	410	43,215	145	43,770
15 Dec.	15,883	11,370	19,741	46,994
Mean	. . .	. . .	. . .	49,564
1977				
4 Jan.	18,250	9,598	1,252	28,100
19 Jan.	12,720	2,894	199	15,813
Mean	. . .	. . .	. . .	21,956
2 Feb.	10,798	2,053	75	12,926
16 Feb.	7,344	7,110	451	14,905
Mean	. . .	. . .	. . .	13,916
2 Mar.	9,275	3,485	480	13,240
16 Mar.	1,380	1,340	1,145	3,865
31 Mar.	1,040	540	265	1,845
Mean	. . .	. . .	. . .	6,317
13 Apr.	. . .	. . .	. . .	390

[a] Counts were made by Robert Crompton except as indicated

[b] Counts were not identified as to area prior to 16 October 1974.

[c] These counts were low because of inexperienced personnel. The figures given are the actual counts doubled.

Table 4.—Average numbers by month of each species of waterfowl at Lake Sangchris and the slag pond from October 1974 through March 1977.

Species	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Surface-feeding ducks						
Mallard	3,766	57,923	68,677	24,950	9,514	3,686
Black duck	211	1,615	1,972	669	303	166
Pintail	352	186	34	5	11	71
Wigeon	968	1,647	621	294	93	262
Blue-winged teal	102	10	0	0	0	28
Green-winged teal	87	132	4	0	0	14
Gadwall	74	131	5	0	0	19
Shoveler	10	7	0	0	0	10
Diving ducks						
Scaup	48	81	18	4	25	143
Ring-necked duck	15	27	16	0	19	213
Canvasback	2	7	9	18	12	165
Redhead	0	0	0	0	0	4
Ruddy duck	6	8	1	0	0	6
Goldeneye	0	5	36	89	188	53
Mergansers	0	2	15	37	108	20
Geese						
Canada goose	195	178	550	1,063	1,425	878
Blue & snow goose	37	54	16	7	22	24
Coot	1,793	1,571	33	13	16	266
Average number of waterfowl present	*7,666*	*63,584*	*72,007*	*27,149*	*11,736*	*6,028*

Table 5.—Percentage composition of waterfowl present at Lake Sangchris and the slag pond from October 1974 through March 1977.

	Average Percentage Represented by Each Species					
Species	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Surface-feeding ducks						
Mallard	49.1	91.1	95.4	91.9	81.1	61.1
Black duck	2.8	2.5	2.7	2.5	2.6	2.8
Pintail	4.6	0.3	<0.1	<0.1	0.1	1.2
Wigeon	12.6	2.6	0.9	1.1	0.8	4.3
Blue-winged teal	1.3	<0.1	0.0	0.0	0.0	0.5
Green-winged teal	1.1	0.2	<0.1	0.0	0.0	0.2
Gadwall	1.0	0.2	<0.1	0.0	0.0	0.3
Shoveler	0.1	<0.1	0.0	0.0	0.0	0.2
Diving ducks						
Scaup	0.6	0.1	<0.1	<0.1	0.2	2.4
Ring-necked duck	0.2	<0.1	<0.1	0.0	0.2	3.5
Canvasback	<0.1	<0.1	<0.1	0.1	0.1	2.7
Redhead	0.0	0.0	0.0	0.0	0.0	0.1
Ruddy duck	0.1	<0.1	<0.1	0.0	0.0	0.1
Goldeneye	0.0	<0.1	<0.1	0.3	1.6	0.9
Mergansers	0.0	<0.1	<0.1	0.1	0.9	0.3
Geese						
Canada goose	2.5	0.3	0.8	3.9	12.1	14.6
Blue & snow goose	0.5	0.1	<0.1	<0.1	0.2	0.4
Coot	23.4	2.5	<0.1	<0.1	0.1	4.4
Average number of waterfowl present	*7,666*	*63,584*	*72,007*	*27,149*	*11,736*	*6,028*

1974–1977

Species	October			November			December			January			February			March		
	1974	1975	1976	1974	1975	1976	1974	1975	1976	1975	1976	1977	1975	1976	1977	1975	1976	1977
Surface feeding ducks																		
Mallard	59.1	44.4	45.3	94.2	85.0	93.8	95.3	94.9	96.4	89.3	90.9	96.9	76.4	69.6	90.3	64.4	46.0	68.9
Black duck	5.6	1.8	1.5	2.6	2.5	2.5	2.7	2.8	2.7	2.7	2.5	2.1	2.6	2.7	2.4	3.7	2.1	2.2
Pintail	4.1	2.2	5.9	0.2	0.4	0.3	0.1	<0.1	0.0	0.0	<0.1	0.0	0.2	0.1	0.0	0.7	2.4	0.8
Wigeon	13.0	8.9	14.0	0.9	5.3	1.8	1.6	0.6	0.1	2.4	0.6	0.0	1.5	0.8	0.1	2.4	9.5	2.6
Blue-winged teal	0.2	0.6	2.3	<0.1	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.2	0.2
Green-winged teal	1.3	2.6	0.4	0.3	0.3	0.1	<0.1	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.3
Gadwall	0.9	2.6	0.3	0.2	0.3	0.1	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.5
Shoveler	0.2	0.3	<0.1	<0.1	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.1
Diving ducks																		
Scaup	1.7	0.4	<0.1	0.2	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.0	0.0	0.5	0.1	0.0	1.2	2.7	3.4
Ring-necked duck	0.1	0.2	0.2	0.0	0.1	<0.1	0.0	<0.1	0.0	0.0	0.0	0.0	<0.1	0.6	0.0	0.2	5.9	5.4
Canvasback	<0.1	0.0	0.1	<0.1	<0.1	<0.1	0.0	<0.1	<0.1	0.1	0.0	<0.1	0.1	0.1	0.1	0.4	5.9	2.9
Redhead	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Ruddy duck	0.0	0.1	0.1	<0.1	<0.1	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	<0.1	0.2	<0.1
Goldeneye	0.0	0.0	0.0	0.0	<0.1	<0.1	<0.1	<0.1	0.1	0.3	0.3	0.4	1.0	1.3	5.1	0.7	0.6	1.3
Mergansers	0.0	0.0	0.0	0.0	0.0	<0.1	<0.1	<0.1	<0.1	0.2	0.1	0.1	0.8	0.6	1.2	0.4	0.3	0.3
Geese																		
Canada goose	0.4	5.1	2.7	0.1	0.4	0.4	0.2	1.4	0.6	5.1	5.4	0.3	16.2	24.0	0.8	23.5	10.8	7.5
Blue & snow goose	1.0	0.4	0.2	0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.0	<0.1	0.0	0.5	0.0	0.0	0.5	0.8	0.0
Coot	12.1	30.4	27.0	1.2	5.4	0.8	<0.1	<0.1	0.0	0.0	<0.1	0.0	0.3	<0.1	0.0	1.4	10.1	3.4
Mute swan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average number of waterfowl present	*6,667*	*4,910*	*11,432*	*76,154*	*62,651*	*52,004*	*81,480*	*84,932*	*49,564*	*29,228*	*30,225*	*21,956*	*13,281*	*8,386*	*13,916*	*6,988*	*4,794*	*6,317*

14.6 percent). Other species constituting more than 2.0 percent of the population for a month included pintail (4.6 percent, October), wigeon (2.6 and 4.3 percent in November and March), lesser scaup (2.4 percent, March), ring-necked duck (3.5 percent, March), canvasback (2.7 percent, March), and coot (2.5 and 4.4 percent, November and March).

Species that showed substantial variation from month to month in the percentage that they contributed to the total population at Lake Sangchris (Table 5) were the mallard (49.1 percent in October to 95.4 percent in December), wigeon (0.9 percent in December and February to 12.6 percent in October), Canada goose (0.3 percent in November to 14.6 percent in March), and coot (< 0.1 percent in December and January to 23.4 percent in October). The average numbers of these and other species present each month are shown in Table 3.

Canada geese showed the greatest monthly percentage variation from year to year (Table 6). They comprised 0.8 percent of the waterfowl present in February 1977 and 24.0 percent in February 1976. Mallards comprised 46.0 percent of the Sangchris population in March 1976 and 68.9 percent in March 1977, and coots constituted 12.0 percent of the population in October 1974 and 30.4 percent in October 1975.

The differences in percentage composition of each species from month to month (Table 5) are related to average food, water, and weather conditions and to the habits of each species. For example, coots migrate early and constitute a substantial percentage (23.4) of the population in October but a low percentage (2.5) in November even though approximately equal numbers of coots are present in October and November (Table 4). The differences from year to year are a result of annual variations in food, water, and weather conditions. For example, the overall low populations at Sangchris in December 1976 and January 1977 (Table 6) probably resulted from the lack of available corn because of higher than average amounts of fall plowing and the unusually severe weather (lower than average temperatures) that prevailed. These low temperatures were reflected in lower mean water temperatures in December 1976 and January 1977 (Table 2).

Mallards—Lake Sangchris Versus The Illinois Valley

The increase and subsequent decrease in numbers of mallards at Lake Sangchris during the falls and winters of 1972–1973 through 1976–1977 exhibited a pattern similar to that for the Illinois River valley (Fig. 3). As might be expected from the location of the Illinois River valley, approximately 100 km to the northwest, the fall buildup at Sangchris occurred 1—2 weeks later than along the Illinois River. However, after the peak population was reached in November, mallards departed from Lake Sangchris at about the same rate as from the Illinois River valley, at least through early January. Counts were not available for the Illinois Valley after the first week in January until after the first of March. The pattern of use by mallards was similar for Sangchris and the Illinois Valley, as shown by the percentage of the peak spring count present on several dates in the two areas (Fig. 3). However, there were relatively far fewer mallards on Sangchris in March than from October through early January (Tables 4 and 7). Whereas peak fall and winter populations on Sangchris averaged about 12 percent of the peak numbers in the Illinois Valley, in March the figure was slightly less than 1.5 percent.

EFFECTS OF TEMPERATURE ON DISTRIBUTION OF WATERFOWL

One of the primary objectives of this study was to determine if waterfowl were attracted or repelled by the heated water in the discharge arm of Lake Sangchris (Fig. 2). The dam area is an inviolate refuge during the waterfowl hunting season, encouraging a greater concentration of waterfowl there. Duck hunting was permitted in the intake arm and control arm but not in the discharge arm.

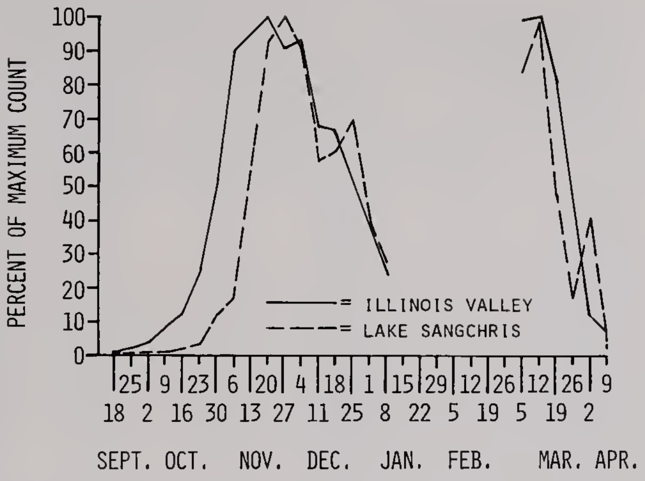

Fig. 3.—Relative abundance of mallards at Lake Sangchris and in the Illinois River valley from Spring Valley to Meredosia during fall and winter from 1972–1973 through 1976–1977.

Fishing was not permitted in the intake arm or the control arm during the waterfowl hunting season. However, fishermen were allowed in all areas except the slag pond before and after the waterfowl season. Thus, hunting was a factor influencing waterfowl use in the unit with unheated water and fishing was a factor in the unit with heated water.

Although we will use such terms as "preference for the warmer water" and "avoidance of the cooler water," we recognize that any correlations between duck density and water temperature may be results of factors other than a response to water temperature per se. Thus, food might be more abundant and available in the heated (or unheated) water than in the unheated (or heated) water. The presence of waterfowl attracted to the food might in turn attract other waterfowl with different feeding habits to the

Table 7.—Average numbers by month of each species of waterfowl in the Illinois Valley from September 1974 through March 1977.

Species	Sept.	Oct.	Nov.	Dec.	Jan.	Mar.
Surface-feeding ducks						
Mallard	11,833	82,719	471,607	368,303	223,475	294,475
Black duck	566	2,079	11,341	10,918	5,858	6,729
Pintail	2,619	9,357	5,260	285	0	22,278
Wigeon	3,414	14,490	11,313	2,018	1,683	25,922
Blue-winged teal	23,398	2,718	364	5	0	4,051
Green-winged teal	4,549	9,497	4,392	151	0	2,204
Gadwall	320	931	1,044	6	25	2,439
Shoveler	334	887	479	0	0	2,654
Diving ducks						
Scaup	56	1,470	4,935	831	0	22,649
Ring-necked duck	7	540	1,383	247	0	15,077
Canvasback	0	161	521	305	0	7,512
Redhead	0	0	0		0	1,627
Ruddy duck	5	275	401	85	0	445
Goldeneye	0	0	442	3,197	4,532	1,438
Mergansers	0	124	286	1,271	2,615	1,300
Geese						
Canada goose	1,001	8,479	5,390	3,199	2,684	22,709
Blue & snow goose	174	4,697	4,394	4,202	893	7,474
Wood duck	871	53	0	0	0	0
Coot	3,303	27,241	29,253	1,052	0	17,328
Average number of waterfowl present	*52,450*	*165,718*	*552,805*	*396,075*	*241,765*	*458,311*

Table 8.—Numbers of waterfowl counted on the discharge arm (warm water) and intake arm (cold water) of Lake Sangchris from October through March—1974–1975, 1975–1976, and 1976–1977.

Month and Year	Total Number of Birds	Number of Censuses	Percentage		Number per 100 ha per Census	
			Discharge Arm	Intake Arm	Discharge Arm	Intake Arm
		Mallards and Black Ducks				
Oct.						
1974	762	3	46.6	53.4	47.3	43.0
1975	727	4	48.6	51.4	35.3	29.6
1976	3,923	5	32.4	67.6	101.7	168.4
Mean						
1974–1976	1,804	4.0	36.6	63.4	66.0	90.8
Nov.						
1974	58,423	4	88.7	11.3	5,182.1	524.0
1975	31,863	3	63.4	36.6	2,693.5	1,234.0
1976	16,201	4	38.9	61.1	630.2	785.6
Mean						
1974–1976	35,496	3.7	73.6	26.4	2,824.3	804.0
Dec.						
1974	69,868	3	48.5	51.5	4,518.1	3,807.6
1975	85,830	4	73.4	26.6	6,299.9	1,812.0
1976	63,144	3	75.8	24.2	6,381.8	1,617.0
Mean						
1974–1976	72,947	3.7	66.1	33.9	5,212.8	2,121.8
Jan.						
1975	71,814	5	43.4	56.6	2,493.4	2,580.7
1976	37,109	3	63.1	36.9	3,122.1	1,449.0
1977	10,705	2	60.8	39.2	1,301.7	666.1
Mean						
1975–1977	39,876	3.3	51.1	48.9	2,469.9	1,875.8
Feb.						
1975	22,978	4	51.6	48.4	1,185.7	882.6
1976	4,372	2	40.9	59.1	357.6	410.1
1977	7,315	2	40.5	59.5	592.5	690.9
Mean						
1975–1977	11,555	2.7	47.9	52.1	820.0	707.8
Mar.						
1975	14,527	4	15.2	84.8	220.8	977.7
1976	3,824	3	26.9	73.1	137.2	295.8
1977	2,710	3	37.9	62.1	136.9	178.1
Mean						
1975–1977	7,020	3.3	20.2	79.8	171.9	538.9
		Pintails and Wigeons				
Oct.						
1974	141	3	58.2	41.8	10.9	6.2
1975	383	4	33.9	66.0	13.0	20.1
1976	520	5	41.0	59.0	17.0	19.5
Mean						
1974–1976	348	4.0	40.7	59.3	14.2	16.4
Nov.						
1974	798	4	83.1	16.9	66.3	11.1
1975	2,241	3	73.1	26.9	218.5	63.7
1976	2,028	4	1.7	98.3	3.5	158.2
Mean						
1974–1976	1,689	3.7	46.1	53.9	84.2	78.1
Dec.						
1974	1,361	3	45.3	54.7	82.1	78.8
1975	584	4	75.8	24.1	44.3	11.2
1976	50	3	90.0	10.0	6.1	0.5
Mean						
1974–1976	665	3.3	55.3	44.7	44.6	28.6
Jan.						
1975	1,695	5	47.8	52.2	64.9	56.1
1976	280	3	65.0	35.0	24.3	10.4
1977	0	2	0.0	0.0	0.0	0.0
Mean						
1975–1977	658	3.3	50.3	49.7	40.1	31.4

Table 8.—Continued.

Month and Year	Total Number of Birds	Number of Censuses	Percentage		Number per 100 ha per Census	
			Discharge Arm	Intake Arm	Discharge Arm	Intake Arm
Feb.						
1975	505	4	63.6	36.4	32.1	14.6
1976	79	2	44.3	55.7	7.0	7.0
1977	0	2	0.0	0.0	0.0	0.0
Mean						
1975–1977	195	2.7	61.0	39.0	17.6	8.9
Mar.						
1975	551	4	35.8	64.2	19.7	28.1
1976	994	3	20.7	79.3	27.4	83.4
1977	247	3	35.2	64.8	11.6	16.9
Mean						
1975–1977	597	3.3	27.3	72.7	19.8	41.8
B.-W. Teals, G.-W. Teals, Gadwalls, and Shovelers						
Oct.						
1974	213	3	32.9	67.1	9.3	15.1
1975	264	4	31.1	68.9	8.2	14.4
1976	266	5	13.5	86.5	2.9	14.6
Mean						
1974–1976	248	4.0	23.8	76.1	5.9	15.0
Nov.						
1974	518	4	57.1	42.8	29.6	17.6
1975	496	3	35.7	64.3	23.6	33.8
1976	85	4	2.4	97.6	0.2	6.6
Mean						
1974–1976	366	3.7	43.2	56.8	17.1	17.8
Dec.						
1974	13	3	100.0	0.0	1.7	0.0
1975	13	4	0.0	100.0	0.0	1.0
1976	0	3	0.0	0.0	0.0	0.0
Mean						
1974–1976	9	3.3	50.0	50.0	0.5	0.4
Jan.						
1975	0	5	0.0	0.0	0.0	0.0
1976	0	3	0.0	0.0	0.0	0.0
1977	0	2	0.0	0.0	0.0	0.0
Mean						
1975–1977	0	3.3	0.0	0.0	0.0	0.0
Feb.						
1975	0	4	0.0	0.0	0.0	0.0
1976	0	2	0.0	0.0	0.0	0.0
1977	0	2	0.0	0.0	0.0	0.0
Mean						
1975–1977	0	2.7	0.0	0.0	0.0	0.0
Mar.						
1975	69	4	20.3	79.7	1.4	4.4
1976	170	3	17.6	82.4	4.0	14.8
1977	80	3	0.0	100.0	0.0	8.5
Mean						
1975–1977	106	3.3	13.8	86.2	1.8	8.8
Scaups, Ring-necked Ducks, Canvasbacks, and Ruddy Ducks						
Oct.						
1974	18	3	100.0	0.0	2.4	0.0
1975	6	4	100.0	0.0	0.6	0.0
1976	0	5	0.0	0.0	0.0	0.0
Mean						
1974–1976	8	4.0	100.0	0.0	0.8	0.0

Table 8.—Continued.

Month and Year	Total Number of Birds	Number of Censuses	Percentage		Number per 100 ha per Census	
			Discharge Arm	Intake Arm	Discharge Arm	Intake Arm
Nov.						
1974	458	4	32.1	67.9	14.7	24.7
1975	93	3	61.3	38.7	7.6	3.8
1976	16	4	100.0	0.0	1.6	0.0
Mean						
1974–1976	189	3.7	38.8	61.2	7.9	9.9
Dec.						
1974	51	3	100.0	0.0	6.8	0.0
1975	86	4	84.9	15.1	7.3	1.0
1976	7	3	100.0	0.0	0.9	0.0
Mean						
1974–1976	48	3.3	91.0	9.0	5.3	0.4
Jan.						
1975	124	5	24.2	75.8	2.4	6.0
1976	13	3	100.0	0.0	1.7	0.0
1977	0	2	0.0	0.0	0.0	0.0
Mean						
1975–1977	46	3.3	31.4	68.6	1.8	3.0
Feb.						
1975	80	4	36.2	63.8	2.9	4.0
1976	41	2	100.0	0.0	8.2	0.0
1977	7	2	100.0	0.0	1.4	0.0
Mean						
1975–1977	43	2.7	60.2	39.8	3.8	2.0
Mar.						
1975	309	4	67.6	32.4	20.9	7.9
1976	1,050	3	53.1	46.8	74.3	52.0
1977	550	3	45.4	54.5	33.3	31.7
Mean						
1975–1977	636	3.3	53.3	46.7	41.1	28.6
Goldeneyes, Common Mergansers, and Hooded Mergansers						
Oct.						
1974	0	3	0.0	0.0	0.0	0.0
1975	0	4	0.0	0.0	0.0	0.0
1976	0	5	0.0	0.0	0.0	0.0
Mean						
1974–1976	0	4.0	0.0	0.0	0.0	0.0
Nov.						
1974	0	4	0.0	0.0	0.0	0.0
1975	11	3	36.4	63.6	0.5	0.7
1976	20	4	0.0	100.0	0.0	1.6
Mean						
1974–1976	10	3.7	12.9	87.1	0.1	0.7
Dec.						
1974	70	3	84.3	15.7	7.9	1.2
1975	94	4	78.7	21.3	7.4	1.6
1976	60	3	75.0	25.0	6.0	1.6
Mean						
1974–1976	75	3.3	79.5	20.5	7.2	1.5
Jan.						
1975	374	5	44.6	55.3	13.3	13.1
1976	182	3	66.7	33.3	16.5	6.6
1977	62	2	87.1	12.9	10.8	1.3
Mean						
1975–1977	207	3.3	55.5	44.5	13.9	8.9
Feb.						
1975	286	4	88.1	11.9	25.2	2.7
1976	170	2	83.5	16.5	28.4	4.4
1977	723	2	51.3	48.7	74.2	55.9
Mean						
1975–1977	393	2.7	64.9	35.1	37.8	16.2

Table 8.—Continued.

Month and Year	Total Number of Birds	Number of Censuses	Percentage		Number per 100 ha per Census	
			Discharge Arm	Intake Arm	Discharge Arm	Intake Arm
Mar.						
1975	122	4	63.1	36.9	7.7	3.6
1976	67	3	41.8	58.2	3.7	4.1
1977	145	3	34.5	65.5	6.7	10.0
Mean						
1975–1977	111	3.3	46.4	53.6	6.2	5.7
Canada Geese and Blue and Snow Geese						
Oct.						
1974	27	3	0.0	100.0	0.0	2.8
1975	551	4	39.6	60.4	21.8	26.4
1976	402	5	28.1	71.9	9.0	18.3
Mean						
1974–1976	327	4.0	33.6	66.0	11.0	17.1
Nov.						
1974	242	4	46.3	53.7	11.2	10.3
1975	136	3	53.7	46.3	9.7	6.7
1976	89	4	22.5	77.5	2.0	5.5
Mean						
1974–1976	156	3.7	43.9	56.1	7.4	7.5
Dec.						
1974	418	3	60.8	39.2	33.9	17.4
1975	2,118	4	74.5	25.5	157.8	42.8
1976	69	3	42.0	58.0	3.9	4.2
Mean						
1974–1976	868	3.3	71.4	28.6	75.1	23.9
Jan.						
1975	3,151	5	35.9	64.1	90.5	128.2
1976	645	3	66.4	33.6	57.1	23.0
1977	16	2	100.0	0.0	3.2	0.0
Mean						
1975–1977	1,271	3.3	41.3	58.7	63.6	77.8
Feb.						
1975	2,687	4	61.9	38.1	166.4	81.2
1976	1,495	2	18.7	81.3	56.0	192.8
1977	100	2	46.0	54.0	9.2	8.6
Mean						
1975–1977	1,427	2.7	46.5	53.5	98.3	89.8
Mar.						
1975	3,835	4	3.8	96.2	14.6	292.8
1976	482	3	20.5	79.5	13.2	40.5
1977	75	3	100.0	0.0	10.0	0.0
Mean						
1975–1977	1,464	3.3	7.3	92.7	13.0	130.6
Coots						
Oct.						
1974	206	3	64.1	35.9	17.6	7.8
1975	671	4	35.9	64.1	24.1	34.1
1976	683	5	35.9	64.1	19.6	27.8
Mean						
1974–1976	520	4.0	39.6	60.4	20.6	24.9
Nov.						
1974	1,214	4	88.0	12.0	106.8	11.6
1975	2,630	3	61.4	38.6	215.3	107.4
1976	439	4	3.4	96.6	1.5	33.6
Mean						
1974–1976	1,428	3.7	63.0	37.0	97.2	45.3
Dec.						
1974	44	3	0.0	100.0	0.0	4.6
1975	42	4	0.0	100.0	0.0	3.3
1976	0	3	0.0	0.0	0.0	0.0
Mean						
1974–1976	29	3.3	0.0	100.0	0.0	2.8

Table 8.—Continued.

Month and Year	Total Number of Birds	Number of Censuses	Percentage		Number per 100 ha per Census	
			Discharge Arm	Intake Arm	Discharge Arm	Intake Arm
Jan.						
1975	83	5	0.0	100.0	0.0	5.3
1976	10	3	0.0	100.0	0.0	1.0
1977	0	2	0.0	0.0	0.0	0.0
Mean 1975–1977	31	3.3	0.0	100.0	0.0	3.0
Feb.						
1975	64	4	70.3	29.7	4.5	1.5
1976	6	2	0.0	100.0	0.0	1.0
1977	0	2	0.0	0.0	0.0	0.0
Mean 1975–1977	23	2.7	64.3	35.7	2.2	1.0
Mar.						
1975	99	4	40.4	59.6	4.0	4.7
1976	541	3	38.3	61.7	27.6	35.3
1977	200	3	22.5	77.5	6.0	16.4
Mean 1975–1977	280	3.3	34.8	65.2	11.8	17.6
		Total Waterfowl				
Oct.						
1974	1,367	3	48.1	51.9	87.6	75.1
1975	2,602	4	39.6	60.4	103.0	124.7
1976	4,049	4	26.5	73.5	107.3	236.2
Mean 1974–1976	2,673	3.7	34.4	65.6	99.4	150.4
Nov.						
1974	61,637	4	87.7	12.3	5,405.7	601.7
1975	37,470	3	63.4	36.6	3,168.8	1,450.2
1976	18,878	4	33.8	66.2	639.0	991.1
Mean 1974–1976	39,328	3.7	71.4	28.6	3,035.7	965.1
Dec.						
1974	71,825	3	48.6	51.4	4,654.2	3,906.7
1975	88,767	4	73.4	26.6	6,516.7	1,873.0
1976	63,330	3	75.8	24.2	6,398.5	1,623.4
Mean 1974–1976	74,641	3.7	66.1	33.9	5,333.8	2,171.0
Jan.						
1975	77,241	5	43.1	56.9	2,664.5	2,789.5
1976	38,243	3	63.1	36.9	3,217.5	1,493.3
1977	10,783	2	61.0	39.0	1,315.8	667.3
Mean 1975–1977	42,089	3.3	50.7	49.3	2,587.5	1,994.2
Feb.						
1975	26,600	4	53.3	46.7	1,417.8	985.9
1976	6,163	2	37.1	62.9	457.3	615.3
1977	8,145	2	41.5	58.5	676.0	756.3
Mean 1975–1977	13,636	2.7	49.0	51.0	989.9	817.7
Mar.						
1975	19,512	4	14.8	85.2	289.1	1,319.1
1976	7,128	3	30.3	69.7	288.0	525.7
1977	4,012[a]	3	38.3	61.7	204.9	261.9
Mean 1975–1977	10,217	3.3	21.5	78.5	266.3	771.6

[a] Includes five redheads.

same area, and this second group might continue to use the area because of habit. Similarly, hunting, fishing, and other human activities might cause waterfowl to develop patterns of use not directly related to water temperature.

As mentioned earlier, surface-water temperatures from one portion of the lake to another were generally significantly different (Table 2). Although waterfowl numbers were counted on five areas of the lake, in our efforts to determine the effects of heated water on the distribution of waterfowl, we have compared populations only on the discharge arm (heated water) with populations on the intake arm (unheated water). The two areas are roughly similar in size, length of shoreline, directional orientation, and proximity to the refuge at the dam and the slag pond (Table 1 and Fig. 2).

Counts of waterfowl in these two areas of Lake Sangchris from October through March—1974–1975, 1975–1976, and 1976–1977—are summarized by months and years in Table 8. The various species were partitioned into seven groups on the basis of similarity in food habits and habitat preferences. For example, mallards and black ducks were placed in one group and scaups, ring-necked ducks, canvasbacks, and ruddy ducks were placed in another group.

Although paired *t*-tests indicated no significant differences ($P > 0.05$) in the population densities of all waterfowl combined by months for the 3 years of these studies on the discharge arm versus the intake arm, the general pattern for all waterfowl combined was for nearly equal concentrations (number of waterfowl per 100 ha per census) on the two areas in October ($P > 0.10$), a tendency to select

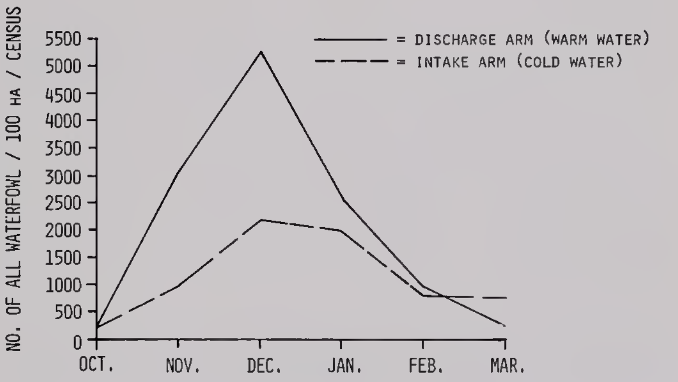

Fig. 4.—Mean number of all waterfowl per 100 ha per census on the discharge arm at Lake Sangchris as compared with the intake arm, October–March 1974–1977.

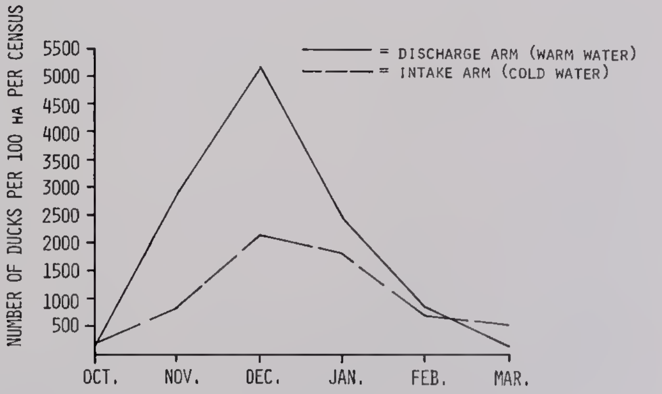

Fig. 5.—Mean number of mallards and black ducks per 100 ha per census on the discharge arm at Lake Sangchris as compared with the intake arm, October–March 1974–1977.

heated water in November and December ($P > 0.10$), a slight preference for heated water in January ($P > 0.90$), no selection in February ($P > 0.90$), and a preference for unheated water in March ($P > 0.05$) (Table 8 and Fig. 4).

Because mallards and black ducks constituted a majority of the population in all months (especially mallards, which constituted from 49.1 percent of the total population in October to 95.4 percent in December, Table 5), it is not surprising that they showed a pattern with respect to water temperature that was almost identical to that of all waterfowl combined (Fig. 5). The surface-feeding species that feed strictly in aquatic environments (blue-winged teal, green-winged teal, gadwall, and shoveler) avoided the heated water in October and March. In November they showed no preference in relation to water temperature (Fig. 6). These species were not abundant at any time at Lake Sangchris, were absent in January and February, and were virtually absent in December (Table 8 and Fig. 6). Coots showed no preference for the heated water in October, preferred it in November, were virtually absent from December through February, and showed a slight avoidance of the heated water in March (Fig. 7).

Pintails and wigeons were always present in low numbers at Lake Sangchris and showed no significant reaction to water temperatures (Fig. 8). Scaups, ring-necked ducks, canvasbacks, and ruddy ducks were never present in large numbers at Lake Sangchris, and they too showed little or no preference with respect to water temperature (Fig. 9), except perhaps in March, when they showed a slight avoidance of the unheated water. Goldeneyes and mergansers were present in low numbers from December through March. They seemed to prefer

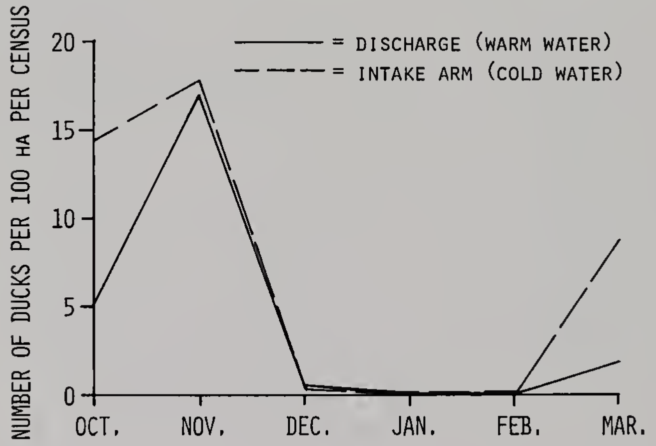

Fig. 6.—Mean number of blue-winged teals, green-winged teals, gadwalls, and shovelers per 100 ha per census on the discharge arm at Lake Sangchris as compared with the intake arm, October–March 1974–1977.

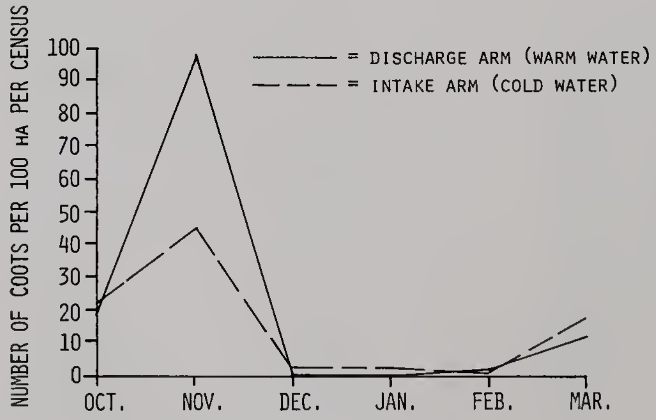

Fig. 7.—Mean number of coots per 100 ha per census on the discharge arm at Lake Sangchris as compared with the intake arm, October–March 1974–1977.

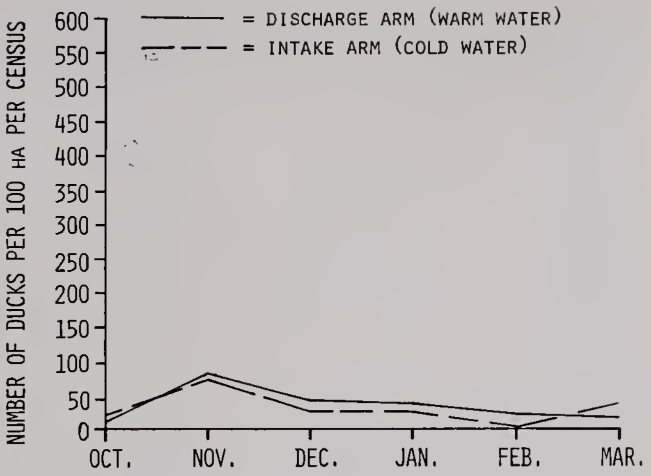

Fig. 8.—Mean number of pintails and wigeons per 100 ha per census on the discharge arm at Lake Sangchris as compared with the intake arm, October-March 1974-1977.

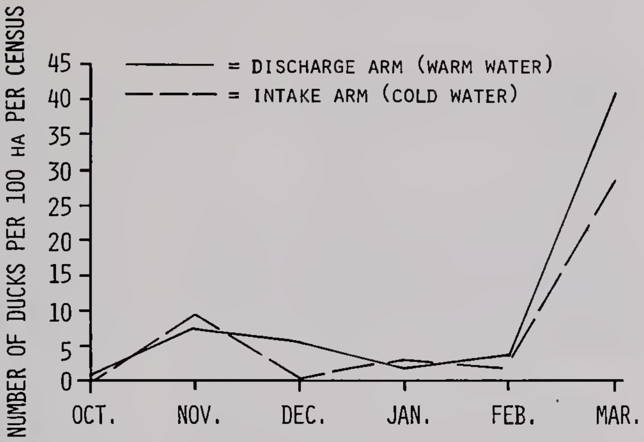

Fig. 9.—Mean number of scaups, ring-necked ducks, canvasbacks, and ruddy ducks per 100 ha per census on the discharge arm at Lake Sangchris as compared with the intake arm, October-March 1974-1977.

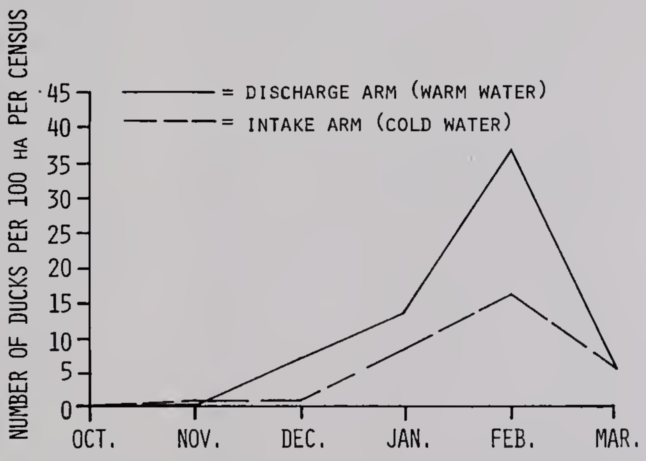

Fig. 10.—Mean number of goldeneyes, common mergansers, and hooded mergansers per 100 ha per census on the discharge arm at Lake Sangchris as compared with the intake arm, October-March 1974-1977.

the heated water from December through February, but had no preference in March (Fig: 10).

Geese (virtually all Canada geese) were present in relatively low concentrations from October through March. No doubt many of the geese in the general area were feeding in nearby cornfields when the censuses were made. Those on the lake seemed to prefer the heated water in

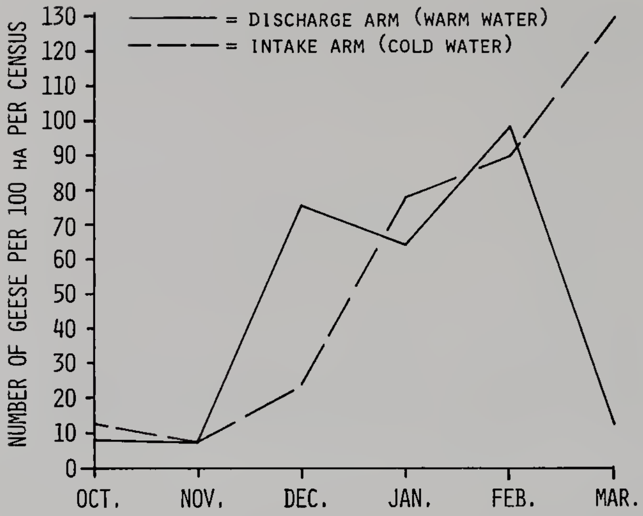

Fig. 11.—Mean number of Canada geese and blue and snow geese per 100 ha per census on the discharge arm at Lake Sangchris as compared with the intake arm, October–March 1974–1977.

December, the unheated water in March, and had no strong preference the other months (Fig. 11).

COLLISIONS WITH POWER LINES

Because the results of this phase of the study have been published separately, we will quote the abstract of the published report (Anderson 1978:77); however, a summary of the results is shown in Table 9.

> Between 200 and 400 waterfowl (0.2–0.4 percent of maximum number present) were killed each fall, 1973–75, by colliding with high-voltage transmission lines that cross the slag pit (32 ha of water) at the Kincaid Power Plant and adjacent Lake Sangchris (872 ha of water), central Illinois. Mallards (*Anas platyrhynchos)*constituted 37 percent of the victims, blue-winged teals (*A. discors)* 17 percent, and American coots (*Fulica americana)* 25 percent. Blue-winged teals were most vulnerable to collisions (0.549 casualty per 1,000 bird-days of use of the slag pit) and mallards least vulnerable (0.026). Factors contributing to frequency of collisions were (1) number of waterfowl present, (2) weather conditions and visibility, (3) species composition or behavior of birds, (4) distrubance, and (5) familiarity of birds with the area. Power lines should not be built over water unless alternate routes do not exist; lines should not cross areas where waterfowl concentrate; and visibility of lines in problem areas should be enhanced.

BODY WEIGHTS

Body weights of mallards, wigeons, and lesser scaups bagged by hunters at Lake Sangchris in 1974, 1975, and 1976 are summarized in Table 10. Juvenile and adult females of the three species weighed 3.2- 13.2 percent less, on the average, in 1975 than in 1974. Except for adult

Table 9.—Numbers of waterfowl found dead or crippled in the slag pond at the Kincaid Generating Station from September to December—1973, 1974, and 1975.[a]

Cause of Injury	1973	1974	1975	All Years
Had collided with power lines	88	139	116	343
Had been shot	0	38	26	64
Had been lead poisoned	3	6	5	14
Unknown	8	13	11	32
Total	*99*	*196*	*158*	*453*

[a] From Anderson (1978).

Table 10.—Mean body weight and standard errors, in grams, of mallards, wigeons, and lesser scaups bagged by hunters at Lake Sangchris from 24 October to 10 December 1974, from 24 October to 8 December 1975, and from 23 October to 9 December 1976. Sample sizes are in parentheses.

Year	Females		Males	
	Juveniles	Adults	Juveniles	Adults
		Mallards		
1974	987 ± 19 (28)	1,124 ± 45 (10)	1,175 ± 18 (44)	1,276 ± 10 (140)
1975	952 ± 22 (26)	1,088 ± 12 (100)	1,152 ± 11 (97)	1,265 ± 7 (305)
1976	995 ± 14 (67)	1,119 ± 9 (157)	1,172 ± 13 (121)	1,315 ± 6 (338)
		Wigeons		
1974	713 ± 21 (20)	774 ± 20 (6)	735 ± 22 (18)	788 ± 23 (12)
1975	628 ± 18 (17)	672 ± 30 (4)	721 ± 21 (18)	777 ± 14 (17)
1976	680 ± 13 (48)	678 ± 22 (6)	761 ± 14 (35)	818 ± 21 (16)
		Lesser Scaups		
1974	752 ± 20 (16)	874 (1)	783 ± 45 (8)	786 ± 28 (12)
1975	698 ± 24 (24)	788 ± 21 (14)	763 ± 22 (27)	870 ± 14 (28)
1976	691 ± 15 (29)	787 ± 19 (15)	733 ± 28 (15)	795 ± 17 (39)

male scaups, males also weighed less in 1975 than during the year before. In 1976, juvenile and adult females of the three species (except for juvenile female mallards, which weighed slightly more) weighed less than in 1974. Except for juvenile male scaups, males also weighed essentially the same or were heavier in 1976 than in 1974. Contrary to the findings of Bellrose & Hawkins (1947:427),

Table 11.—Mean body weights and standard errors, in grams, of mallards bagged by hunters at Lake Sangchris during early, middle, and late portions of the hunting season in 1974, 1975, and 1976. Sample sizes are in parentheses.

	Females		Males	
Date	Juveniles	Adults	Juveniles	Adults
1974				
24 Oct.–9 Nov.	987 ± 22 (16)	1,031 ± 44 (8)	1,141 ± 28 (17)	1,231 ± 14 (47)
10–25 Nov.	973 ± 48 (7)	1,106 ± 27 (22)	1,202 ± 35 (12)	1,270 ± 19 (42)
26 Nov.–11 Dec.	1,011 ± 58 (5)	1,124 ± 45 (10)	1,192 ± 33 (15)	1,321 ± 16 (51)
1975				
24 Oct.–9 Nov.	942 ± 40 (10)	1,047 ± 18 (30)	1,134 ± 17 (35)	1,227 ± 10 (99)
10–25 Nov.	942 ± 34 (10)	1,100 ± 16 (46)	1,165 ± 22 (22)	1,256 ± 10 (132)
26 Nov.–8 Dec.	988 ± 44 (6)	1,115 ± 29 (24)	1,159 ± 20 (20)	1,332 ± 16 (74)
1976				
24 Oct.– 9 Nov.	977 ± 25 (17)	1,073 ± 13 (68)	1,172 ± 23 (32)	1,261 ± 13 (83)
10–25 Nov.	987 ± 25 (26)	1,133 ± 16 (49)	1,168 ± 22 (46)	1,327 ± 13 (83)
26 Nov.– 9 Dec.	1,018 ± 21 (24)	1,179 ± 18 (40)	1,176 ± 22 (43)	1,335 ± 8 (172)

mean weights of mallards bagged late in the hunting season were greater than those of mallards bagged early in the season (Table 11).

Juvenile female mallards at Sangchris weighed 978 g as compared with 1,048 g for a large series reported by Bellrose (1976:229). Juvenile male mallards at Sangchris averaged 1,166 g compared with 1,193 g reported by Bellrose (1976:229). Adult female (1,110 g) and adult male (1,285 g) mallards at Sangchris weighed more than the average weights reported by Bellrose (1976:229) for adult females (1,107 g) and adult males (1,247 g). Among wigeons and lesser scaups bagged by hunters at Sangchris, only adult female lesser scaups had average weights that were heavier than the mean weights reported by Bellrose (1976:198, 343) for these two species.

FOOD HABITS

Examination of the contents of stomachs from ducks bagged by hunters revealed that mallards at Lake Sangchris relied heavily on corn for food (Table 12). Foods in gizzards, taken from ducks in 1974, suggested that 88 percent of the mallards' diet was corn. Moreover, foods in proventriculi, taken from ducks in 1975 and considered more reliable than gizzards for determining food habits, indicated that virtually 100 percent of the mallards' diet was corn.

In 1974, 453 gizzards from 16 species of waterfowl were examined for the presence of *Corbicula* shells, slag, and lead pellets. The percentages of gizzards in which these items occurred was 36, 66, and 3.8 percent, respectively. Values for 286 mallards were 43, 67, and 4.9 percent. In 1975, 702 gizzards from 16 species were examined; 29 percent contained *Corbicula,* 51 percent contained slag, and 1.6 percent contained lead pellets (Table 13). Values for 407 mallards were 36, 54, and 1.2 percent. Both *Corbicula* and slag were found in most of the species represented in the sample—the exceptions had small sample sizes.

As in 1974, the incidence of *Corbicula* and slag in gizzards of mallards, wigeons, and lesser scaups examined in 1975 increased as the hunting season progressed (Table 14). The incidence of lead pellets decreased for mallards and wigeons but not for scaups.

Field observations at the Lake Sangchris-Kincaid Generating Station complex in 1973, 1974, and 1975 revealed that waterfowl make extensive use of the power plant's slag pond during the fall months. As many as 90,000 birds were counted at one time on this 32-ha body of water, and 40,000 were commonplace. Waterfowl are attracted to the slag pond because it provides an abundance of food in the form of brittle naiad (*Najas minor)* and other aquatic plants and because it serves as a refuge—the slag pond is not open to the public. However, there are several reasons for being concerned about the welfare of waterfowl that congregate on slag ponds, one of which is the possible adverse effects of ingested slag on the birds. This concern came sharply into focus with the discovery that 57 percent of the 1,155 gizzards examined in 1974 and 1975 contained slag.

Findings of other researchers at Lake Sangchris suggest that, in general, the

Table 12.—The relative importance of corn in the diet of mallards at Lake Sangchris from October to December in 1974 and 1975. The data were obtained by examining the contents of gizzards (providing gizzard contained ≥ 1 g of food) in 1974 and the contents of proventriculi in 1975.

Year	Gizzards or Proventriculi Examined	Percent of Gizzards or Proventriculi in Which Corn Occurred	Percent Corn Constituted of all Foods in all Gizzards or Proventriculi[a]
1974	66	89.4	87.7
1975	68	97.1	99.9

[a] Only gizzards were collected in 1974. In 1975 kinds of food ingested were determined from proventriculi, and amounts of *Corbicula* shells, slag, and lead shot were determined from gizzards.

Table 13.—The incidence of *Corbicula* shells, slag, and lead shot in gizzards of waterfowl bagged by hunters at Lake Sangchris between 24 October and 11 December 1974 and 24 October and 8 December 1975.

	Number Examined		Percent That Contained					
			Corbicula Shells		Slag		Lead Pellets[a]	
Species	1974	1975	1974	1975	1974	1975	1974	1975
Surface-feeding ducks								
Mallard	286	407	43	36	67	54	4.9	1.2
Black duck	0	15	. . .	40	. . .	87	. . .	6.6
Pintail	0	5	. . .	20	. . .	60	. . .	0.0
Wigeon	64	44	16	7	91	73	0.0	2.3
Blue-winged teal	2	8	100	38	50	38	0.0	0.0
Green-winged teal	13	53	15	13	92	74	0.0	0.0
Gadwall	10	19	0	5	80	42	0.0	0.0
Shoveler	2	8	0	0	50	25	0.0	0.0
Wood duck	1	9	0	0	0	22	0.0	0.0
Diving ducks								
Redhead	4	13	50	31	75	31	0.0	0.0
Scaup	45	67	33	33	33	31	4.4	3.0
Ring-necked duck	13	32	15	25	38	34	7.7	6.3
Goldeneye	5	6	20	17	20	0	0.0	0.0
Bufflehead	1	4	0	0	0	50	0.0	0.0
Ruddy duck	3	0	67	. . .	0	. . .	0.0	. . .
Mergansers								
Common merganser	2	6	100	0	0	0	0.0	0.0
Hooded merganser	1	6	0	0	0	17	0.0	0.0
Blue goose	1	0	0	. . .	100	. . .	0.0	. . .
All Species	*453*	*702*	*36*	*29*	*66*	*51*	*3.8*	*1.6*

[a] Includes only those pellets that had been ingested by the birds.

heated water had a slightly positive effect on organisms that waterfowl use for food. American water lotus (*Nelumbo lutea*) responded favorably in terms of biomass to the warmer water, American pondweed (*Potamogeton nodosus*) responded slightly negatively, and brittle naiad (*Najas minor)* apparently exhibited no preference for either the heated or unheated water and was extremely abundant throughout the lake in some years (Moran 1981). The latter two species are

Table 14.—The incidence of *Corbicula* shells, slag, and lead pellets in gizzards of mallards, wigeons, and lesser scaups bagged by hunters at Lake Sangchris during early, middle, and late portions of the hunting seasons in 1974 and 1975.

	Number Examined		Percent That Contained					
			Corbicula Shells		Slag		Lead Pellets[a]	
Date	1974	1975	1974	1975	1974	1975	1974	1975
			Mallards					
24 Oct.–9 Nov.	113	112	16	15	62	45	6.2	1.8
10–25 Nov.	86	166	55	45	70	48	4.7	1.2
26 Nov.–8 Dec.	87	129	67	42	64	71	3.4	0.8
			Wigeons					
24 Oct.–9 Nov.	17	25	12	0	82	68	0.0	4.0
10–25 Nov.	14	9	14	11	93	78	0.0	0.0
26 Nov.–8 Dec.	33	10	18	20	94	80	0.0	0.0
			Lesser Scaups					
24 Oct.–9 Nov.	19	27	21	11	32	15	11.0	0.0
10–25 Nov.	16	31	13	45	19	39	0.0	3.2
26 Nov.–8 Dec.	10	9	90	78	60	67	0.0	11.1

[a] Includes only those pellets that had been ingested by the birds.

The slag pond adjacent to the Kincaid Generating Station, where waterfowl congregate in the fall.

important waterfowl foods. *Corbicula* was favored somewhat by the heated water (Dreier & Tranquilli 1981), whereas other macroinvertebrates—primarily Chaoborids and Chironomids—exhibited no change in abundance between the intake and discharge arms (Webb 1981). Several species of fishes concentrate in the heated water during the winter months (Tranquilli et al. 1981) but are not ordinarily consumed by waterfowl, except for mergansers and goldeneyes.

RESPONSES OF MALLARDS TO INGESTED SLAG

The purpose of this phase of the investigations was to determine the effects, if any, of prescribed amounts of ingested slag on captive mallards for an extended period of time. The experimental birds were fed slag from 11 October to 6 December 1976.

All 20 ducks fed corn or commercial maintenance chow and all 20 ducks fed corn and slag or chow and slag survived the entire 8-week feeding period. Furthermore, no ducks were emaciated or obviously sick at the termination of the experiment. The mean weight of ducks fed chow and slag was appreciably less than the mean weight of the ducks fed chow, both at the beginning of the experiment and at the end (Table 15). At the latter time the difference was statistically significant. Mean weights of

Table 15.—Body weights of juvenile male mallards fed exclusive diets of corn, corn plus slag, commercial maintenance chow, or chow plus slag for an 8-week period—11 October–6 December 1976.

	Mean Weight in Grams ± Standard Error			
	Corn	Corn + Slag	Chow	Chow + Slag
Initial weight (October 11)	1,192 ± 24	1,206 ± 27	1,241 ± 21	1,188 ± 23
Final weight (December 6)	1,230 ± 41	1,229 ± 41	1,344 ± 35[a]	1,226 ± 33[a]
Change in weight	+ 38 ± 23	+ 23 ± 26	+ 103 ± 17	+ 38 ± 26

[a] Difference between means is statistically significant ($P<0.05$).

the ducks fed corn and of those fed corn and slag were similar at the beginning of the study and also at its termination. The ducks fed corn and those fed chow gained more weight, on the average, than their counterparts receiving slag (Table 15). However, the differences were not significant.

The patterns of change in body weight during the experiment for the ducks fed corn and slag and those fed corn were almost identical through the 4th week

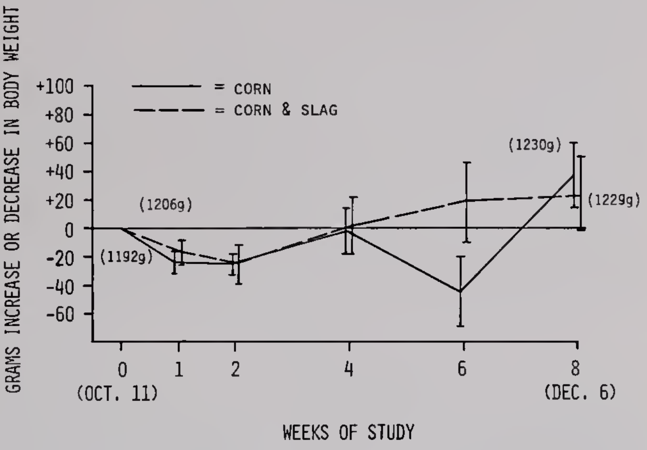

Fig. 12.—Mean change in body weight of juvenile male mallards fed corn or corn plus slag for 8 weeks. Vertical lines indicate standard errors. The mean initial and final body weights for each group of ducks are given in parentheses. None of the differences between means for the weekly and biweekly periods were statistically significant ($P > 0.05$). N = 10 in each group.

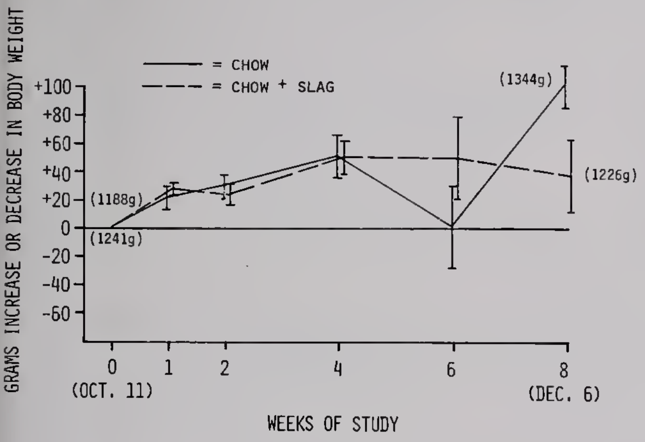

Fig. 13.—Mean change in body weight of juvenile male mallards fed chow or chow plus slag for 8 weeks. Vertical lines indicate standard errors. The mean initial and final body weights for each group of ducks are given in parentheses. None of the differences between means for the weekly and biweekly periods were statistically significant ($P > 0.05$). N = 10 in each group.

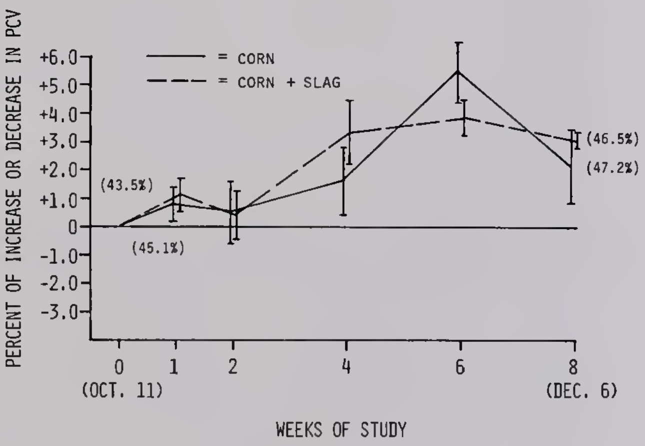

Fig. 14.—Mean change in packed cell volume (PCV) for juvenile male mallards fed corn or corn plus slag for 8 weeks. Vertical lines indicate standard errors. The mean initial and final PCVs for each group of ducks are given in parentheses. None of the differences between means for the weekly and biweekly periods were statistically significant ($P > 0.05$). N = 10 in each group.

(Fig. 12). Similarly, the patterns of change for the ducks fed chow and slag and those fed chow were also much alike through the 4th week (Fig. 13). Between the 4th and 6th weeks the ducks fed corn and those fed chow lost an average of 43 and 50 g, respectively. For purposes of comparison, the ducks fed corn and slag gain-

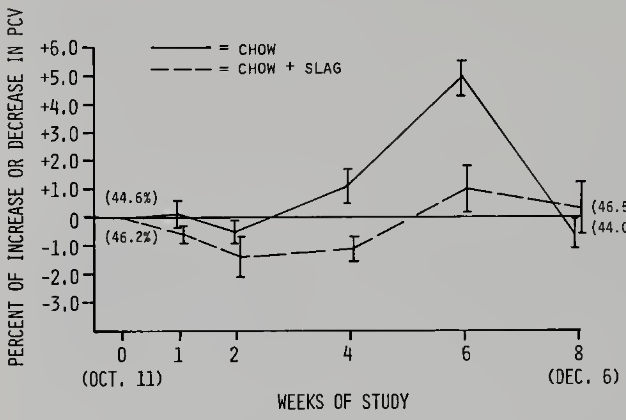

Fig. 15.—Mean change in packed cell volume (PCV) for juvenile male mallards fed chow or chow plus slag for 8 weeks. Vertical lines indicate standard errors. The mean initial and final PCVs for each group of ducks are given in parentheses. Statistically significant ($P < 0.05$) differences occurred between means for the two groups of ducks at the ends of the 4th and 6th weeks. N = 10 in each group.

Table 16.—Mean weights (plus or minus the standard error) of the liver, kidneys, gizzard and proventriculus, and adrenals from juvenile male mallards fed corn or corn plus slag for 8 weeks—11 October–6 December 1976. The differences between paired means are not statistically significant. N = 10 in each group.

Organ or Gland	Weight		Percent of Body Weight at End of Experiment	
	Corn	Corn + Slag	Corn	Corn + Slag
Liver	20.6 ± 1.0 g	19.1 ± 0.8 g	1.68 ± 0.08	1.55 ± 0.05
Kidneys	5.9 ± 0.2 g	5.9 ± 0.2 g	0.49 ± 0.02	0.49 ± 0.02
Gizzard and proventriculus	31.4 ± 0.9 g	33.2 ± 1.0 g	2.57 ± 0.08	2.71 ± 0.06
Adrenals	95.8 ± 6.8 mg	92.8 ± 3.7 mg	77.8 ± 5.0[a]	76.2 ± 3.4[a]

[a] Percent X 10^4.

Table 17.—Mean weights (plus or minus the standard error) of the liver, kidneys, gizzard and proventriculus, and adrenals from juvenile male mallards fed commercial maintenance chow or chow plus slag for 8 weeks—11 October–6 December 1976. N = 10 in each group.

Organ or Gland	Weight		Percent of Body Weight at End of Experiment	
	Chow	Chow + Slag	Chow	Chow + Slag
Liver	25.1 ± 1.2 g	24.0 ± 1.5 g	1.87 ± 0.06	1.97 ± 0.12
Kidneys	8.6 ± 0.3 g	8.3 ± 0.5 g	0.64 ± 0.02	0.68 ± 0.03
Gizzard and proventriculus	41.8 ± 1.0 g[a]	37.4 ± 1.1 g[a]	3.12 ± 0.09	3.07 ± 0.10
Adrenals	90.6 ± 5.1 mg	94.3 ± 2.8 mg	73.6 ± 4.0[b]	77.4 ± 3.0[b]

[a] The difference between means is statistically significant ($P < 0.05$).
[b] Percent X 10^4.

Table 18.—Mean weights in grams (plus or minus the standard error) of grit and slag in gizzards of juvenile male mallards fed corn, corn plus slag, commercial maintenance chow, or chow plus slag for 8 weeks—11 October–6 December 1976. N = 10 in each group.

Item	Corn	Corn + Slag	Chow	Chow + Slag
Grit	1.08 ± 0.20	0.87 ± 0.11	1.62 ± 0.19[b]	0.74 ± 0.14[b]
Slag	0.77 ± 0.09[a]	2.21 ± 0.21[a]	0.00[b]	2.40 ± 0.29[b]
Total	*1.85 ± 0.24*[a]	*3.08 ± 0.19*[a]	*1.62 ± 0.19*[b]	*3.14 ± 0.29*[b]

[a] The difference between paired means is statistically significant ($P < 0.05$).
[b] The difference between paired means is statistically significant ($P < 0.05$).

ed an average of 17 g, and those fed chow and slag lost an average of 1 g during the same period. Because of large gains during the last 2 weeks, the net increases in body weight during the entire experiment were greater for the ducks fed corn and those fed chow than for their counterparts receiving slag (Fig. 12 and 13).

Ducks fed corn and those fed corn and slag exhibited almost identical patterns of change in packed cell volume (PCV) during the experiment (Fig. 14). However, the pattern of change in PCV of ducks fed chow and slag occurred at a lower level, during all weeks except the last, than the pattern of ducks fed chow (Fig. 15). The differences between these two groups of ducks at the ends of the 4th and 6th weeks were statistically significant.

The only significant difference detected in mean weights of internal organs occurred between gizzards-proventriculi of ducks fed maintenance chow and those fed chow and slag (Tables 16 and 17). The latter ducks had relatively small gizzards. Interestingly, these small gizzards contained almost twice as much grit and slag, on the average, as did gizzards from ducks fed chow (Table 18). The linings of gizzards from the ducks that consumed slag were not eroded or otherwise irritated.

NUTRIENT LOADING

The amounts of total nitrogen and of available phosphorus deposited in Lake Sangchris by waterfowl in 1974–1975, 1975–1976, and 1976–1977 are presented in Table 19. Interesting differences existed among the 3 years in the two areas subject to heavy nutrient loading. The dam area, where the waterfowl refuge is located, received twice as much nitrogen and phosphorus in 1975–1976 as in 1974–1975. Offsetting this increase was a 57-percent decrease in the amounts of these nutrients added to the slag pond between 1974–1975 and 1975–1976. The dam area received almost as much nitrogen and phosphorus in 1976–1977 as in 1975–1976. Except for the dam area, all areas had the lowest levels of nitrogen and phosphorus added in 1976–1977, reflecting the generally lowest level of use in 1976–1977 of any year of the study (Table 6).

The two large bays west of the dam, where ducks congregate, received most of the nitrogen and phosphorus added to the dam area. Thus, the bays, comprising 42 ha of surface water, could have received nutrient loads as high as 61.85 kg of nitrogen and 34.50 kg of phosphorus per hectare in 1975–1976.

DISCUSSION

The difficulty of making an evaluation of waterfowl responses (nonresponses) to the water heated by the Kincaid Generating Station and released into the discharge arm of Lake Sangchris is compounded by many variables. However, two factors loom above all others: food and protec-

Table 19.—Amounts of total nitrogen (N_2) and of available phosphorus (P_2O_5) in kilograms per hectare of lake surface added to Lake Sangchris and the slag pond by waterfowl from October to March, 1974–1975, 1975–1976, and 1976–1977.

	Discharge Arm		Dam	Intake	Control	Slag	
Year	South	North	Area	Arm	Arm	Pond	Total
			Nitrogen				
1974–1975	3.95	3.48	16.41	2.47	1.48	64.59	6.00
1975–1976	3.16	3.76	32.88	1.55	0.65	27.63	5.53
1976–1977	1.36	3.11	28.08	1.15	0.37	19.94	4.25
Mean	*2.82*	*3.45*	*25.79*	*1.72*	*0.83*	*37.39*	*5.26*
			Phosphorus				
1974–1975	2.22	1.95	9.14	1.36	0.84	36.00	3.39
1975–1976	1.76	2.10	18.34	0.86	0.36	15.41	3.08
1976–1977	0.76	1.73	15.94	0.65	0.20	11.27	2.41
Mean	*1.58*	*1.93*	*14.47*	*0.96*	*0.47*	*20.89*	*2.96*
Hectares of water	104	147	79	315	227	32	904

tion—or their counterparts, lack of food and disturbance. For species that feed in cornfields and soybean fields (mallard, black duck, pintail, wigeon, and geese), sources of food are relatively plentiful at Lake Sangchris. All other species that stop over at Lake Sangchris (teals, gadwall, shoveler, diving ducks, mergansers, and coot) are restricted to aquatic environments for feeding activities. Thus, the heated water could affect the latter group of birds indirectly by influencing, either favorably or unfavorably, plants and animals that they use for food. Obvious sources of disturbance are (1) hunting activities—permitted in the intake arm and control arm during the waterfowl hunting season, (2) fishing activities—permitted in the discharge arm during the hunting season and in the entire lake at all other times, and (3) aquatic biologists' research—conducted on the entire lake but often involving the full length of the discharge arm because the boat dock was in the discharge canal. Also, unlike fishes and other aquatic organisms, waterfowl are directly affected by *both* air temperature and water temperature.

The available evidence suggests that waterfowl, at least certain species, avoided the discharge arm of Lake Sangchris in October and March and were attracted to it during November, December, and January (Table 8). However, were those birds *repelled from* (attracted to) the discharge arm or were they *attracted to* (repelled from) some other portion of the lake? The net result would be the same—relatively few (relatively many) birds in the discharge arm. There is little doubt that waterfowl were attracted to at least one portion of the lake, the refuge in the dam area.

The tendency to avoid the discharge arm was most evident among species of surface-feeding ducks that rely heavily on aquatic vegetation and invertebrates for food—blue-winged teal, green-winged teal, gadwall, and shovelers—and occurred during months when water temperatures and air temperatures were relatively high (Table 2). Mallards and black ducks, geese, and coots also tended to avoid the heated water during March. Positive responses to the discharge arm were most pronounced among fish-eating species—goldeneye and mergansers—and occurred during months when water temperatures and air temperatures were relatively low. These ducks were almost certainly attracted to gizzard shad—which comprised 76.3 percent of the lake's standing fish crop (Tranquilli et al. 1981)—that concentrate in the heated water during the winter months.

We obtained no evidence during three fall-winter-spring periods that the heated water in Lake Sangchris altered the chronology of migration of mallards through central Illinois (Fig. 3). In fact, the data suggest that mallards departed from Sangchris during November and December for more southern latitudes on the same dates and in the same magnitude as from the Illinois River valley. Similarly, the mallards' migration northward in spring was neither accelerated nor delayed at Sangchris. The species that spent the entire winter at Sangchris (mallard, black duck, wigeon, goldeneye, mergansers, and Canada goose) were essentially the same as those that winter along the Illinois River (Tables 4 and 7).

Brisbin (1974) found that surface-feeding ducks, diving ducks, and coots generally responded negatively to heated portions of a reactor cooling reservoir in South Carolina. However, he noted (1974: 592) that after a severe ice and snow storm in December, waterfowl abundance and species richness decreased appreciably on the unheated water but remained the same in the heated area—findings that parallel ours for Lake Sangchris during the winter months. Brisbin (1974:585) also reported that the lesser scaup was much more tolerant of the heated water than its taxonomic cousin, the ring-necked duck, because the scaup's diet is primarily animal matter and the ringneck is basically a vegetarian. These findings also parallel ours.

The number of waterfowl lost at Lake Sangchris through collisions with the power lines that cross the slag pond and the lake is not serious in terms of the total population. At least 114 birds were killed or crippled at the slag pond during the fall of each season (Table 9). If we assume that we found 58 percent of the birds that collided with the lines at the slag pond (Anderson 1978:81), the total annual kill would be approximately 200 waterfowl. Furthermore, if 200 additional birds collided with the lines that cross the lake, the total annual mortality at Lake Sangchris would be about 400 waterfowl. We consider these estimates conservative.

If for some reason the number of waterfowl lost to the power lines increases substantially, or if additional lines are constructed at Lake Sangchris, precautions should be taken to minimize this cause of mortality. Existing lines in problem areas such as the slag pond should be made more visible—painted international orange, for example. New lines should not be constructed over main portions of the lake or in potential problem areas such as sites of future slag ponds.

Waterfowl should not be driven from the slag pond or otherwise discouraged from using that body of water. The 32 ha of water in the slag pond offer the birds almost complete protection and provide a good source of food in the form of brittle naiad and other aquatic plants. The slag pond, as it now exists, is a major factor—if not *the* major factor—contributing to the buildup and maintenance of the waterfowl population at Lake Sangchris in recent years.

Mean body weights (Table 10) and stomach contents of mallards suggest that the physical condition of this important game species is good at Lake Sangchris. Unlike mallards in the Illinois River valley, mallards at Lake Sangchris (Table 11) did not lose weight as the hunting season progressed. Mallards at Lake Sangchris can obtain a nearly perfect diet simply by eating corn and *Corbicula* (Tables 12 and 13). Corn is 78 percent carbohydrate (a rich source of calories) and the *Corbicula* provides both flesh (a source of protein) and shell (a source of minerals).

Corn, when fed as an exclusive diet, is grossly deficient in several organic and inorganic (mineral) nutrients. Therefore, the possibility exists that slag, which is rich in calcium, phosphorus, iron, and essential trace elements, would be beneficial to mallards maintained on that grain. Unfortunately, the diet of corn fed to mallards during the slag-feeding experiment was contaminated with slag. Thus, it is not surprising that the ducks fed corn and those fed corn and slag exhibited almost identical responses in terms of changes in body weight, changes in PCV, and weights of internal organs (Tables 15 and 16, Fig. 12 and 14).

All 10 ducks fed maintenance chow and slag survived the 8-week feeding period, and 8 of the 10 actually gained weight. However, findings of this study suggest that these ducks did not fare as well as those fed chow alone. The former did not gain as much weight and had lower PCV values during the experiment than the latter (Table 15 and Fig. 15). Furthermore, at the termination of the feeding period, the ducks fed chow and slag weighed significantly less and had significantly smaller gizzards-proventriculi than ducks fed chow (Tables 15 and 17).

It is tentatively concluded that slag is not a toxicant of catastrophic proportions when ingested by mallards at levels equal to or below those administered during this study. However, the evidence also indicates that ducks would be in better condition if they were not exposed to slag for long periods of time.

Nutrient loading at the rates of 4 g of nitrogen and 0.3 g of phosphorus per square meter per year have produced nuisance conditions in a lake with an average depth of 20 m (U.S. Environmental Protection Agency 1973:22). These values equate to 40 kg and 3 kg of nitrogen and phosphorus, respectively, per surface hectare of water. If similar rates of nutrient loading were to result in dense growths of aquatic vegetation in Lake Sangchris, where the average depth is only 4.6 m, the amount of phosphorus added to the dam area and the slag pond by waterfowl was undesirably high, averaging 14.47 and 20.89 kg, respectively, per hectare (Table 19) for the 3 years.

The only area where the average amounts of nitrogen for the 3 years approached the threshold of undesirable levels was in the slag pond, where 37.39 kg per hectare were deposited (Table 19). The level of 40 kg per hectare of nitrogen was exceeded for the slag pond in 1974–1975 (64.59, Table 19).

As previously pointed out, the slag pond supports a dense stand of brittle naiad during late summer and fall. A cycle of sorts exists in the slag pond among the naiad, the waterfowl, and nitrogen and phosphorus: the naiad attracts the waterfowl, which add nitrogen and phosphorus to the water, which promote another dense growth of naiad the next year. The amounts of nitrogen and phosphorus added annually during the 3-year period to the two bays west of the dam (48.51 and 29.22 kg per hectare, respectively) are sufficient to cause eventual development of dense stands of vegetation in these shallow areas.

CONCLUSIONS

1.—Waterfowl populations at Lake Sangchris begin to increase in October with the arrival of substantial numbers of mallards, coots, and wigeons and lesser numbers of several other species.

2.—Peak numbers for a single count are reached in November with the arrival of many more mallards and substantial numbers of black ducks. Coot and wigeon populations remain about the same as in October.

3.—The monthly average for all waterfowl present reaches a peak in December, when still more mallards arrive, numbers of black ducks remain about the same, numbers of wigeons and coots decline, and numbers of Canada geese increase.

4.—The total waterfowl population level shows a steady decline from December through March.

5.—Although present in relatively low numbers, Canada geese, goldeneyes, and mergansers are the only species that show peak numbers in January and February, whereas scaups, ring-necked ducks, and canvasbacks are the only species most abundant in March.

6.—Mallards comprise from 50 percent of the total population in October to more than 95 percent in December.

7.—Peak numbers of mallards arrive at Lake Sangchris 1–2 weeks later than they arrive in the Illinois River valley but depart at similar rates from the two areas.

8.—In the spring relatively fewer mallards stop at Lake Sangchris than stop in the Illinois Valley.

9.—Correlations between waterfowl population densities and water temperatures at Lake Sangchris may result from such factors as abundance of food, attraction to other species already present that have different feeding habits, and disturbance by humans rather than from water temperature per se.

10.—Because mallards always comprised from 50 to 95 percent of the waterfowl at Lake Sangchris, they showed a pattern with respect to water temperature that was similar to the pattern showed by all waterfowl combined.

11.—The pattern for all waterfowl (and mallards) is for equal concentrations on the heated and unheated water in October, higher concentrations on the heated water in November and December, slightly higher concentrations on the heated water in January, equal concentrations on heated and unheated water in February, and slightly higher concentrations on the unheated water in March.

12.—Gadwalls, shovelers, and both species of teals—surface-feeding ducks that feed in aquatic environments—seem to avoid the heated water in October and March, and their concentrations are about equal on the heated and unheated water in November. These species are not present in January and February, and only a few are present in December.

13.—Numbers of coots are similar on the unheated and heated water in October, but their numbers are more concentrated on the heated water in November and on the unheated water in March. Few coots are present from December through February.

14.—Goldeneyes and mergansers, species most abundant in January and February, have higher concentrations on the heated water from December through February, but their numbers per hectare are about equal on the heated and unheated water in March.

15.—Canada geese show higher population levels on the heated water in December and on the unheated water in March but have similar levels during other months.

16.—An estimated 200–400 (0.2–0.4 percent of the maximum number present) waterfowl are killed each fall and winter by colliding with the power lines at Lake Sangchris.

17.—Body weights of mallards, wigeons, and lesser scaups bagged by hunters at Lake Sangchris are within the ranges reported in the literature, but except for adult mallards of both sexes and adult female lesser scaups, are lower at Sangchris than the mean weights reported in the literature.

18.—Mean weights of mallards bagged early in the hunting season are significantly lower than the weights of mallards bagged late in the hunting season.

19.—We tentatively conclude that slag is not a toxicant of catastrophic proportions when ingested by mallards at levels equal to or less than those administered during this study. However, the evidence also indicates that ducks would be better off if they were not exposed to slag for long periods of time.

20.—The diet of mallards at Sangchris is from 88 to nearly 100 percent corn.

21.—Most or all ducks at Sangchris ingest both *Corbicula* shells and slag.

22.—The water areas receiving heaviest use by waterfowl may have received as much as 65 kg of nitrogen and 36 kg of phosphorus per hectare in 1 year from the feces of the birds.

REFERENCES CITED

Anderson, W. L. 1978. Waterfowl collisions with power lines at a coal-fired power plant. Wildlife Society Bulletin 6 (2): 77–83.

Bellrose, F. C. 1976. Ducks, geese & swans of North America. Stackpole Books, Harrisburg, PA. 543 p.

———, and A. S. Hawkins. 1947. Duck weights in Illinois. Auk 64 (3): 422–430.

Bossenmaier, E. L., and W.H. Marshall. 1958. Field-feeding by waterfowl in southwestern Manitoba. Wildlife Monographs 1. 32 p.

Brisbin, I. L., Jr. 1974. Abundance and diversity of waterfowl inhabiting heated and unheated portions of a reactor cooling reservoir. Pages 579–593 *in* J.W. Gibbons and R.R. Sharitz, eds., Thermal ecology. AEC Symposium Series (CONF-730505), Augusta, GA.

Dreier, H., and J. A. Tranquilli. 1981. Reproduction, growth, distribution, and abundance of *Corbicula* in an Illinois cooling lake. Pages 378–393 *in* R. W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32 (4).

Kear, J. 1963. The agricultural importance of wild goose droppings. Wildfowl Trust Annual Report 14:72–77.

Manny, B.A., R.G. Wetzel, and W.C. Johnson. 1975. Annual contribution of carbon, nitrogen and phosphorus by migrant Canada geese to a hardwater lake. Internationale Vereinigung fur Theoretische und Angewandte Limnologie Verhandlungen 19:949–951.

Moran, R.L. 1981. Aquatic macrophytes in Lake Sangchris. Pages 394–412 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

National Oceanic and Atmospheric Administration. 1974–1977. Climatological Data: Illinois. Vol. 79–82.

National Coal Association. 1974. Steam-electric plant factors (fuel consumption and costs, plant capacity, net generation, 1972, and planned capacity 1973–1979), 1973 edition. 118 p.

Paloumpis, A. A., and W. C. Starrett. 1960. An ecological study of benthic organisms in three Illinois River flood plain lakes. American Midland Naturalist 64 (2):406–435.

Sanderson, Wallace W. 1953. Studies of the character and treatment of wastes from duck farms. Proceedings of the 8th Indiana Waste Conference, Purdue University Extension Series 83:170–176.

Steel, R.G.D., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Company, Inc., New York, Toronto and London. 481 p.

Tranquilli, J.A., R. Kocher, and J.M.

McNurney. 1981. Population dynamics of the Lake Sangchris fishery. Pages 413–499 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

U.S. Environmental Protection Agency. 1973. Water quality criteria 1972. National Academy of Sciences and National Academy of Engineering, Washington, D.C. 594 p.

Webb, D.W. 1981. The benthic macroinvertebrates from the cooling lake of a coal-fired electric generating station. Pages 358–377 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32 (4).

Distribution and Accumulation of Trace Metals at a Coal-Fired Power Plant and Adjacent Cooling Lake

Kenneth E. Smith and William L. Anderson

ABSTRACT

The distribution of 13 elements at the Kincaid Generating Station-Lake Sangchris complex in central Illinois was investigated by collecting and analyzing samples of coal, slag, fly ash, airborne particulate matter, soil, lake sediment, aquatic macrophytes, clams, and fishes. Of the 2.7 million metric tons of coal burned during the study, it was estimated that up to 97 percent of some metals contained in the coal escaped the power plant through atmospheric discharge. Considerable amounts of boron, chromium, nickel, lead, sulfur, and vanadium were determined to be contained in the slag produced by the plant. These metals can be leached from the slag, and the leachates can enter Lake Sangchris. Positive correlations were found between metal concentrations in the airborne particulate matter and the time that a sampler was beneath the Kincaid Generating Station's smokestack plume. Significant variations in the soil concentrations of cadmium, lead, and zinc were found in the predominantly downwind direction from the power plant. The highest concentrations of most metals in American pondweed were in the discharge arm of the lake, while the highest concentrations of all metals were in clams collected from the slag pond. Fish from the control arm of the lake had the highest concentrations of metals overall, while the mercury concentrations were quite low when compared with those of fish from other Illinois lakes. Compared with other materials analyzed from Lake Sangchris, the fishes contained the lowest concentrations of all metals except mercury, which was higher in the fishes than in any other material.

INTRODUCTION

The burning of coal by electricity generating stations is one of the major uses of fossil fuel in this country. Since such coal consumption amounts to millions of tons annually for Illinois, and since coal contains a large number of potentially volatile trace elements, it is probable that large quantities of these elements will be released to the environment. Among highly volatile elements like mercury, essentially all of the element in the coal burned would be released.

This study was undertaken to investigate the physical and biological dynamics of several trace elements in Lake Sangchris and the environment surrounding the Kincaid Generating Station. The trace elements initially selected for this study were arsenic (As), boron (B), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se), vanadium (V), and zinc (Zn). Coal, slag, and fly ash samples were analyzed for sulfur (S) by the Illinois State Geological Survey. Arsenic, boron, selenium, and sulfur were eliminated from the analyses after initial findings indicated that they were below the analytical detection limits or, in the case of sulfur, would require additional facilities not currently available.

STUDY AREA

Lake Sangchris is an 876-ha body of water in northwestern Christian County,

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central Illinois. The lake was formed in 1963–1966 by damming Clear Creek and is used for cooling purposes by the 1,232-megawatt Kincaid Generating Station. Lake Sangchris consists of three long, relatively narrow arms that extend southward for distances of 8.0–11.3 km from the dam (Fig. 1). The power plant lies between the west and middle arms; water is taken from the west, or intake arm, cycled through the plant, and returned to the middle, or discharge arm. The east arm is the control arm in that it is not within the power plant's cooling loop and acts to a certain, limited extent as a control data collection area. Seven

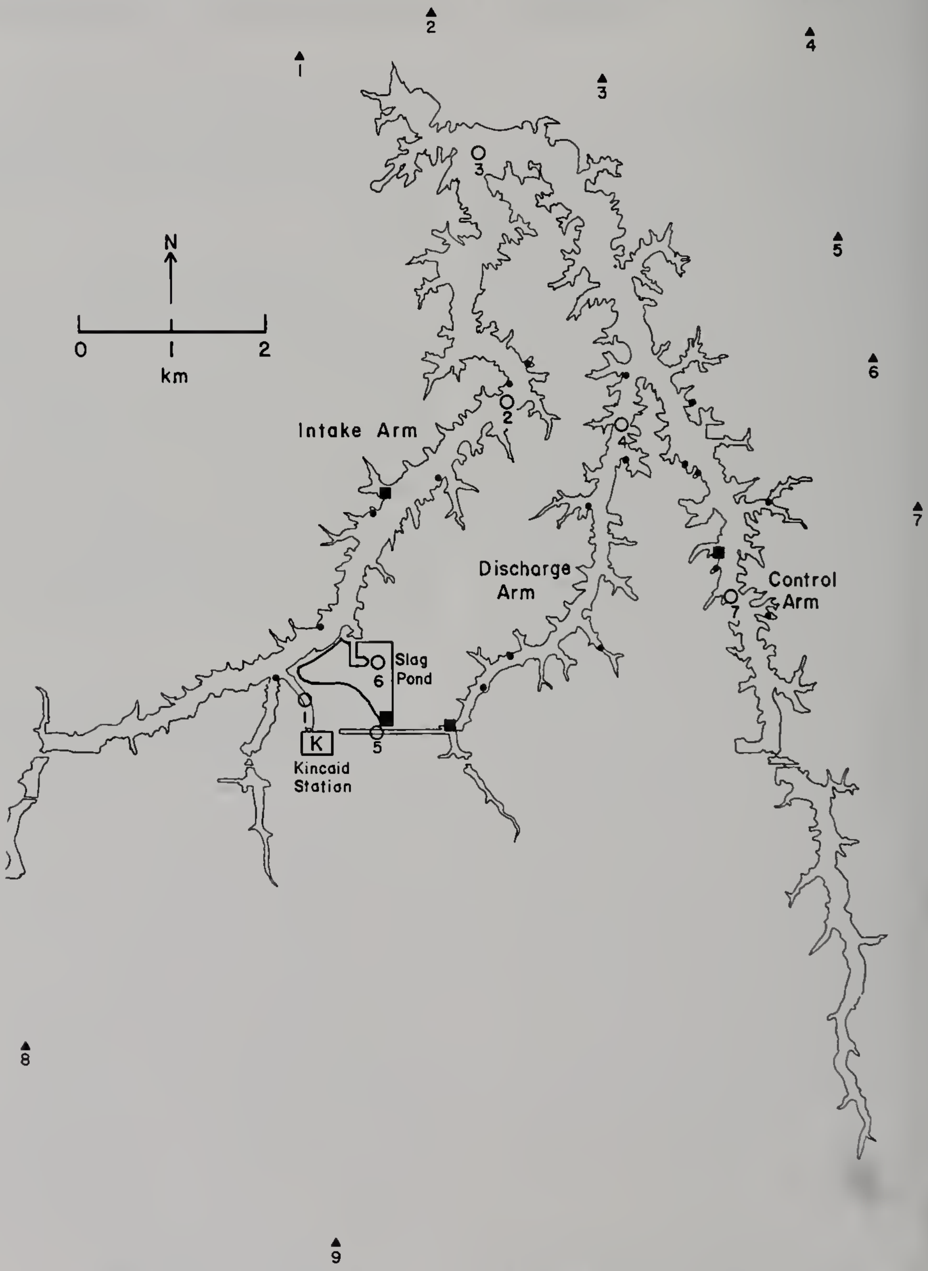

Fig. 1.—Lake Sangchris and the 7 lake sampling sites for sediments and fish (○), 18 for aquatic macrophytes(●), and 4 for *Corbicula fluminea* (■), and the 9 permanent air particulate sampling sites (▲).

sampling sites were established for sediments from Lake Sangchris (Fig. 1): Station 1 was in the intake canal of the power plant; stations 2, 3, and 4 were representative of the intake arm, the deep water area near the dam, and the discharge arm of the lake, respectively; Station 5 was in the power plant's discharge canal; and Station 6 was in the slag settling pond. Station 7 was in the control arm and was not influenced by the power plant's water circulation.

Lake Sangchris' watershed covers approximately 18,880 ha. The watershed and other land surrounding the lake are nearly level to moderately sloping. The principal soil types are Illiopolis (Sable) silty clay loam, adjacent to the lake and to the north of the power plant, and Virden silty clay loam, in the lake's watershed and to the south of the plant (Fehrenbacher et al. 1950). These similar soil types are dark colored and poorly drained; they developed from 1.2 to 2.1 m of loess under prairie vegetation (Fehrenbacher et al. 1967:8,10). The land is intensively farmed, the principal crops being corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.).

The Kincaid Station began generating electricity for commercial consumption in 1967 and consumed 2.98 million tons of coal in 1972. Upon being burned in this plant, coal is reduced to approximately 15 percent of its original weight. About half the residue is slag that is slurried and pumped into the slag pond, a diked area of 32 ha, containing water and located immediately northeast of the plant. The other half of the residue is primarily fly ash, 99 percent of which is removed from the smoke by electrostatic precipitators on each of the plant's two, 168-m-high smokestacks.

Peabody Coal Company's Mine No. 10, a shaft (underground) mine, supplies all coal burned by the Kincaid Generating Station. The mine is 1.6 km west of the power plant.

METHODS

The first year of investigation was dedicated to the study of mercury in all environmental compartments, and the remaining 3 years to the study of the other trace metals. Because of this dichotomy, procedures of collection changed for some samples as our early work showed some deficiencies. Also, the preparative methods used for the samples to be analyzed for mercury were often different from those used for the other metals because of mercury's volatility. It is this high volatility which allowed the use of the sensitive cold-vapor atomic absorption spectrophotometric (AAS) technique for mercury, while more conventional flame AAS methods were used for the other metals.

COLLECTION AND PREPARATION OF SAMPLES

Coal, Slag, and Fly Ash

Samples of coal, slag, and fly ash were taken at the Kincaid Generating Station on 5–20 days each month from September 1973 through August 1974 by plant personnel. The coal samples were composites, taken over 24-hour periods with an automatic sampling device, from coal going into storage silos within the plant prior to being burned. Slag was taken from one of the several pipes used to carry the residue slurry to the settling pond. Samples of fly ash were removed from the bottoms of the precipitator hoppers. This ash had recently come out of the precipitators but had not entered silos used for holding fly ash.

The coal, slag, and fly ash samples for each month were air dried, combined by type, and reduced to a manageable size by means of a Jones sample splitter. The coal samples were then ground in an air-cooled micro mill to pass a 200-mesh sieve. A portion of each of the monthly composite samples of slag was hand ground with a mullite mortar and pestle. Because of their extremely small particle size, it was not necessary to grind the samples of fly ash. These samples were used in all subsequent analyses.

Airborne Particulates

In the mercury study, three samples of airborne particulate matter were collected during a single 24-hour period each month from October 1973 through August 1974 (except December 1973) with BGI Model IIA high-volume air samplers. Two samplers were positioned approximately 5 and 10 km downwind and one approximately 5 km upwind from the power plant. Since the samplers were placed under the smokestack plume on the day of sample collection, relocation of the samplers was necessary for each collection. This relocating in turn necessitated recalibration of the samplers after they were transported. The operational parameters for the air samplers are shown in Appendix A (Table A1). The particulate matter was collected on 20.3- x 25.4-cm mats of high purity glass fiber with a collection efficiency of 99.98 percent of 0.2-nm dioctylphthalate (DOP) particles. After the mass of the particulate matter collected was determined, the mats were cut into eight approximately equal, wedge-shaped sections for analysis.

In the later collections for metals other than mercury, seven similar high-volume air samplers were located permanently northeast of the power plant along an arc with a radius of approximately 6.4 km, a distance between those used in the first collections, and as close as feasible to electrical service. Permanent locations eliminated the need to recalibrate the samplers before every sample. Two additional samplers were placed southwest of the power plant to sample the air prior to its passing the Kincaid Generating Station (Fig. 1). Samples were taken monthly during a single 24-hour period using the same type of glass fiber mats as those described above. The time periods selected were based on local weather conditions, i.e., wind from the southwest, expected wind direction stability for 24 hours, and no precipitation. Such conditions were found in January, April, May, June, July, August, October, and November 1975. Further attempts to gather samples were terminated in February 1976. Operational parameters for these samplers are also in Appendix A (Table A2).

Soil

Samples of soil were taken at intervals of approximately 3.2 km on a square grid,

Setting up a portable high-volume air sampler to measure smokestack emissions.

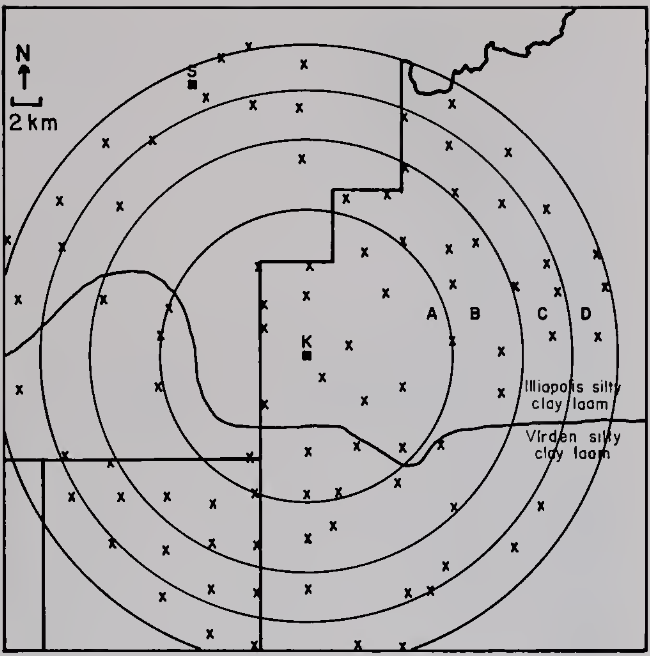

Fig. 2.—Soil sampling sites (X) around Kincaid Generating Station (K), the boundary between the two primary soil types, and the radial sectors (A, B, C, and D) used for statistical analysis (see Table 8). Also shown are county boundary lines and the Springfield Power Plant (S).

38.6 km across, with the power plant at the center. The sampling sites are shown in Fig. 2. Sampling was limited to two closely related soil types, Illiopolis (Sable) silty clay loam (north of the plant) and Virden silty clay loam (south of the plant). Samples were taken from the upper 2 cm of soil in agricultural fields that had not been disturbed for several months. Subsamples were scraped from three separate level areas at each site and pooled to make a single sample. The sampling sites were at least 50 m (usually 100 m) from secondary roads and at least 200 m from highways and railroad tracks. The samples were air dried, placed in plastic bottles, and rolled for 2 hours to homogenize the soil before an aliquot was removed for analysis.

Lake Sediment

Sediment samples were taken from Lake Sangchris with an Ekman dredge and a Phleger corer. In the mercury study the Ekman dredge was used at six regular lake stations (the slag pond was excluded) on a quarterly basis. Subsequent yearly samples were taken for continued monitoring of the sediment's mercury concentration. The Phleger corer, equipped with 34 kg of weights and a 61-cm collecting tube, was used to take three core samples at each station, penetrating in each case into the original bottom material. One such series was taken during the first year of the project, and a second series in the third year. Each core was held intact within a plastic sleeve inserted into the collecting tube prior to taking the sample. The cores were frozen for storage and to facilitate sectioning. Later, the plastic sleeve was warmed under running water, and the frozen core was extruded. The interface between the sediment and the original bottom material was identified, and the sediment portion was sectioned into equal parts, believed to represent individual years of the lake's existence on the assumption of an almost constant deposition rate. There were 10 sections for the 1974 collection, and 12 for the 1976 collection. Although sediments are known to become compacted and dewatered with time, dry weights of the sections indicated that the consequent errors in dating the sections were less than 1 year. Two additional sections, the same size as those in the sediment, were cut from the upper end of the remainder (original bottom material) of the core. The lower of those two sections, plus the upper 9 sections of 10 or 11 of 12, were kept for analysis. The mean thickness of sediment at the six stations was 28.8 cm with a standard deviation of 10.7 cm for the first collection, and 33.7 cm mean thickness with a standard deviation of 12.1 cm for the second collection.

Macrophytes

For the mercury study a sample of American pondweed (*Potamogeton nodosus* Poir.) was collected from Lake Sangchris in 1974 at each of 18 sites where it grew in each of the three arms of the lake (Fig. 1). In 1976 another 18 samples of pondweed were collected from the same sites. For all samples, the leaves and stems were separated and were washed with deionized water, and as much surface water as possible was removed before they were weighed. Each sample was cut into small pieces, lyophilized for 48 hours, and then pulverized in a micro mill.

Clams

A sample of clam, *Corbicula fluminea*, was collected from each of three sites in Lake Sangchris and from the slag pond (Fig. 1). The clams were raked from the upper sediments along the shoreline in water ranging from 0.3 to 1 m deep. Muscle tissue was removed from the shell, lyophilized for 72 hours, and pulverized in a micro mill.

Fishes

The initial sample of fish from Lake Sangchris consisted of from 10 to 12 fish of each of seven species: largemouth bass, *Micropterus salmoides;* green sunfish, *Lepomis cyanellus;* bluegill, *L. macrochirus;* white crappie, *Pomoxis annularis;* white bass, *Morone chrysops;* channel catfish, *Ictalurus punctatus;* and black bullhead, *I. melas,* taken in October 1973. Ten to 12 largemouth bass and similar numbers of channel catfish were also collected during January, April, and July 1974. Ten largemouth bass and 10 black bullheads were taken in May 1975, May 1976, and June 1977 to monitor mercury concentrations in Lake Sangchris fishes. All collections of fish were taken from the general areas of the established stations (Fig. 1). For purposes of comparison, largemouth bass were collected from Lake Decatur, Otter Lake, and Lake Shelbyville, and black bullheads from the latter two lakes. All of these samples were analyzed only for mercury. A collection of 10–18 fish of each of the same seven species was taken in addition to 14 carp, *Cyprinus carpio,* in July 1976 for analysis for other trace metals. The fish were collected primarily by electrofishing and with gill nets, as described by Tranquilli et al. (1981). However, trotlines were used to collect the bullheads and approximately half of the channel catfish. After body weight and total length were recorded, muscle tissue was removed from each carcass by conventional filleting techniques to obtain a representative sample of 100–200 g of tissue from each fish. For the larger fishes (over 1 kg), the fillets were ground in a food grinder and mixed thoroughly prior to the removal of a 100–200-g sample. The samples were freeze dried and pulverized in a micro mill. The carcasses and some livers from the fish in the initial collection were treated in the same manner.

ANALYTICAL PROCEDURES

Mercury

The tissue samples from the plants and animals were weighed, placed in flasks, and digested in a mixture of sulfuric acid (H_2SO_4), nitric acid (HNO_3), 5-percent potassium permanganate ($KMnO_4$), and 5-percent potassium persulfate ($K_2S_2O_8$) in a 95°C water bath for 2 hours. Standards, containing 0.05 μg of mercury as a chloride, were carried through the digestion with each batch of samples. The analyses were performed on an Instrumentation Laboratory model 353 atomic absorption spectrophotometer equipped with a cold-vapor mercury analysis system. Reduction of the mercury (II) in the digested samples was accomplished with a

Taking sediment core samples from the Lake Sangchris basin for trace metal analyses.

5-percent stannous chloride ($SnCl_2$) solution in 4-N hydrochloric acid (HCl), as described by Hwang et al. (1971). Recovery of 0.05-μg spikes of mercury from samples of fish tissue was 98 ± 3 percent by this analytical procedure. Samples of National Bureau of Standards Standard Reference Materials SRM 1571, Orchard Leaves, and SRM 1577, Bovine Liver, were also analyzed by this method and gave results within the limits provided in the NBS certificate of analysis for both SRM materials.

The soil, sediment, and air filter samples were digested following the procedure of Jacobs & Keeney (1974) with a few simple modifications. The samples were digested in BOD bottles in the manner of the U.S. Environmental Protection Agency's procedure (1972), but a 30-minute treatment in a 95°C water bath was substituted for the 16-hour room temperature final digestion. Analysis was also done by a cold-vapor atomic absorption technique, again using a $SnCl_2$ reductant added to each bottle immediately before it was attached to a Perkin-Elmer MAS-50 mercury analyzer. Because of the previous boil-off of HNO_3 fumes, little background was found when blanks were run.

The mercury in the coal, slag, and fly ash samples was liberated by a high-temperature volatilization technique, since the digestion methods described previously did not give satisfactory results. The coal, slag, and fly ash samples all left residues when analyzed by these open digestions. In the procedure adopted, 0.5-g samples were weighed into porcelain combustion boats, which were then placed in a Vycor tube and heated to 600°C with a tube furnace. Oxygen was passed over the hot sample at the rate of approximately 50 ml/min. The end of the tube downstream from the sample was connected to a silver wool amalgamator (Long et al. 1973) to collect the volatilized mercury. After 30 minutes the collector was removed and quantitatively analyzed in an apparatus similar to that of Long et al. (1973).

Coal, Slag, and Fly Ash

The sample digestion techniques used for the determination of arsenic (As), boron (B), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), selenium (Se), vanadium (V), and zinc (Zn) were quite similar except for the starting material. For coal, high temperature ash (HTA) was used for the determination of boron, cadmium, cobalt, chromium, copper, nickel, lead, vanadium, and zinc, while low temperature ash (LTA) was used for the determination of arsenic and selenium. The HTA was prepared by igniting coal samples for 14 hours at 550°C in platinum (Pt) crucibles in a muffle furnace. The LTA was prepared by Dr. H. J. Gluskoter's laboratory (Illinois State Geological Survey) by means of microwave plasma ashing at a temperature never exceeding 150°C. Slag and fly ash were dried and then used directly for trace metals analysis.

Digestion of the coal, slag, and fly ash samples for cadmium, cobalt, chromium, copper, nickel, lead, vanadium, and zinc was performed in a Parr 4745 acid digestion bomb using aqua regia (1 part HNO_3 to 3 parts HCl) and hydrofluoric acid (HF). The technique follows that of Bernas (1968) and Hartstein et al. (1973) with minor modifications to fit available equipment. After 4 hours at 100°C, the bomb was cooled and opened, and the remaining HF was complexed with boric acid (HBO_3). Standards were made in a matrix containing 300 ppm aluminum (Al), 35 ppm potassium (K), 30 ppm sodium (Na), and 10 ppm magnesium (Mg) to approximate the content of these minor elements in the samples.

For analyses of the boron in the coal and fly ash samples, a sodium carbonate (Na_2CO_3) fusion was perfomed in platinum crucibles. The cooled melt was leached with warm water and then analyzed spectrophotometrically using carminic acid (Hatcher & Wilcox 1950). Slag was not analyzed for boron, since its high iron content would contaminate the platinum crucibles, rendering them useless for further work.

Airborne Particulates

The soiled filter mats from the air particulate sampling were returned to the laboratory and weighed to determine the amount of particulate matter collected. They were then quartered, and one-quarter of each sample was used in the analysis. The section was cut into small pieces and extracted with a mixture of 0.05-N HCl and 0.025-N H_2SO_4. Forty-five ml of this extracting solution were used for each quarter sample analyzed. The mixture of the small pieces of the filter media and the extracting solution was shaken vigorously for 2 hours on a mechanical shaker. Afterwards, the solution was filtered into a 100-ml volumetric flask and made to volume with deionized water. Standards for comparison during analysis were made in the same concentrations of extracting solution. To test the recovery efficiency, 8- x 8-cm squares of clean filter media were treated with a solution containing 5 μg of each of the metals being analyzed. After air drying, these squares were extracted by the same method that was used for the samples collected in the field. Analyses of the squares gave results ranging from 86 to 110 percent recovery for the seven metals placed on the mats.

Soil and Sediment

Soil analyses were made to determine the quantities of trace elements associated with the soils, not the total cation makeup of the soil. Therefore, it was decided to analyze the cations extractable by a dilute acid mixture of 0.05-N HCl and 0.025-N H_2SO_4 (1:1, v:v), using 5 g of soil shaken with 20 ml of this mixture for 1 hour. The sample was then centrifuged for 10 minutes at 20,000 rpm, the supernatant was filtered, and the resulting solution was analyzed directly by atomic absorption spectrophotometry.

Macrophytes, Clams, and Fishes

The digestion procedure used for the macrophytes, clams, and fishes was begun with a 500°C overnight ashing in a muffle furnace and treatment with 5 ml of HNO_3 to complete the destruction of all organic material. The sample was then taken to dryness on a hot plate, covered, and returned to the 500°C muffle furnace for approximately 20 minutes. It was then treated with 5 ml of HCl to solubilize the resultant solid, refluxed on the hot plate until the sample had dissolved, diluted to volume in a 100-ml volumetric flask, and analyzed by atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

COAL, SLAG, AND FLY ASH

Concentrations of trace elements found in the coal, slag, and fly ash are shown in Tables 1, 2, and 3, respectively. The values for arsenic and selenium are given as less than the limit of detection, since it was not possible to detect them with the techniques used. The amounts of trace metals in coal from a given coal seam vary widely. The mean values obtained for our samples compared quite well with values presented by Ruch et al. (1974), samples C-14838 and C-17016, as shown in Table 4.

In an attempt to obtain a mass balance on some of the trace elements in the coal as it passed through the Kincaid Generating Station, the concentrations found in the coal, slag, and fly ash were mathematically converted to total amounts. This was done by finding the product of the concentration of an element and the amount of coal consumed monthly. To arrive at comparable figures for slag and fly ash, the monthly coal consumption was multiplied by 0.075, based on the assumption that the 15-percent solid residue of coal burning is equally divided between slag and fly ash. The 15-percent solid residue value was obtained from the operating personnel at the Kincaid Generating Station, and it agrees quite well with those obtained by Klein et al. (1975) of 8.5 percent for slag and 4.8 percent for fly ash at the Allen Power Plant in Memphis, Tennessee. The products of the 0.075 value and the concentrations of each element yielded the calculated total amounts of the elements in the slag and fly ash.

The yearly amounts of trace elements calculated from the total amount of coal burned by the Kincaid Generating Station are summarized in Table 5. The amounts shown for atmospheric discharge are simply 1 percent of the figures for fly ash (this procedure assumes electrostatic precipitation efficiency of 99 percent) and do not take into account the relationship of concentration to particle size (described below). Therefore, they represent the lower limits of possible atmospheric discharge. The exception to this procedure is mercury, which is shown as the total difference between the coal value and the slag and fly ash values.

Davison et al. (1974), Natusch et al. (1974), and Klein et al. (1975) classified the elements in their investigations according to their relative volatilities and associated recondensations on particulate material. Natusch's and Davison's mechanism explained size-concentration behavior for many elements. Those elements that accumulate on the smaller fly ash particles are assumed to be volatile at the temperature of combustion (1300°–1600°C); as the flue gas cools, the volatiles condense on or are adsorbed on the fly ash. Since condensation and adsorption are surface phenomena, the concentration of condensed elements should be inversely proportional to particle size. Those elements not volatile in the combustion zone form the fly ash par-

Table 1.—Concentrations of trace elements analyzed in coal samples from Kincaid Generating Station.

Composite Sample Date	Concentration of Element (μg/g of whole coal)												Percent
	As	B	Cd	Co	Cr	Cu	Hg	Ni	Pb	Se	V	Zn	S
1973													
Sept.	<5	215	0.98	6.7	28	41	0.18	20	16	<5	27	61	3.66
Oct.	<5	202	0.91	6.2	25	15	0.21	18	10	<5	28	57	3.71
Nov.	<5	205	0.78	5.8	29	11	0.14	19	12	<5	25	53	3.59
Dec.	<5	209	0.66	5.3	27	10	0.11	17	10	<5	23	65	3.64
1974													
Jan.	<5	212	0.87	5.2	27	9.4	0.63	16	8.7	<5	24	71	3.37
Feb.	<5	241	0.86	6.0	42	10	0.18	21	11	<5	28	132	3.31
Mar.	<5	211	0.76	6.6	37	15	0.17	24	18	<5	30	126	3.56
Apr.	<5	222	0.94	7.0	33	19	0.17	23	14	<5	27	96	3.05
May	<5	179	0.74	6.4	42	13	0.12	24	12	<5	33	68	2.90
June	<5	203	0.60	5.1	55	11	0.11	20	7.5	<5	22	57	3.39
July	<5	228	0.89	5.7	53	12	0.11	21	11	<5	25	61	3.17
Aug.	<5	236	0.96	6.5	37	12	0.29	20	13	<5	27	79	2.36
Mean	*<5*	*214*	*0.83*	*6.0*	*36*	*15*	*0.20*	*20*	*12*	*<5*	*27*	*77*	*3.31*
Standard Deviation		*16.7*	*0.121*	*0.624*	*10.1*	*8.66*	*0.14*	*2.65*	*2.92*		*3.06*	*26.1*	*0.393*

Table 2.—Concentrations of trace elements analyzed in slag samples from Kincaid Generating Station.

Composite Sample Date	Concentration of Element (μg/g slag)												Percent
	As	B	Cd	Co	Cr	Cu	Hg	Ni	Pb	Se	V	Zn	S
1973													
Sept.	<10	2,620	3.0	65	100	40	0.0030	149	50	<10	150	40	2.76
Oct.	<10	3,590	3.5	55	90	20	0.0049	90	50	<10	100	50	2.70
Nov.	<10	2,840	3.0	69	108	49	0.0038	167	49	<10	150	30	2.65
Dec.	<10	3,820	5.0	56	116	30	0.0055	126	50	<10	100	45	2.58
1974													
Jan.	<10	2,970	3.5	50	110	35	0.171	105	50	<10	100	55	2.91
Feb.	<10	3,430	3.0	56	102	41	0.0490	132	51	<10	100	41	2.97
Mar.	<10	2,600	4.0	64	104	50	0.0108	144	50	<10	100	45	2.78
Apr.	<10	2,470	2.0	59	104	30	0.0919	104	50	<10	150	30	3.09
May	<10	2,640	4.0	55	111	60	0.0270	171	50	<10	100	45	2.37
June	<10	2,940	3.0	50	263	25	0.0075	104	50	<10	100	20	2.15
July	<10	2,280	4.0	49	93	20	0.0252	69	49	<10	100	29	2.85
Aug.	<10	2,980	2.0	55	116	45	0.0682	126	50	<10	150	25	2.88
Mean	*<10*	*2,930*	*3.3*	*57*	*118*	*37*	*0.0390*	*124*	*50*	*<10*	*117*	*38*	*2.72*
Standard Deviation		*468*	*0.862*	*6.30*	*46.3*	*12.6*	*0.0506*	*30.9*	*0.515*		*24.6*	*10.9*	*0.262*

Table 3.—Concentrations of trace elements analyzed in fly ash samples from Kincaid Generating Station.

Composite Sample Date	Concentration of Element (μg/g fly ash)												Percent
	As	B	Cd	Co	Cr	Cu	Hg	Ni	Pb	Se	V	Zn	S
1973													
Sept.	<10	1,509	7.6	25	136	116	0.0190	126	76	<10	200	1,030	3.80
Oct.	<10	1,790	10.0	35	145	135	0.0133	145	100	<10	200	1,250	1.42
Nov.	<10	1,551	7.4	30	134	124	0.0083	134	99	<10	150	1,270	1.52
Dec.	<10	1,735	7.6	35	171	136	0.0133	176	126	<10	200	1,110	1.85
1974													
Jan.	<10	1,704	9.8	24	132	122	0.188	132	122	<10	250	1,220	0.87
Feb.	<10	1,473	7.5	15	181	116	0.0563	131	126	<10	200	1,080	0.42
Mar.	<10	1,329	7.4	20	158	114	0.0127	129	99	<10	200	1,160	0.61
Apr.	<10	1,434	9.8	20	148	790[a]	0.0324	143	123	<10	200	1,550	0.42
May	<10	1,543	9.9	20	164	119	0.0229	134	99	<10	200	1,090	0.49
June	<10	1,300	7.6	20	131	106	0.0236	116	76	<10	200	910	0.62
July	<10	935	7.4	10	98	79	0.0130	108	98	<10	150	640	0.30
Aug.	<10	1,433	12.6	15	151	131	0.0416	141	126	<10	200	1,310	0.34
Mean	*<10*	*1,478*	*8.7*	*22*	*146*	*118*	*0.0370*	*135*	*106*	*<10*	*196*	*1,135*	*1.06*
Standard Deviation		*229*	*1.68*	*7.81*	*22.0*	*15.2*	*0.0496*	*16.8*	*18.6*		*25.7*	*224*	*1.00*

[a] April Cu value was not used in calculating the mean. If included, the mean Cu concentration would be 174 μg/g.

Table 4.—Comparison of trace element concentrations in coal as analyzed by Illinois State Geological Survey (ISGS) and the present study.

Element	Concentration (μg/g whole coal) Present Study	ISGS[a]
Arsenic	<5	3.7
Boron	214	196
Cadmium	0.83	0.45
Cobalt	6.0	5.5
Chromium	36	11.5
Copper	15	11
Mercury	0.20	0.17
Nickel	20	18
Lead	12	5.5
Selenium	<5	1.6
Sulfur (percent)	3.31	4.91
Vanadium	27	24
Zinc	77	34

[a] Mean for samples C-14838 and C-17016 (Ruch et al. 1974) taken from the Peabody No. 10 mine.

ticles upon which the volatiles condense. Of the elements in the present study, cadmium, chromium, nickel, lead, sulfur, vanadium, and zinc have been shown to have a definite inverse relationship between concentration and fly ash particle size and are therefore preferentially emitted from the power plant smokestacks on the smaller fly ash particles, the very particles which the electrostatic precipitators are least efficient in collecting. Cobalt and copper do not exhibit such a trend and are equally distributed among all fly ash size fractions. Mercury and selenium were shown by Klein et al. (1975) to occur in both fly ash and flue gas and, in the case of mercury, to predominate in flue gas. The present study shows this same trend, as an estimated 97 percent of the mercury entering the plant in the coal escapes as vapor when the coal is burned (Table 5).

AIRBORNE PARTICULATES

The data obtained from the analysis of the airborne particulate samples are tabulated in Appendix A (Tables A3–A9). Two means were calculated for each sampling period; the first includes all stations sampled, while the second excludes stations 8 and 9 to the south of the power plant and upwind during the sample collection. In many cases, the concentrations of metals in upwind samples were extremely high. Since their intended use was as control samples, this condition was

Table 5.—Calculated total amounts of trace elements in all coal burned by the Kincaid Generating Station from September 1973 through August 1974.

Element	Element Flow in Kilograms Coal	Slag	Fly Ash	Imbalance[a] (Percent)	Atmospheric Discharge[b] in Kilograms
Boron[c]	586,200	590,500	295,900	+51	2,959
Cadmium	2,261	675	1,782	+9	18
Cobalt	16,668	11,361	4,306	−6	43
Chromium	101,710	24,121	29,590	−47	296
Copper	40,030	7,559	23,730	−22	237
Mercury	577	9	9	−97	560
Nickel	55,350	24,821	27,150	−6	272
Lead	32,340	10,175	21,758	−1	218
Sulfur	$88.86 \text{x} 10^6$	$5.59 \text{x} 10^6$	$1.99 \text{x} 10^6$	−91	1.99x10[d]
Vanadium	72,040	23,580	40,320	−11	403
Zinc	216,380	7,675	228,400	−1	2,284

[a] Imbalance = (slag flow + fly ash flow − coal flow)/coal flow x 100.

[b] Calculated as 1 percent of the fly ash content. For mercury, it is the total of 1 percent of the fly ash content and the amount not accounted for from the coal value.

[c] The large positive imbalance indicates an analytical error, probably in the coal analyses.

[d] Probably additional sulfur is emitted in gaseous forms; this value reflects only the sulfur associated with the unprecipitated fly ash emitted as airborne particulates.

intolerable, but can be explained. The Virden soil type, which exists primarily to the south of the power plant, is higher in trace metals than the Illiopolis soil to the north of the plant. The samplers at stations 8 and 9 were immediately north of land cultivated for farming and were exposed to high levels of dust from this soil. All other samplers had been located in pastures or other grassy fields at least 500 m from cultivated fields that could produce dust. Undoubtedly all samples did include some dust from nearby soils, but it is felt that those downwind from the plant were significantly influenced by the plant's smokestack effluent. The mean values calculated, excluding the station 8 and 9 data, are summarized in Table 6.

Since only one sample was collected at each site during each sampling period, it was not possible to apply statistical tests based on means and deviations to the data. However, the data were subjected to a multiple regression analysis that also used a sample collection date, location, average air flow, and time under the smokestack plume as dependent variables. The test was designed to determine whether the variations in metal concentrations could be accounted for by these variables. The multiple regression coefficients calculated for cadmium, chromium, copper, nickel, and zinc were highly significant at the $P < 0.01$ confidence level. No significant correlations were found with fewer dependent variables.

This fact allows us to conclude that the variations observed in the amounts of the metals collected can be related to these parameters. Only one of them is related to the power plant, the amount of time the smokestack plume remained over a given sampler, and it was calculated on a maximum of eight wind direction observations in a 24-hour period (Appendix A, Table A2).

Table 6.—Mean concentrations of trace metals (μg/g) in the airborne particulate matter collected in the vicinity of Kincaid Generating Station in 1975.

Month	Cd	Cr	Co	Cu	Ni	Pb	Zn
Jan.	118	<20	22	172	34	4,230	3,596
Apr.	27	<20	18	434	18	1,430	1,025
May	32	<20	11	1,204	24	2,020	534
June	97	<20	17	1,932	84	3,180	1,994
July	90	<20	15	1,954	40	2,080	2,604
Aug.	131	36	13	610	57	2,510	2,082
Oct.	132	<20	15	443	15	3,710	2,177
Nov.	59	<20	18	476	18	2,950	6,327

Table 7.—Concentrations of total mercury (μg Hg/g dry particulate matter) in airborne particulate matter collected in the vicinity of the Kincaid Generating Station.

Collection		Downwind	
Month	Upwind	4.8 km	9.6 km
1973			
Oct.	1.45	0.83	1.72
Nov.	1.23	0.65	1.82
1974			
Jan.	0.59	0.51	0.64
Feb.	0.62	1.13	0.86
Mar.	<0.01	0.14	0.19
Apr.	<0.01	1.99	0.11
May	1.11	0.74	0.62
June	1.09	<0.01	0.53
July	0.04	0.01	0.24
Aug.	0.38	1.15	0.72
Mean	*0.65*	*0.71*	*0.75*

As has been noted, the samples taken for mercury analysis were collected by a different procedure than that used for the other metals, and the results are given in Table 7.

The concentrations of particulate matter in the air and of mercury in the particulate matter were generally greater at the samplers 4.8 km and 9.6 km downwind than at the sampler upwind. Concentrations of mercury in the air were also greater at the sampler 9.6 km downwind than at the sampler upwind.

However, none of these differences was statistically significant ($P < 0.05$) when tested by analysis of variance. Subjection of the raw data to Wilcoxon's sign ranked test (Steele & Torrie 1960) also indicated no significant differences except between the amounts of particulate matter in the air 9.6 km downwind and those upwind.

SOIL

The area sampled around the power plant was divided approximately in half by the boundary between two soil types (Fig. 2).

Wind vector data obtained from the

Air Weather Service of the U.S. Air Force (1963) for the 10-year period from 1953 through 1962 indicate a strong southerly wind flow, with winds from the northwest making an important but lesser contribution. These data are illustrated in Fig. 3.

The traditional wind rose has been rotated through 180° to better illustrate a resulting fallout pattern. That is, the compass headings on the map show the directions the winds were blowing toward, and not the directions they came from. The contours indicate the percentages of the winds that blew in the directions in-

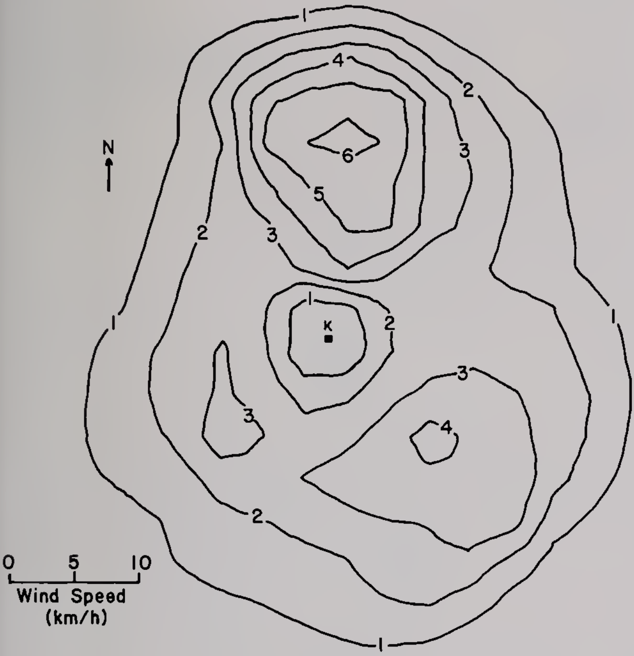

Fig. 3.—Wind distribution around the Kincaid Generating Station (K). Each contour line denotes the percentage of total wind observations (87,225) having the velocity indicated by its distance from the power plant.

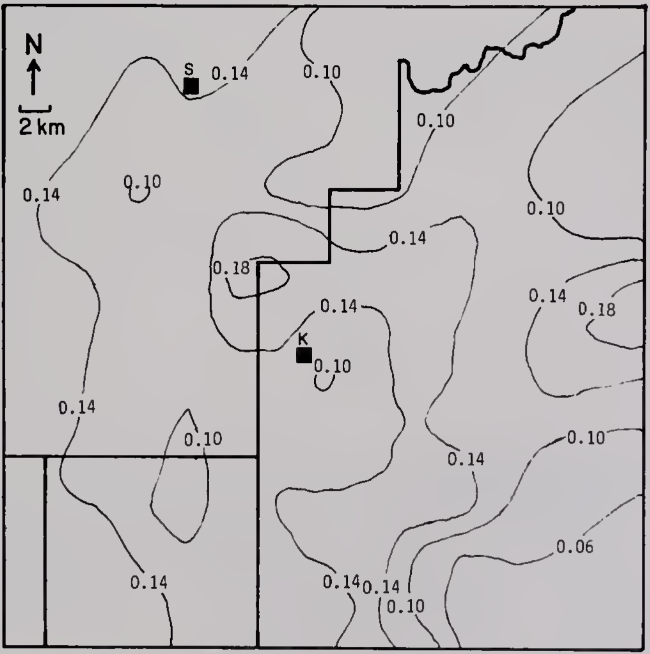

Fig. 4.—Distribution of cadmium (μg/g) in the soils surrounding the Kincaid Generating Station.

dicated on the map and that had a wind speed equal to the distance from the Kincaid Generating Station. For example, the area to the north of the Kincaid Station labeled 6 indicates that 6 percent of the winds observed blew to the north at a speed of approximately 15 km/h. The speed is indicated by the distance on the map between the 6-percent area and the Kincaid Station (see scale).

The results of the soil analyses are presented in Fig. 4–11. The isograms of these figures denote equal concentrations of each given element. The isograms were

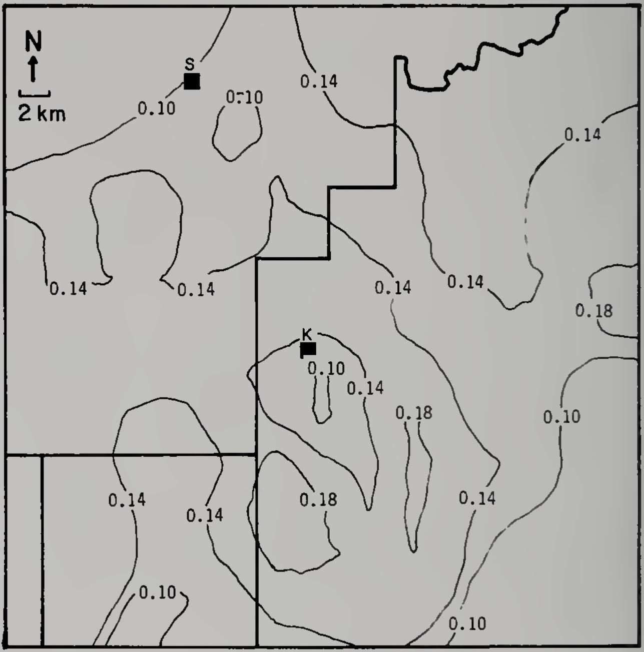

Fig. 5.—Distribution of chromium (μg/g) in the soils surrounding the Kincaid Generating Station.

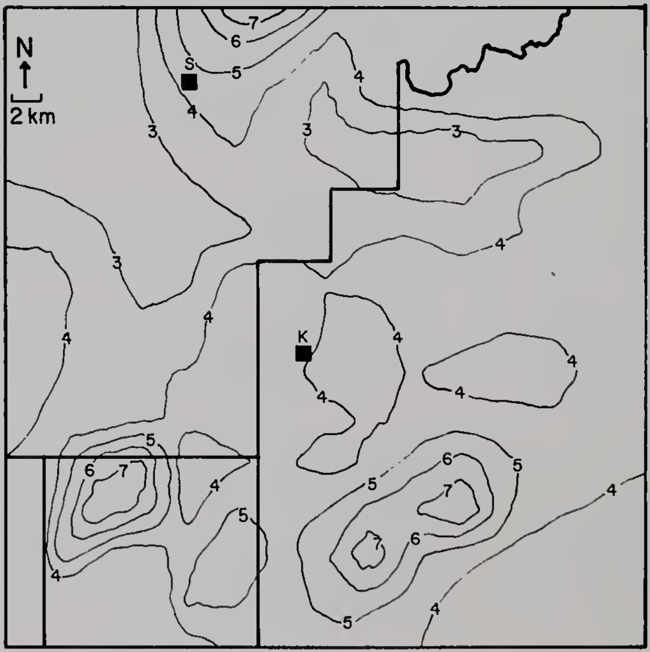

Fig. 6.—Distribution of cobalt (μg/g) in the soils surrounding the Kincaid Generating Station.

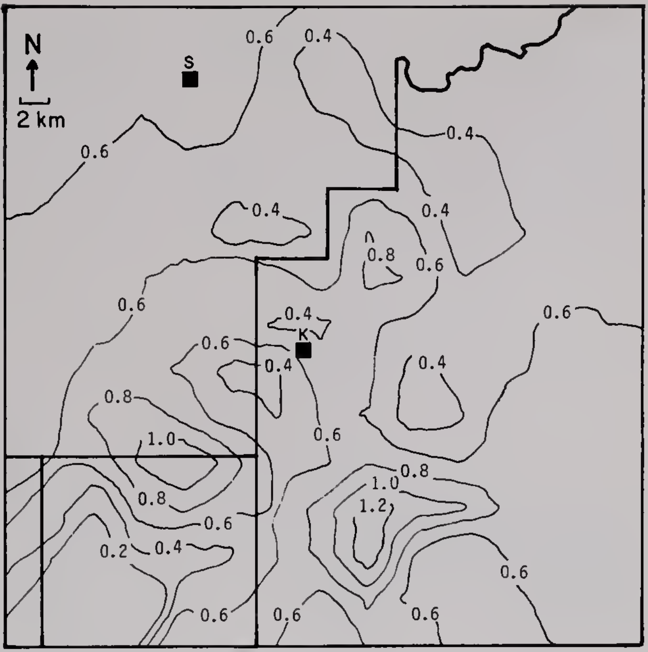

Fig. 7.—Distribution of copper (μg/g) in the soils surrounding the Kincaid Generating Station.

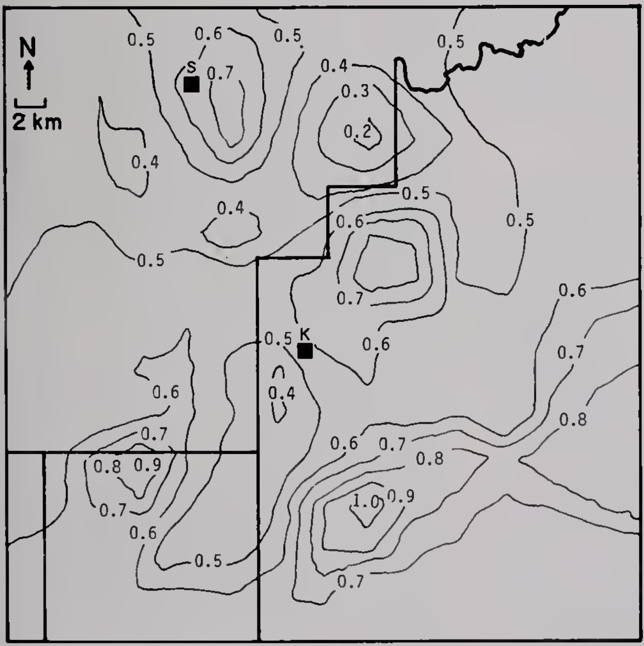

Fig. 8.—Distribution of lead (μg/g) in the soils surrounding the Kincaid Generating Station.

plotted using the Illinois State Geological Survey's "Illimap" program package, which also calculated the contour lines. This set of programs was developed to plot positions of geological features on a map of Illinois or a portion of it. Illimap programs can interpolate between values of the parameters whose positions are shown by the plotted points, when the values represent elemental concentrations, soil composition percentages, or other continuously variable parameters. This interpolation results in constant value contour lines, which can also be plotted on the map. The data for the mercury in soil were not sufficiently coherent for the computer to plot a map and have thus been omitted.

Interpretation of the results of the soil analyses is difficult at best and is complicated by the occurrence of two soil types in the study area. Analysis of variance among mean sample concentrations from the two soil types shows significant differences of cobalt, copper, lead, and zinc at $P < 0.01$. However, for these elements the higher mean value occurred for the Virden soil, which occurs primarily to the south of the power plant. Yet the wind data indicate that the majority of the par-

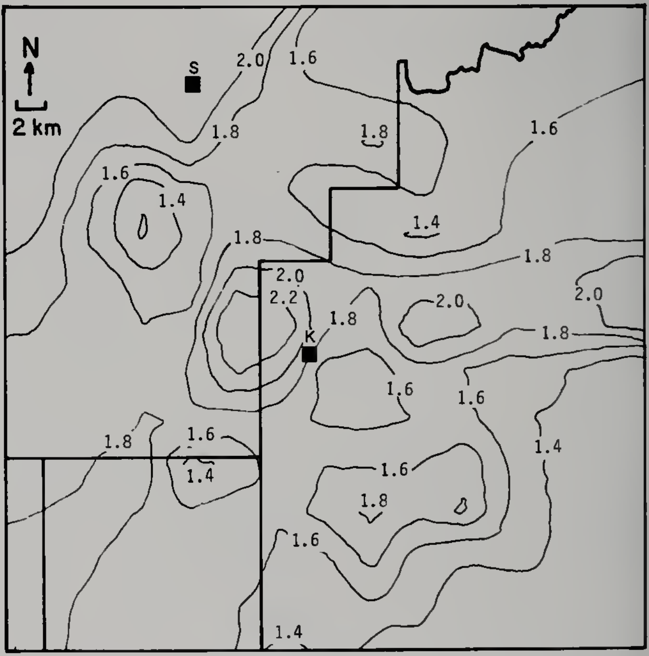

Fig. 9.—Distribution of nickel (μg/g) in the soils surrounding the Kincaid Generating Station.

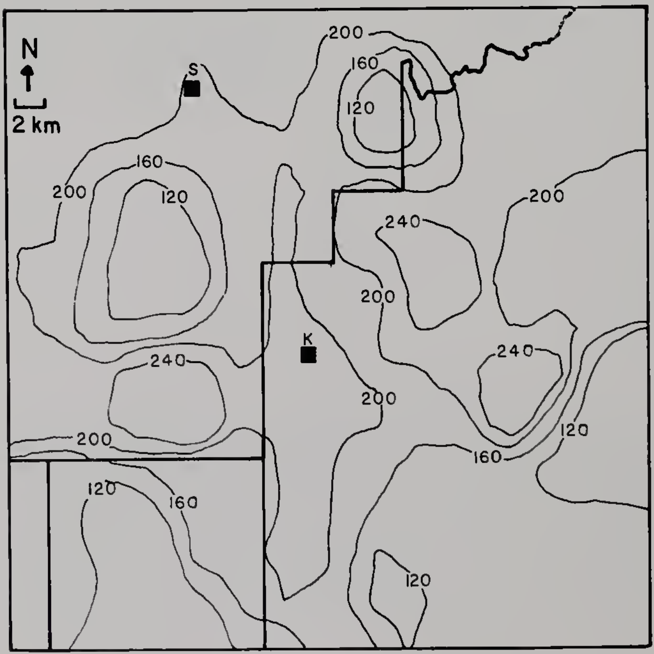

Fig. 10.—Distribution of sulfur (μg/g) in the soils surrounding the Kincaid Generating Station.

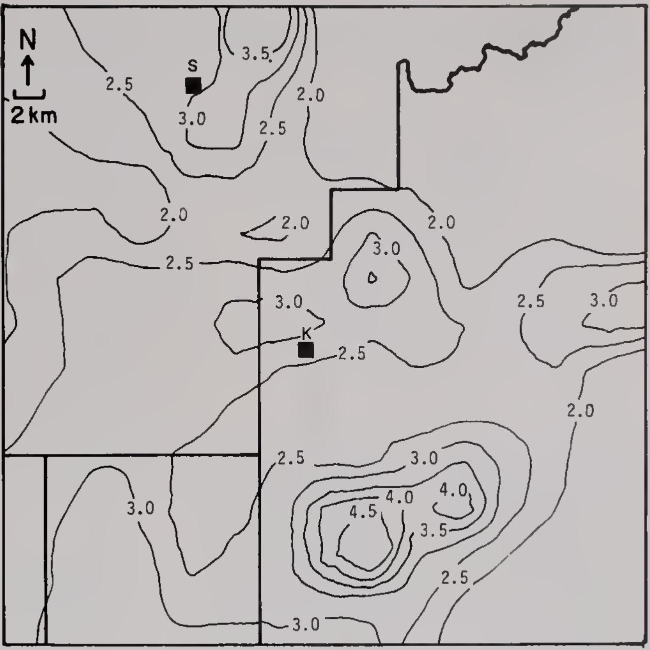

Fig. 11.—Distribution of zinc (μg/g) in the soils surrounding the Kincaid Generating Station.

ticulate fallout from the power plant should be to the north of the plant.

To evaluate the radial distribution of trace metals in the soil, it was assumed that Kincaid Generating Station was a point source emitter. Then, on a radial basis, approximately equal areas of land were partitioned (Fig. 2) and an analysis of variance was made between those areas. Statistically significant ($P < 0.05$) variations were found for cadmium, lead, and zinc in the Illiopolis soil. For all three elements the area with the highest mean value was closest to the plant, the second highest value was the farthest sector, the third highest in the next-to-outermost ring, and the lowest in the next-to-innermost ring. The application of Duncan's multiple range test showed the sample from the 0.97-km radius section was significantly different from the outer two areas in all cases (Table 8). The higher values on the inner ring reflect the deposition of the relatively heavy particulate matter escaping the stacks. The remaining material is carried farther from the plant before deposition. This finer material contains much higher concentrations of metals (Natusch et al. 1974) and thus has a greater influence when it is incorporated into the soil.

Table 8.—Radial variation of concentrations of cadmium, lead, and zinc (μg/g dry soil) in Illiopolis silty clay loam with the Kincaid Generating Station at the center. Underscored means do not differ significantly when tested by Duncan's multiple range test.

	Radial Sector[a]			
	A	D	C	B
Initial radius in km	0	17.7	14.5	9.7
Final radius in km	9.7	20.9	17.7	14.5
Surface area in ha	45.7	61.1	51.0	57.1
Number of samples	15	14	12	10
Cadmium mean	0.15	0.13	0.12	0.11
Lead mean	0.61	0.53	0.49	0.45
Zinc mean	2.68	2.43	2.22	2.03

[a] See Fig. 2.

It must be pointed out that the concentrations found in the soils reflect only short-term values. All of the sampled areas are under intensive agricultural cultivation, and therefore the upper 17 cm (plow depth) of soil are mixed annually. Attempts to correlate the concentrations of elements in the soils with wind vectors revealed no statistically significant correlations.

SEDIMENTS

The collecting of sediment cores from Lake Sangchris in September 1975 for multiple trace element analysis allowed a comparison of sediment depths (Table 9)

Table 9.—Lake Sangchris sedimentation rates as determined from core samples in September 1973 and 1975 (see Fig. 1 for sampling sites).

Station	Sediment Depth in cm		Sediment Depth Change	Mean Sedimentation Rate in cm per Year
	1973	1975		
1	36.3	16.5	−19.8	. . .
2	15.7[a]	29.2	13.5	8.1
3	23.3	36.8	13.5	6.8
4	34.7[a]	56.2	21.5	10.8
5	44.0	44.4	0.4	. . .
7	18.7	25.9	7.2	3.6

[a] Samples collected in January 1974.

with those obtained in the September 1973 core sampling for mercury analysis and made possible the estimating of sedimentation rates. The crude sedimentation rates indicated that no appreciable sedimentation is occurring in either the intake or discharge canals, but sedimentation in the cooling loop is higher than that in the control arm of the lake. The greatest sedimentation was observed at Station 4, where there was an annual deposition rate of 10.8 cm.

The results of the analyses of the sediment core sections are presented in Appendix B for cadmium, chromium, cobalt, copper, lead, mercury, nickel, and zinc. Also included are the results of the analyses of variance, and where there was significant variation, the results of Duncan's multiple range test are indicated by underlining and superscript letters on each table. The average results for all stations and all sections are presented in Table 10 and Fig. 12 and Table 11 and Fig. 13, respectively. These data show that the layers associated with the years 1965 and 1966 contained lower concentrations of cadmium, mercury, nickel, and zinc than did the 1967–1974 layers. The same holds true for chromium except in the oldest layer analyzed. Even for copper there was an overall increase in concentration from 1967 to 1972. All metals analyzed had lower concentrations in the top one or two layers than were present in the earlier layers.

The Kincaid Generating Station began operating in 1967, and it could be postulated that its emissions were the source of these trace metal concentrations, since Klein & Russell (1973) have found similar sediment contamination caused by a coal-fired power plant in Ohio. It would follow that in the years prior to the operation of the plant the metal concentrations would be lower than after operation began. However, since metal absorption is directly correlated with the particle size of the sediment and the available organic material, and since neither particle size analysis nor total organic content analysis was per-

Table 10.—Mean concentrations of trace metals (μg/g dry sediment) in sediment core sections for all stations taken from Lake Sangchris in September 1975. Values followed by the same letter do not differ significantly from each other, each column taken separately. All values were tested by Duncan's multiple range test at $P < 0.05$.

Approximate Year of Deposition	Cd	Co	Cr	Cu	Hg[2]	Ni	Pb	Zn
1975	0.44^{abc}	2.09^{ab}	0.17^{a}	0.65^{abc}	. . .	4.44^{a}	0.95^{a}	13.3^{abc}
1974	0.57^{c}	2.26^{a}	0.29^{a}	1.73^{bc}	. . .	5.31^{ab}	1.76^{abc}	17.6^{a}
1973	0.59^{c}	2.20^{a}	0.25^{a}	1.74^{bc}	0.043^{abcd}	5.08^{ab}	1.71^{abc}	18.1^{ab}
1972	0.57^{c}	2.16^{a}	0.39^{a}	2.18^{c}	0.046^{abc}	4.82^{ab}	1.95^{abc}	19.8^{ab}
1971	0.55^{c}	2.00^{ab}	0.48^{a}	2.31^{c}	0.046^{abc}	4.21^{ab}	1.67^{ab}	20.0^{abc}
1970	0.51^{c}	1.91^{ab}	0.28^{a}	1.92^{c}	0.057^{a}	3.78^{ab}	1.74^{abc}	18.6^{abc}
1969	0.58^{c}	1.86^{ab}	0.35^{a}	2.13^{c}	0.055^{ab}	3.62^{ab}	1.89^{abc}	20.1^{bc}
1968	0.49^{ac}	1.90^{ab}	0.26^{a}	2.01^{bc}	0.049^{abc}	3.41^{ab}	1.79^{abc}	18.1^{cd}
1967	0.35^{abc}	1.85^{ab}	0.24^{a}	1.80^{bc}	0.044^{abcd}	3.04^{ab}	1.90^{abc}	15.5^{d}
1966	0.24^{ab}	1.51^{ab}	0.22^{a}	2.21^{abc}	0.038^{bcd}	2.45^{ab}	2.55^{abc}	11.8^{d}
1965	0.22^{b}	1.40^{ab}	0.31^{a}	2.89^{ab}	0.036^{cd}	2.41^{b}	3.08^{bc}	10.8^{d}
Original soil	0.19	1.20^{b}	0.27^{a}	3.05^{a}	0.028^{d}	2.00^{b}	3.42^{c}	7.58^{d}
Mean[1]	*0.46*	*1.92*	*0.29*	*1.96*	*0.096*	*3.87*	*1.91*	*16.7*

[1] Original soil section is not included in the mean.

[2] Samples obtained in 1973.

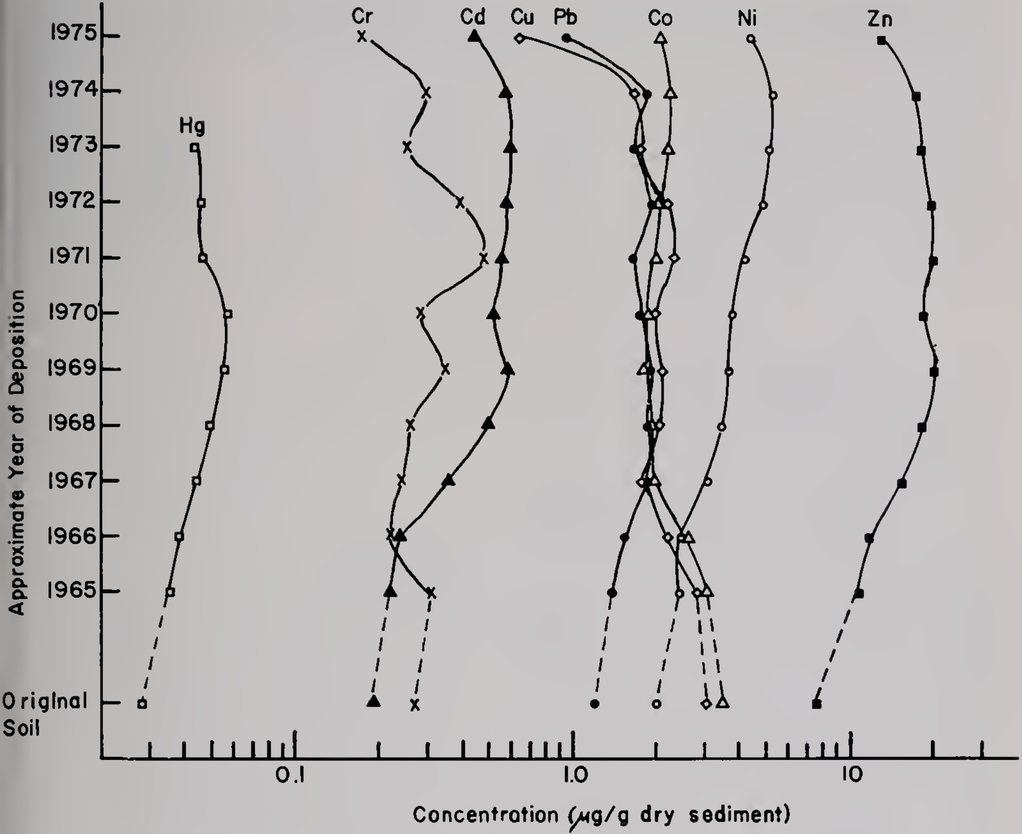

Fig. 12.—Mean concentrations of trace metals in sediment core sections for all stations in Lake Sangchris in September 1975.

formed, this postulation cannot be confirmed. Dreher et al. (1977) found in southern Illinois lakes that one important factor in determining trace element concentrations was the clay content of the sediment.

The settling of matter suspended in the water which has passed through the plant does not occur until the high relative velocity of the water provided by Kincaid Generating Station's pumps is slowed near Station 4, as shown by the high annual sedimentation rate (Table 9). The concentration of most metals increased at Station 4, and cobalt and nickel continued to increase at Station 3 (Fig. 13). The anomalies exhibited by copper and chromium at Station 4 are unexplained, since we would expect these elements to act the same as the others.

Results of analyses of sediment samples for total mercury are shown in Table 12. No sample was obtained at Station 2 in October 1973, since the stations were redefined after that time. No significant variation was found between the stations' mean values. However, mean values for all stations combined did show significant variation at $P < 0.05$. When tested by Duncan's multiple range test, the values for the more recent samples were significantly higher than the others. Except for those of October 1973, the data exhibit a trend toward an increasing amount of total mercury in the upper sediment. However, the coal usage at Kincaid Generating Station decreased from 2,941,008 tons in 1974 to 1,646,507 tons in 1976, while mercury concentrations in the lake-bottom sediment were increasing. If the mercury concentration in the coal remained relatively constant

Table 11.—Mean concentrations of trace metals (µg/g dry sediment) in sediment core sections from Lake Sangchris (see Fig. 1 for sampling sites). Values followed by the same letter do not differ significantly from each other, each column separately, when tested by Duncan's multiple range test at $P < 0.05$.

Station	Cd	Cr	Co	Cu	Hg	Ni	Pb	Zn
1	0.17^{a}	0.09^{a}	1.10^{a}	0.15^{a}	0.055^{a}	1.98^{a}	0.65^{a}	4.60
2	0.50	0.33^{b}	2.39^{b}	3.88^{b}	0.049^{ab}	4.84^{bc}	3.77	18.54^{a}
3	0.67^{b}	0.27^{bc}	2.90	3.26^{bc}	0.042^{b}	5.49^{b}	2.72^{b}	21.53^{a}
4	0.74^{b}	0.14^{ac}	2.23^{b}	0.85^{ad}	0.054^{a}	4.57^{c}	1.22^{a}	25.87
5	0.29^{a}	0.70	0.88^{a}	1.49^{d}	0.027	2.33^{a}	0.91^{a}	14.13
7	0.23^{a}	0.20^{abc}	1.57	2.68^{c}	0.039^{b}	2.72^{a}	2.97^{b}	9.48

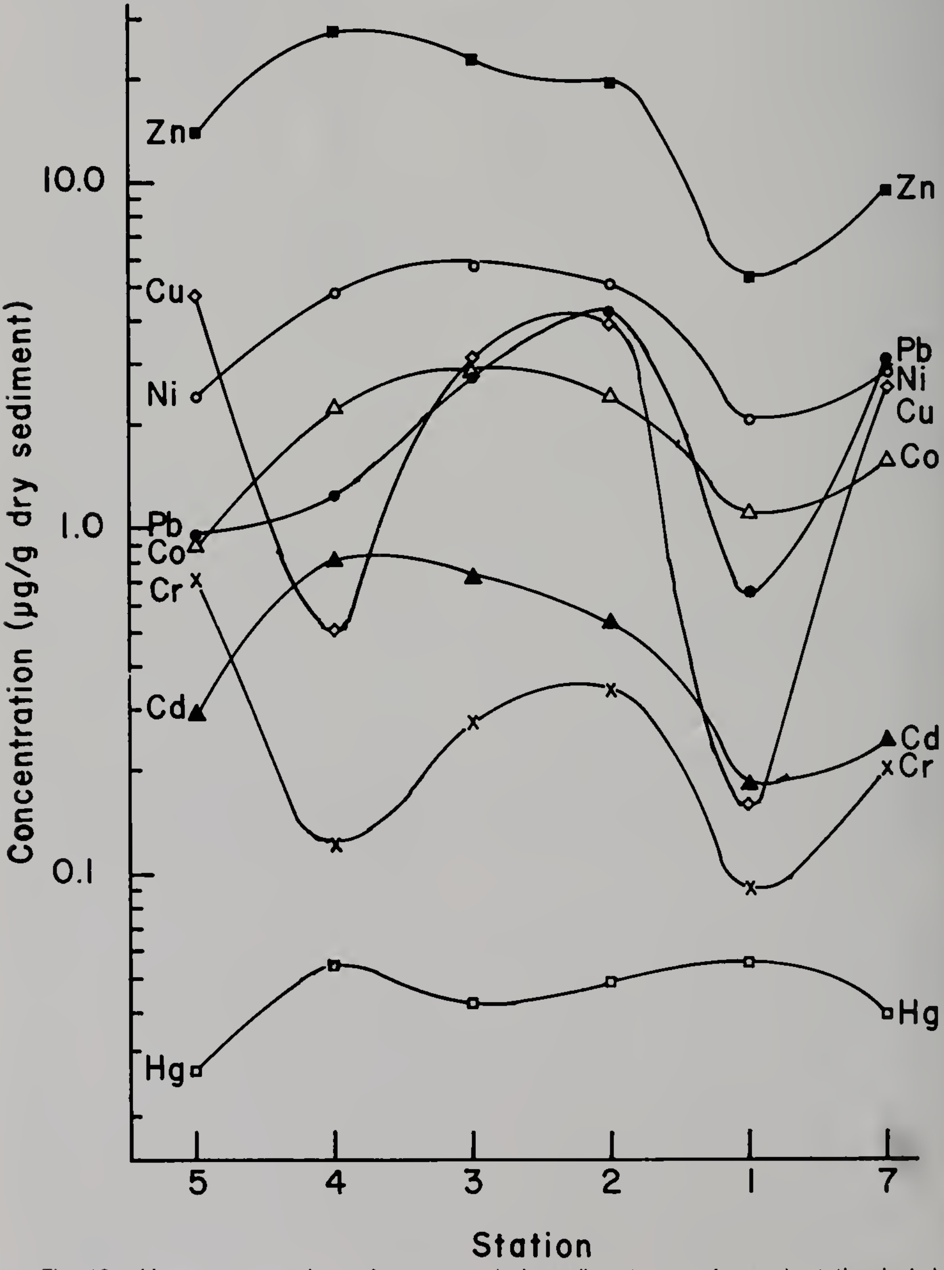

Fig. 13.—Mean concentrations of trace metals in sediment cores for each station in Lake Sangchris in September 1975.

Table 12.—Concentrations of total mercury (μg/g dry sediment) in samples of the upper 1 cm of sediment from Lake Sangchris (see Fig 1 for sampling sites). Values followed by the same letter do not differ significantly from each other when tested by Duncan's multiple range test at $P < 0.05$.

Sampling Month	Station 1	2	3	4	5	7	Mean
Oct. 1973	0.065	. . .	0.056	0.038	0.032	0.030	0.044^{bc}
Jan. 1974	0.030	0.037	0.030	0.033	0.011	0.033	0.029^{ab}
Apr. 1974	0.037	0.019	0.013	0.013	0.037	0.016	0.022^{a}
July 1974	0.038	0.015	0.042	0.037	0.041	0.020	0.032^{ab}
May 1975	0.057	0.080	0.038	0.078	0.046	0.054	0.059^{cd}
June 1976	0.062	0.074	0.095	0.046	0.053	0.064	0.066^{d}
Mean	*0.048*	*0.045*	*0.046*	*0.041*	*0.037*	*0.036*	

over the time span, it seems unlikely that the power plant's output was the major source of the mercury. However, an alternative source of mercury is not apparent.

MACROPHYTES

Concentrations of trace elements in the stems and leaves of American pondweed (*Potamogeton nodosus*) collected from Lake Sangchris are shown in Table 13. Concentrations of metals analyzed were highest in the samples from the discharge arm, intermediate in the control arm, and lowest in the intake arm. For zinc, the control arm-intake arm relationship was reversed, while for mercury the highest mean concentration was in plants from the intake arm and the lowest in those from the discharge arm. Moran (1981) in his analysis of *Potamogeton nodosus* from Lake Sangchris for macronutrient and micronutrient elements, reported that the highest concentrations occurred in plants from the discharge arm. However, in our study only a few such variations were statistically significant. Analysis of variance and Duncan's multiple range test were applied to the trace metal data separately for the stems and leaves. Cadmium, nickel, and zinc concentrations in the stems from the discharge arm were significantly higher than these concentrations in the stems taken from the other two arms. Likewise, cadmium, chromium, nickel, and zinc concentrations in the leaves from the discharge arm were significantly higher than these concentrations in the leaves from the other two arms, except for nickel, of which the mean concentration differed significantly only from that of the intake arm.

CLAMS

The samples of *Corbicula fluminea* were analyzed for trace metals to evaluate the potential accumulation by a sedentary species which actively filters water, thereby representing the area from which it is collected. The results of the analyses for cadmium, cobalt, chromium, copper, nickel, lead, vanadium, and zinc (Table

Table 13.—Mean concentrations of trace metals (μg/g wet tissue) in American pondweed (*Potamogeton nodosus*) collected from Lake Sangchris (see Fig. 1 for sampling sites).

Lake Area	Cd	Co	Cr	Cu	Hg	Ni	Pb	V	Zn
					Stems				
Intake	0.08	3.52	0.27	0.76	0.059	0.73^{a}	2.42	6.00	6.16
Discharge	0.14^{b}	3.72	0.54	1.05	0.022	1.32^{a}	6.95^{c}	7.67	7.63^{b}
Control	0.10	3.50	0.52	0.84	0.028	1.09^{a}	4.75	7.67	5.04
					Leaves				
Intake	0.07	3.03	0.19	1.05	0.093	0.56	3.30	3.83	5.77
Discharge	0.17^{b}	4.15	0.55^{b}	1.49	0.018	1.47^{c}	7.90^{b}	7.83	8.85^{b}
Control	0.12	3.25	0.32	1.06	0.061	0.99	4.78	5.17	5.38

[a] All means were significantly different from each other ($P < 0.05$)

[b] The mean for the discharge arm was significantly different from the other two means, which did not differ significantly from each other ($P < 0.05$).

[c] The mean for the discharge arm differed significantly only from the mean for the intake arm. Other differences were not significant ($P < 0.05$).

14) show that the highest concentrations were in the samples from the slag pond. When tested by one-way analysis of variance, significant variation was found for every element except zinc. Application of Duncan's multiple range test to the other data showed that in every case the values from the slag pond samples varied significantly from the other samples, which did not vary from one another.

Pringle et al. (1968) concluded that for several species of estuarine mollusks the accumulation rates for trace metals are dependent upon the environmental concentration, the temperature, and the time of exposure. It seems reasonable that the aquatic environment present in the slag pond would be higher than other sites in trace elements due to the proximity of the slag which is being constantly leached by the slurry water. In this environment clams might accumulate much higher concentrations of these metals than would clams exposed to water several miles down the discharge arm. In the course of their movement out of the slag pond and around the cooling loop, the concentrations of metals leached from the slag pond become greatly diluted and may be attenuated by absorption by the bottom sediments or by other aquatic organisms.

Dreesen et al. (1977) have shown that chromium and vanadium are solubilized in ash pond effluent, while zinc is not significantly increased. High values were found for both chromium and vanadium in Kincaid Generating Station slag, but zinc was preferentially partitioned into the fly ash (Table 5). The data for metal concentrations in clams reflect the trends suggested by Dreesen et al. (1977) and the slag analyses (Table 2); i.e., chromium and vanadium were concentrated to a much greater extent than zinc in the clams from the slag pond when compared with clams from other parts of the lake (Table 14).

Table 14.—Concentrations of trace metals (μg/g wet tissue) in clams (*Corbicula fluminea*) collected from Lake Sangchris and the slag pond (see Fig. 1 for sampling sites).

Collection Site	Number of Clams	Mean Weight in grams	Cd	Co	Cr	Cu	Ni	Pb	V	Zn
Slag Pond	61	2.53	8.37[a]	12.18[a]	1.01[a]	10.57[a]	3.22[a]	1.78[a]	1.16[a]	55.13
Discharge Arm	51	2.29	0.53	0.61	<0.01	4.89	0.07	0.09	0.12	40.81
Intake Arm	42	2.70	0.30	1.00	<0.01	5.54	<0.01	0.26	0.24	33.25
Control Arm	62	0.65	0.29	0.79	<0.01	3.19	<0.01	0.23	0.22	34.55

[a] For each element, values differed significantly between slag pond samples and those from other sites at $P < 0.05$.

Table 15.—Physical characteristics of eight species of fishes from Lake Sangchris for trace metal analysis.

Species	Collection Date	Number of Fish	Mean Weight in Grams (Standard Deviation)	Mean Length in Millimeters (Standard Deviation)
Black bullhead *(Ictalurus melas)*	October 1973	10	157 (51)	235 (18)
	September 1974	11	98 (44)	195 (31)
	May 1975	15	144 (28)	222 (15)
	May 1976	11	117 (32)	210 (18)
	June 1977	11	118 (33)	205 (21)
Bluegill *(Lepomis machrochirus)*	October 1973	12	54 (10)	148 (10)
	July 1976	12	62 (12)	149 (7)
Carp *(Cyprinus corpio)*	July 1976	12	919 (334)	416 (60)
Channel catfish *(Ictalurus punctatus)*	October 1973	12	293 (73)	332 (55)
	January 1974	10	473 (405)	354 (97)
	April 1974	10	460 (405)	336 (59)
	July 1974	10	309 (92)	340 (28)
	July 1976	13	417 (338)	343 (85)
Green sunfish *(Lepomis cyanellus)*	October 1973	10	54 (13)	152 (13)
Largemouth bass *(Micropterus salmoides)*	October 1973	12	287 (145)	243 (80)
	January 1974	10	584 (161)	337 (28)
	April 1974	12	601 (381)	330 (51)
	July 1974	10	492 (177)	319 (38)
	May 1975	15	1,223 (533)	435 (41)
	May 1976	12	1,094 (568)	409 (65)
	July 1976	14	611 (401)	333 (73)
	June 1977	12	966 (334)	390 (45)
White bass *(Morone chrysops)*	October 1973	10	206 (142)	245 (57)
	July 1976	12	338 (206)	291 (50)
White crappie *(Pomoxis onnularis)*	October 1973	12	149 (35)	227 (14)
	July 1976	10	129 (119)	203 (60)

FISHES

A summary of the species, numbers, dates of collection, mean weights and mean lengths of fishes analyzed in this study is given in Table 15. Those collected in October 1973 were analyzed for total mercury concentrations in the fillets, carcasses, and whole fish (Table 16). Mean concentrations of mercury were consistently higher in the fillets than in the carcasses or the entire fish. The bulk of the mercury present in fish was in organic forms (Kamps et al. 1972, Rivers et al. 1972), which have an affinity for protein, and therefore it is not surprising that the highest values detected in fish from Lake Sangchris occurred in the muscle tissues (fillets). Consequently, black bullheads and largemouth bass collected on dates later than October 1973 were analyzed only for the total mercury concentrations in their fillets (Table 17). The data for largemouth bass were subjected to an analysis of variance, using the weight and length of each fish as covariants, since significant correlation has been found at $P < 0.05$ between the total mercury concentration and the size of the fish. The results showed a significant variation in the mercury concentrations in the fillets from 1973 to 1976. The amount found in the 1975 sample, 0.26 μg/g, was significantly different from all other means when tested by Duncan's multiple range test as modified by Kramer (1956). No reason can be postulated for this sample's being higher than all the others. No significant variation in the concentrations observed in black bullheads was found over the study period.

It was found that concentrations of mercury in the largemouth bass and black bullheads from the other lakes in central Illinois were as high as or higher than concentrations in the bass and bullheads from Lake Sangchris (Table 18). The mean concentration for bass from Lake Sangchris was only about one-half of that for bass from Lake Decatur, one-third of that for bass from Otter Lake, and one-eighth of that for bass from Lake Shelbyville. The highest mercury concentration in bass from Lake Sangchris (0.15 μg/g) was less than the lowest concentration found in bass from Lake Shelbyville (0.23 μg). The lowest concentration determined for bass from Lake Decatur was 0.11 μg/g. The concentrations of mercury were, at first, considered to be atypically low for central Illinois bass (Anderson & Smith 1977). However, our latest sample, taken in June 1977 (Table 17), shows a value more in line with those of bass from other lakes although the mean weight of Lake Sangchris bass is higher than the mean weights of bass from other lakes.

Mercury concentrations in bass collected after 1974 show that the wide gap between mercury levels in Lake Sangchris bass and those of bass in other lakes has closed noticeably. The mean concentration of mercury in bass from Lake Sangchris (0.18 μg/g, the mean of 1975, 1976, and 1977) (Table 17) is between the means for Lake Decatur and Otter Lake bass but is still less than one-third of the Lake Shelbyville bass mean concentration. The mean mercury concentration in black bullheads from Lake Sangchris (0.10 μg/g) is still approximately one-half

Table 16.—Concentrations of total mercury (μg/g wet tissue) in seven species of fishes collected from Lake Sangchris during October 1973.

Species	Number of Fish	Total Mercury		
		Fillet	Carcass	Entire Fish
Black bullhead	10	0.16	0.049	0.071
Bluegill	12	0.11	0.10	0.10
Channel catfish	12	0.088	0.082	0.083
Green sunfish	10	0.17	0.13	0.14
Largemouth bass	12	0.063	0.049	0.053
White bass	10	0.081	0.063	0.069
White crappie	12	0.069	0.035	0.047

Table 17.—Mean concentrations of total mercury (μg/g wet tissue) in the fillets of largemouth bass and black bullheads from Lake Sangchris.

Collection Dates	Number	Total Mercury
	Largemouth Bass	
Oct. 1973	12	0.063
Jan. 1974	10	0.053
Apr 1974	12	0.089
July 1974	10	0.089
May 1975	15	0.26
May 1976	12	0.13
June 1977	12	0.13
	Black Bullheads	
Oct. 1973	10	0.16
Sept. 1974	11	0.093
May 1975	15	0.12
May 1976	11	0.079
June 1977	11	0.079

the concentration found in bullheads from Lake Shelbyville and Otter Lake.

Fillets of fish collected in July 1976 were analyzed for cadmium, cobalt, chromium, copper, nickel, lead, vanadium, and zinc (Table 19). Analyses of variance performed on data grouped by species showed that there was significant variation at $P < 0.01$ in the cobalt and zinc concentrations. Further analysis by Duncan's multiple range test (Kramer 1956) showed that for cobalt only the mean concentration in carp (0.067 μg/g) was significantly higher than that in green sunfish (0.010 μg/g). For zinc, a similar analysis showed that the mean concentration in black bullheads (9.79 μg/g) was significantly greater than the mean concentrations in channel catfish (6.85 μg/g), green sunfish (6.96 μg/g), largemouth bass (6.66 μg/g), white bass (5.34 μg/g), and white crappie (5.78 μg/g). Concentrations found in bluegill (8.23 μg/g) and carp (7.22 μg/g) were not statistically different from those in other species.

Attempts to correlate the various metal concentrations with the weight or length of the individual fish yielded significant ($P < 0.05$) positive correlations only for cadmium in white bass; mercury in black bullheads, largemouth bass, and white bass; and lead in white bass. Atchison et al. (1977) were not able to relate cadmium, lead, or zinc concentrations to the sizes of bluegills analyzed in their study on Indiana lakes. When the results of the current study were grouped by the arm of the lake from which fishes had been collected and analyses of variance were performed, significant ($P < 0.05$) variation occurred for nickel in bluegill; cobalt, copper, and lead in carp; chromium and nickel in channel catfish; nickel in green sunfish; chromium in largemouth bass; and cadmium, cobalt, lead, and

Table 18.—Comparison of the concentrations of total mercury (μg/g; wet tissue) in the fillets of largemouth bass and black bullheads from Lake Sangchris and other lakes in central Illinois.

Lake	Date	Number of Fish	Mean Weight in Grams	Mean Length in mm	Total Mercury Mean	Total Mercury Range
			Largemouth Bass			
Shelbyville	July 1974	12	539	334	0.56	0.23–1.24
Otter	July 1974	12	430	303	0.24	0.17–0.32
Decatur	July 1974	12	586	317	0.16	0.11–0.29
Sangchris	Oct. 1973–July 1974	44	487	305	0.07	0.03–0.15
			Black Bullhead			
Shelbyville	July 1974	12	173	235	0.18	0.12–0.27
Otter	July 1974	12	111	197	0.25	0.16–0.39
Sangchris	Oct. 1973	10	157	235	0.16	0.09–0.36

Table 19.—Mean concentrations of trace metals (μg/g wet tissue) in fishes from Lake Sangchris.

Species	Number of Fish	Cd	Co	Cr	Cu	Ni	Pb	V	Zn
Black bullhead	12	0.028	0.057	0.81	0.59	1.27	0.90	0.52	9.79[a]
Bluegill	12	0.018	0.027	0.22	0.22	0.11	0.11	0.035	8.23
Carp	12	0.013	0.067[b]	0.28	0.41	0.17	0.070	0.030	7.22
Channel catfish	13	0.015	0.017	0.25	0.19	0.12	0.049	0.012	6.85
Green sunfish	18	0.017	0.010	0.21	0.12	0.14	0.045	0.016	6.96
Largemouth bass	14	0.006	0.013	0.16	0.12	0.060	0.013	0.009	6.66
White bass	12	0.014	0.036	0.31	0.33	0.17	0.091	0.030	5.34
White crappie	10	0.012	0.012	0.22	0.17	0.091	0.023	0.018	5.78

[a] Significantly larger than zinc concentrations for all other fishes except bluegill and carp. All other means do not vary significantly.
[b] Significantly larger than cobalt concentrations for all other fishes.

vanadium in white bass. Since cadmium and lead concentrations in white bass had both significant correlation to the fish's weight and significant variance between means grouped by location of collection, these two groupings were tested by analysis of variance, using weight and length as covariants.

Duncan's multiple-range test was applied to determine which values were different for each group which showed significant variation (Table 20). In most cases (7 of 12) the highest concentrations were found in the fish collected from the control arm of the lake. Exceptions to this were found for the white bass, of which intake-arm fish had the highest concentrations, and bluegill, of which the discharge-arm fish had the highest concentrations.

By considering the mean values calculated for all species-metal-location combinations, including those not significantly different, the lowest values occurred most frequently in carp, channel catfish, green sunfish, largemouth bass, and white crappie from the intake arm; in black bullheads and white bass from the discharge arm; and in bluegill from the control arm. Overall, the highest mean values appeared most fre-

Table 20.—Mean concentrations of trace metals (μg/g wet tissue) in fishes for which significant variance was found at $P < 0.05$. Values underlined by the same kind of line do not differ significantly at $P < 0.05$ when tested by Duncan's multiple range test.

Element	Intake Arm	Discharge Arm	Control Arm
	Bluegill		
Nickel	0.12	0.18	0.026
	Carp		
Cobalt	0.064	0.009	0.13
Copper	0.27	0.28	0.67
Lead	0.010	0.014	0.19
	Channel Catfish		
Chromium	0.14	0.25	0.37
Nickel	0.058	0.074	0.24
	Green Sunfish		
Nickel	0.067	0.10	0.56
	Largemouth Bass		
Chromium	0.014	0.22	0.24
	White Bass		
Cadmium	0.030	0.005	0.014
Cobalt	0.076	0.005	0.027
Lead	0.200	0.005	0.091
Vanadium	0.054	0.007	0.029

quently in fish from the control arm. The highest mean values occurred in bluegill and white crappie from the discharge arm; in the black bullheads from the intake arm; and in carp, channel catfish, and largemouth bass from the control arm. For green sunfish and white bass the highest overall means were evenly divided between the discharge and control arms and the intake and discharge arms, respectively. In total, of 64 possible means the highest values occurred in the intake arm 14 times, in the discharge arm 21 times, and in the control arm 29 times. The lowest values occurred 34 times in the intake arm, 19 in the discharge arm, and 11 times in the control arm. Since the control arm is not in the predominant wind drift pattern from the plant and since it is not influenced by the circulation pattern of the lake, the higher values observed in fish from this arm have probably been caused by some other source.

Mean values were calculated for the trace metal concentrations in the sediments, aquatic macrophytes, clams, omnivorous fishes and piscivorous fishes, respectively (Table 21). It can be seen that, for all metals except mercury and chromium, lake sediments contain the highest or second highest concentrations of all materials analyzed. The aquatic macrophytes accumulated higher concentrations of cobalt (2.91 μg/g) and lead (5.02 μg/g) than did the sediments (1.92 and 1.91 μg/g), while the clams had higher concentrations of copper (4.54 μg/g) and zinc (36.2 μg/g) than had the sediments (1.96 and 16.7 μg/g).

For metals other than mercury, the fishes of Lake Sangchris in general contain lower concentrations than do the other materials tested. However, chromium and nickel concentrations in clams are lower than those in fish and indicate outright rejection of these metals by the clams. For mercury, the omnivorous fishes (0.12 μg/g) contain higher concentrations than the piscivorous fishes (0.072 μg/g), a reversal of the trend of bioaccumulation noted by Cumbie (1975), D'Itri (1972) and Potter et al. (1975). The slightly basic pH of Lake Sangchris (Brigham 1981) may be the major factor in the overall low accumulation of mercury, as more acid waters are considered to favor mercury accumulation by fish (Nelson et al. 1971). Gillespie (1972) has shown that guppies (*Poecilia reticulata*) accumulated up to 0.9 μg/g of total mercury when exposed to lake sediments containing 0.15 μg/g of mercury over a 140-day period. Gillespie also noted that mercury mobilization in guppies from industrial sediments with low mercury concentrations is much higher than from lake sediments with higher mercury contents. Since the sediments of Lake Sangchris contain relatively low mercury concentrations, little mercury mobilization would be expected in this lake.

SUMMARY

The vapor emissions, untrapped by ash, and the accumulated slag from the Kincaid Generating Station contributed significant amounts of chromium, copper, mercury, and sulfur to the surrounding land, including the watershed of Lake Sangchris, and to the lake itself. Smaller amounts of boron, cobalt, and nickel also are emitted by the same sources. Airborne particulate sample analysis indicated a relationship to the smokestack emissions of the power plant. Smokestack emissions also seemed to deposit cadmium, lead, and zinc on the soils downwind from the plant.

In the lake itself, sediment trace metal

Table 21.—Mean trace metal concentrations (μg/g) in five components of Lake Sangchris.

Component	Cd	Co	Cr	Cu	Hg	Ni	Pb	Zn
Sediments	0.46	1.92	0.29	1.96	0.044	3.87	1.91	16.7
Plants	0.11	2.91	0.40	1.04	0.047	1.03	5.02	6.36
Clams	0.37	0.80	<0.01	4.54	. . .	<0.03	0.19	36.2
Omnivorous fish	0.017	0.032	0.33	0.28	0.12	0.32	0.20	7.47
Piscivorous fish	0.010	0.026	0.24	0.23	0.072	0.12	0.052	6.00

concentrations tended to be higher in the discharge arm or dam sampling sites. The highest trace metal values in the aquatic macrophytes were also found in samples from the discharge arm except for mercury, of which the intake-arm samples contained the highest levels. Concentrations of trace metals in clams were related to the close proximity of a source of water-soluble metal contaminants in the slag pond. Only cadmium and lead in white bass and mercury in black bullheads, largemouth bass, and white bass were positively correlated with fish size. For fish species whose concentrations varied by the location of collection, those collected in the control arm had the highest concentrations. The mercury concentrations in all fishes seemed atypically low, but the lack of mercury accumulation may be due to the high pH of the lake's water.

REFERENCES CITED

Anderson, W.L., and K.E. Smith. 1977. Dynamics of mercury at coal-fired power plant and adjacent cooling lake. Environmental Science and Technology 11:75–80.

Atchison, G.J., B.R. Murphy, W.E. Bishop, A.W. McIntosh, and R.A. Mayes. 1977. Trace metal contamination of bluegill (*Lepomis macrochirus)* from two Indiana lakes. American Fisheries Society Transactions 106:637–640.

Bernas, B. 1968. A new method for decomposition and comprehensive analysis of silicates by atomic absorption spectrometry. Analytical Chemistry 40:1682–1686.

Brigham, A.R. 1981. Water quality in a cooling water reservoir. Pages 290–319 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32 (4).

Cumbie, P.M. 1975. Mercury levels in Georgia otter, mink and freshwater fish. Bulletin of Environmental Contamination and Toxicology 14:193–196.

Davison, R.L., D.F.S. Natusch, J.R. Wallace, and C.A. Evans, Jr. 1974. Trace elements in fly ash. Dependence of concentration on particle size. Environmental Science and Technology 8: 1107–1113.

D'Itri, F. 1972. The environmental mercury problem. Chemical Rubber Co., Cleveland, OH.

Dreesen, D.R., E.S. Gladney, J.W. Owens, B.L. Perkins, C.L. Wienke, and L.E. Wangen. 1977. Comparison of levels of trace elements extracted from fly ash and levels found in effluent waters from a coal-fired power plant. Environmental Science and Technology 10:1017–1018.

Dreher, G.B., C.B. Muchmore, and D.W. Stover. 1977. Major, minor, and trace elements of bottom sediments in Lake Du Quoin, Johnston City Lake, and Little Grassy Lake in Southern Illinois. Illinois State Geological Survey Environmental Geology Note 82. 37 p.

Fehrenbacher, J.B., R.S. Smith, and R.T. Odell. 1950. Christian County soils. University of Illinois Agricultural Experiment Station Soil Report 73. 64 p.

______, G.O. Walker, and H. L. Wascher. 1967. Soils of Illinois. University of Illinois, College of Agriculture, Agricultural Experiment Station Bulletin 725. 47 p.

Gillespie, D.C. 1972. Mobilization of mercury from sediments into guppies (*Poecilia reticulata)*. Canada Fisheries Research Board Journal 29:1035–1041.

Hartstein, A.M., R.W. Freedman, and D.W. Platter. 1973. Novel wet-digestion procedure for trace-metal analysis of coal by atomic absorption. Analytical Chemistry 45:611–614.

Hatcher, J.T., and L.V. Wilcox. 1950. Colorimetric determination of boron using carmine. Analytical Chemistry 22:567–569.

Hwang, J.Y., P.A. Ullucci, and A.L. Malenfant. 1971. Determination of mercury by a flameless atomic absorption technique. Canadian Spectroscopy 16:100–106.

Jacobs, L.W., and D.R. Keeney. 1974. Aqua regia for quantitative recovery of mercuric sulfide from sediments. Environmental Science and Technology 8:267–268.

Kamps, L.R., R. Carr, and H. Miller. 1972. Total mercury-monomethylmercury content of several species of fish. Bulletin of Environmental Contamination and Toxicology 8:273–279.

Klein, D.H., A.W. Andren, J.A. Carter, J.F. Emery, C. Feldman, W. Fulkerson, W.S. Lyon, J.C. Ogle, Y. Talmi, R.I. Van Hook, and N. Bolton. 1975. Pathways of thirty-seven trace elements through coal-fired power plant. Environmental Science and Technology 9:973–979.

______, and P. Russell. 1973. Heavy metals: Fallout around a power plant. Environmental Science and Technology 7:357–358.

Kramer, C.Y. 1956. Extension of multiple range tests to group means with unequal numbers of replications. Biometrics 12:307–310.

Long, S.J., D.R. Scott, and R.J. Thompson. 1973. Atomic absorption determination of elemental mercury collected from ambient air on silver wool. Analytical Chemistry 45:2227–2233.

Moran, R. L. 1981. Phytoplankton dynamics in a cooling-water reservoir. Pages 320–341 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4).

Natusch, D.F.S., J.R. Wallace, and C.A. Evans, Jr. 1974. Toxic trace elements: Preferential concentration in respirable particles. Science 183:202–204.

NELSON, N., T. C. BYERLY, A. C. KOLBYE, JR., L.T. KURLAND, R.E. SHAPIRO, S.I. SHIBKO, W.H. STICKEL, J.E. THOMPSON, L.A. VAN DEN BERG, and A. WEISSLER. 1971. Hazards of mercury. Environmental Research 4:1–69.

POTTER, L., D. KIDD, and D. STANDIFORD. 1975. Mercury levels in Lake Powell: Bioamplification of mercury in man-made desert reservoir. Environmental Science and Technology 9:41–46.

PRINGLE, B.H., D.E. HISSONG, E.L. KATZ, and S.T. MULAWKA. 1968. Trace metal accumulation by estuarine mollusks. Sanitary Engineering Division Journal, American Society of Civil Engineers Proceedings 94:455–475.

RIVERS, J.B., J.E. PEARSON, and C.D. SHULTZ. 1972. Total and organic mercury in marine fish. Bulletin of Environmental Contamination and Toxicology 8:257–266.

RUCH, R.R., H.J. GLUSKOTER, and N.F. SHIMP. 1974. Occurrence and distribution of potentially volatile trace elements in coal: a final report. Illinois State Geological Survey Environmental Geology Note 72. 96 p.

STEELE, R. G. D., and J. H. TORRIE. 1960. Principles and procedures of statistics, with special reference to the biological sciences. McGraw-Hill Co., New York. 481 p.

TRANQUILLI, J.A., R. KOCHER, and J.M. MCNURNEY. 1981. Population dynamics of the Lake Sangchris fishery. Pages 413–499 *in* R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32 (4).

U.S. AIR FORCE AIR WEATHER SERVICE. 1963. Uniform summary of surface weather observations. Springfield, Ill. Jan. 1953–Dec. 1962. Data Processing Division, Climatic Center, Asheville, N.C.

U.S. ENVIRONMENTAL PROTECTION AGENCY. 1972. Mercury in sediment (cold vapor technique). Analytical Quality Control Laboratory, Cincinnati, OH. Mimeographed. 8 p.

APPENDIX A

AIRBORNE PARTICULATE SAMPLING

Table A1.—Operational parameters for the high-volume air samplers used to collect airborne particulate matter in the vicinity of the Kincaid Generating Station for total mercury analysis, 1973–1974.

Date	Location	Time Operated in Minutes	Mean Air Flow in m^3/min	Weight in mg of Particulates Collected
12 Oct. 1973	8.9 km (+)[a]	1,410	1.472	149.2
	4.8 km (+)	1,370	1.331	100.9
	4.8 km (−)	1,340	1.416	113.6
13 Nov. 1973	9.7 km (+)	1,445	1.501	107.3
	4.8 km (+)	1,440	1.274	131.1
	4.8 km (−)	1,440	1.331	83.6
15 Jan. 1974	9.7 km (+)	1,440	0.872	105.1
	4.8 km (+)	1,440	1.211	97.7
	4.8 km (−)	1,440	1.368	109.2
27 Feb. 1974	9.7 km (+)	1,440	1.387	65.1
	4.8 km (+)	1,440	1.370	32.6
	4.8 km (−)	1,440	1.515	62.8
26 Mar. 1974	8.4 km (+)	1,440	1.416	82.6
	5.6 km (+)	1,415	1.529	86.8
	4.8 km (−)	1,430	1.402	95.5
11 Apr. 1974	8.9 km (+)	1,440	1.331	72.4
	4.8 km (+)	1,305	1.345	73.0
	4.8 km (−)	1,440	1.430	85.5
4 May 1974	8.9 km (+)	1,440	1.331	191.9
	4.8 km (+)	1,440	1.388	168.9
	4.8 km (−)	1,425	1.274	167.3
19 June 1974	8.9 km (+)	1,440	1.232	98.7
	4.8 km (+)	1,320	1.345	126.8
	4.8 km (−)	1,440	1.505	107.2
18 July 1974	8.9 km (+)	1,440	1.246	228.9
	4.8 km (+)	1,440	1.260	211.7
	4.8 km (−)	1,440	1.303	223.8
27 Aug. 1974	9.7 km (+)	1,440	0.943	138.6
	4.8 km (+)	1,440	1.423	141.9
	4.8 km (−)	1,440	1.586	114.4

[a] (+) indicates that the sampler was downwind from the plant; (−) indicates upwind.

Table A2.—Operational parameters for high-volume air samplers used to collect airborne particulate matter in the vicinity of the Kincaid Generating Plant in 1975.

Date Sample Collection Began

Jan.	Apr.	May	June	July	Aug.	Oct.	Nov.
23	28	21	24	15	21	20	17

Time Unit Started (CST)

Station[a]	Jan.	Apr.	May	June	July	Aug.	Oct.	Nov.
1	1550	1725	1540	1220	1555	1215	1640	1615
2	1540	1740	1515	1230	1545	. . .	1625	1600
3	1523	1750	1500	1320	1530	1235	1610	1540
4	1500	1805	1435	1340	1455	1250	1545	1525
5	1435	1825	1415	1350	1440	1300	1520	1505
6	1412	1835	1355	1400	1425	1320	1500	1455
7	1350	1845	1335	1415	1400	1330	1440	1440
8	1308	1635	1635	1140	1630	1140	1725	1655
9	1235	1650	1610	1200	1615	1155	1705	1640

Time Unit Operated in Minutes

Station	Jan.	Apr.	May	June	July	Aug.	Oct.	Nov.
1	1,365	1,425	1,420	1,390	1,405	1,425	1,280	1,445
2	1,365	1,430	1,435	1,390	1,405	. . .	1,280	1,450
3	1,372	1,430	1,430	1,350	1,405	1,420	1,280	1,455
4	1,375	1,430	1,435	1,345	1,430	1,420	1,290	1,460
5	1,430	1,425	1,440	1,350	1,430	1,425	1,300	1,465
6	1,403	1,425	1,445	1,350	1,430	1,420	1,300	1,465
7	1,335	1,430	1,450	1,360	1,440	1,420	1,300	1,470
8	1,387	1,435	1,405	1,400	1,415	1,430	1,275	1,450
9	1,435	1,435	1,415	1,390	1,410	1,410	1,280	1,455

Wind Direction Observations During Sampling Period
(date/time CST/compass heading)

Jan.	Apr.	May	June	July
23/1200/10°	28/1635/50°	21/1335/33°	24/1145/12°	15/1400/52°
1500/10°	29/0600/79°	1915/52°	1900/15°	16/0630/39°
1600/10°	1845/65°	1635/33°	1345/33°	2000/32°
24/0800/15°	0730/73°	22/0700/45°	2100/85°	1030/20°
	1230/1°	1000/45°	25/0600/360°	1400/349°
	1630/337°	1345/45°	0845/357°	
	1800/340°	1600/70°	1100/359°	

Aug.	Oct.	Nov.
21/1125/60°	20/1420/30°	17/1440/13°
1730/10°	1725/30°	1710/13°
22/0645/75°	21/0900/54°	18/0600/19°
1200/70°	1220/69°	1000/14°
		1300/14°
		1630/350°

Tons of Coal Burned by Power Plant During Sampling Period

Jan.	Apr.	May	June	July	Aug.	Oct.	Nov.
6,874	5,750	1,200	6,800	12,300	10,500	12,000	9,600

Mean Air Flow Rate During Collection in m^3/min

Station	Jan.	Apr.	May	June	July	Aug.	Oct.	Nov.
1	1.459	1.444	1.410	1.374	1.388	1.041	1.055	1.388
2	1.189	1.119	1.141	0.885	0.906	. . .	0.977	1.008
3	1.253	1.110	1.003	0.765	1.281	1.264	1.187	1.175
4	1.444	1.410	1.368	1.274	1.008	0.991	1.221	1.250
5	1.402	1.365	1.294	1.310	1.347	0.765	1.321	1.324
6	1.402	1.433	1.416	1.444	0.991	1.286	1.585	1.459
7	1.218	0.954	0.915	1.034	0.748	0.857	0.845	1.165
8	1.289	1.215	1.167	1.225	1.218	1.218	1.297	1.314
9	1.381	1.289	1.274	1.282	1.211	1.274	1.320	1.369

Weight in Milligrams of Particulate Matter Collected

Station	Jan.	Apr.	May	June	July	Aug.	Oct.	Nov.
1	89.5	149.1	221.8	136.4	144.9	152.2	133.8	126.3
2	86.2	100.4	174.2	103.8	125.2	. . .	109.3	87.4
3	73.1	86.9	128.2	82.0	117.0	127.1	112.7	126.3
4	83.6	94.4	158.6	192.6	118.5	149.7	131.1	100.7
5	77.1	85.3	181.1	79.8	114.5	138.5	118.4	84.2
6	84.0	91.7	171.0	84.2	105.8	144.3	134.8	99.6
7	70.1	96.0	133.3	126.8	117.9	116.9	101.0	75.7
8	94.2	89.5	168.6	91.5	114.4	132.8	248.4	94.5
9	94.2	89.5	168.6	91.5	114.4	132.8	248.4	94.5

[a] See Fig 1 for locations.

Table A3.—Cadmium concentrations (μg Cd/g dry particulate matter) in the airborne particulate matter collected in the vicinity of the Kincaid Generating Station in 1975.

Station[a]	Jan.	Apr.	May	June	July	Aug.	Oct.	Nov.	Mean
1	85	27	14	108	75	158	124	86	85
2	100	18	15	114	65	. . .	131	77	74
3	92	32	42	82	37	120	110	21	67
4	86	19	42	79	233	266	110	67	113
5	94	21	34	100	83	85	167	38	78
6	75	24	24	117	60	62	104	45	64
7	297	47	55	78	74	96	177	82	113
8	110	38	18	108	58	107	136	115	86
9	169	84	58	295	136	211	70	108	141
Mean[b]	*123*	*34*	*34*	*120*	*91*	*138*	*125*	*71*	
Mean[c]	*118*	*27*	*32*	*97*	*90*	*131*	*132*	*59*	

[a] See Fig 1 for locations.
[b] All stations included.
[c] Stations 8 and 9 excluded; see text for explanation.

Table A4.—Chromium concentrations (μg Cr/g dry particulate matter) in the airborne particulate matter collected in the vicinity of the Kincaid Generating Station in 1975.

Station[a]	Jan.	Apr.	May	June	July	Aug.	Oct.	Nov.	Mean
1	<20	<20	<20	<20	<20	29	<20	<20	<20
2	<20	<20	<20	<20	<20	. . .	<20	<20	<20
3	<20	<20	<20	<20	<20	28	<20	<20	<20
4	<20	<20	<20	<20	<20	26	<20	<20	<20
5	<20	21	<20	<20	<20	39	<20	<20	<20
6	<20	<20	<20	<20	<20	37	<20	<20	<20
7	<20	<20	<20	<20	<20	46	<20	<20	<20
8	<20	22	<20	<20	<20	47	<20	<20	<20
9	<20	20	<20	<20	<20	40	<20	<20	<20
Mean[b]	*<20*	*<20*	*<20*	*<20*	*<20*	*38*	*<20*	*<20*	
Mean[c]	*<20*	*<20*	*<20*	*<20*	*<20*	*36*	*<20*	*<20*	

[a] See Fig 1 for locations.
[b] All stations included
[c] Stations 8 and 9 excluded; see text for explanation.

Table A5.—Cobalt concentrations (μg Co/g dry particulate matter) in the airborne particulate matter collected in the vicinity of the Kincaid Generating Station in 1975.

Station[a]	Jan.	Apr.	May	June	July	Aug.	Oct.	Nov.	Mean
1	20	12	8	13	12	12	13	14	13
2	21	18	10	17	14	. . .	16	20	14
3	24	21	14	22	15	14	16	14	18
4	21	19	11	9	15	12	14	18	15
5	23	21	10	22	16	13	15	21	18
6	21	19	10	21	17	12	13	18	16
7	26	19	14	14	15	15	18	23	18
8	22	22	12	21	17	12	16	18	16
9	19	20	10	20	15	13	7	19	15
Mean[b]	22	*19*	*11*	*18*	*15*	*13*	*14*	*18*	
Mean[c]	22	*18*	*11*	*17*	*15*	*13*	*15*	*18*	

[a] See Fig. 1 for locations.
[b] All stations included.
[c] Stations 8 and 9 excluded; see text for explanation.

Table A6.—Copper concentrations (μg Cu/g dry particulate matter) in the airborne particulate matter collected in the vicinity of the Kincaid Generating Station in 1975.

Station[a]	Jan.	Apr.	May	June	July	Aug.	Oct.	Nov.	Mean
1	110	154	157	530	500	522	341	342	332
2	317	301	348	694	648	. . .	534	678	503
3	283	452	1,500	1,720	1,200	434	410	206	776
4	150	363	1,850	2,600	4,740	538	283	340	1,358
5	94	476	1,685	5,400	3,610	854	804	696	1,702
6	107	1,020	1,630	1,750	2,210	694	438	678	1,066
7	142	272	1,260	832	776	615	292	390	572
8	154	763	1,140	868	1,250	511	198	240	641
9	122	368	252	856	1,700	2,150	188	282	1,115
Mean[b]	*164*	*463*	*1,091*	*1,694*	*1,848*	*790*	*387*	*428*	
Mean[c]	*172*	*434*	*1,204*	*1,932*	*1,954*	*610*	*443*	*476*	

[a] See Fig 1 for locations.

[b] All stations included

[c] Stations 8 and 9 excluded; see text for explanation

Table A7.—Nickel concentrations (μg Ni/g dry particulate matter) in the airborne particulate matter collected in the vicinity of the Kincaid Generating Station in 1975.

Station[a]	Jan.	Apr.	May	June	July	Aug.	Oct.	Nov.	Mean
1	50	12	12	85	38	64	13	14	36
2	42	18	10	84	50	. . .	17	20	34
3	24	21	28	65	30	57	16	14	32
4	21	19	34	60	60	108	14	18	42
5	23	21	25	90	24	32	15	21	31
6	43	19	42	170	34	50	13	18	49
7	38	19	14	35	46	31	18	23	28
8	33	22	23	54	17	53	17	18	30
9	94	30	21	79	62	60	11	19	47
Mean[b]	*41*	*20*	*23*	*80*	*40*	*57*	*15*	*18*	
Mean[c]	*34*	*18*	*24*	*84*	*40*	*57*	*15*	*18*	

[a] See Fig 1 for locations.

[b] All stations included.

[c] Stations 8 and 9 excluded; see text for explanation.

Table A8.—Lead concentrations (μg Pb/g dry particulate matter) in the airborne particulate matter collected in the vicinity of the Kincaid Generating Station in 1975.

Station[a]	Jan.	Apr.	May	June	July	Aug.	Oct.	Nov.	Mean
1	4,620	1,050	1,760	2,715	1,960	2,390	3,580	2,420	2,560
2	4,490	1,590	2,240	3,620	2,610	. . .	4,160	3,250	3,140
3	3,950	1,570	2,410	3,100	2,010	2,690	3,825	2,220	2,800
4	4,260	1,560	2,230	1,550	1,870	2,410	3,630	3,110	2,580
5	4,420	1,520	1,820	4,180	1,960	2,480	3,600	3,230	2,900
6	4,100	1,550	1,860	4,380	2,150	2,540	3,570	3,230	2,920
7	3,770	1,000	1,850	2,090	2,020	2,560	2,630	3,210	2,540
8	3,570	1,700	1,610	3,860	2,060	2,600	4,120	3,220	2,840
9	4,040	1,600	2,090	4,240	2,400	2,640	1,930	3,360	2,790
Mean[b]	*4,140*	*1,490*	*1,990*	*3,390*	*2,120*	*2,540*	*3,560*	*3,040*	
Mean[c]	*4,230*	*1,430*	*2,020*	*3,180*	*2,080*	*2,510*	*3,710*	*2,950*	

[a] See Fig 1 for locations.
[b] All stations included.
[c] Stations 8 and 9 excluded; see text for explanation.

Table A9.—Zinc concentrations (μg Zn/g dry particulate matter) in the airborne particulate matter collected in the vicinity of the Kincaid Generating Station in 1975.

Station[a]	Jan.	Apr.	May	June	July	Aug.	Oct.	Nov.	Mean
1	3,250	675	671	2,210	2,340	1,730	3,280	8,460	2,827
2	3,220	842	559	2,350	2,630	. . .	2,920	9,340	3,123
3	2,890	863	430	1,730	2,580	2,170	2,330	5,620	2,327
4	3,000	916	576	965	2,560	2,000	1,900	6,130	2,256
5	3,450	1,090	462	2,580	2,790	1,760	1,700	5,560	2,424
6	3,870	1,040	634	3,060	3,110	3,290	1,550	5,280	2,729
7	5,490	1,750	406	1,060	2,220	1,540	1,560	3,900	2,241
8	4,230	1,430	415	2,970	3,640	2,520	3,460	13,800	4,058
9	5,260	887	421	1,850	2,320	974	468	17,800	3,748
Mean[b]	*3,851*	*1,055*	*508*	*2,086*	*2,688*	*1,998*	*2,130*	*7,052*	
Mean[c]	*3,596*	*1,025*	*534*	*1,994*	*2,604*	*2,082*	*2,177*	*6,327*	

[a] See Fig 1 for locations
[b] All stations included.
[c] Stations 8 and 9 excluded; see text for explanation.

APPENDIX B

SEDIMENT CORE SAMPLES

Table B1.—Cadmium concentrations (μg Cd/g dry sediment) in sediment core sections taken from Lake Sangchris in September 1975 (see Fig. 1 for sampling sites). Values underlined by the same type of line do not differ significantly from each other, each row taken separately. Values followed by the same letter do not differ significantly from each other, each column taken separately. All values tested by Duncan's multiple range test used $P < 0.05$.

Approximate Year of Deposition	Station					
	1	2	3	4	5	7
1975	0.40	0.41^{a}	0.67	0.64^{a}	0.28^{a}	0.24^{a}
1974	0.30^{a}	0.70^{b}	0.91^{a}	0.92^{bc}	0.28^{a}	0.23^{a}
1973	0.31^{a}	0.70^{b}	0.91^{a}	1.01^{c}	0.28^{a}	0.21^{a}
1972	0.25^{ab}	0.73^{b}	0.81^{b}	1.02^{c}	0.34^{a}	0.29^{a}
1971	0.18^{bc}	0.71^{b}	0.88^{c}	0.82^{bd}	0.40^{a}	0.25^{a}
1970	0.19^{bc}	0.71^{b}	0.96^{a}	0.63^{a}	0.24^{a}	0.27^{a}
1969	0.15^{cd}	0.56	0.91^{ac}	1.30	0.29^{a}	0.27^{a}
1968	0.13^{cd}	0.42^{a}	0.81^{b}	0.93^{bc}	0.31^{a}	0.26^{a}
1967	0.10^{d}	0.31^{c}	0.47	0.72^{ad}	0.31^{a}	0.16^{a}
1966	0.09^{d}	0.26^{cd}	0.26^{d}	0.44	0.20^{a}	0.18^{a}
1965	0.08^{d}	0.22^{d}	0.22^{d}	0.28^{e}	0.29^{a}	0.22^{a}
Original soil	0.08^{d}	0.21^{d}	0.21^{d}	0.20^{e}	0.28^{a}	0.16^{a}

Table B2.—Chromium concentrations (μg Cr/g dry sediment) in sediment core sections taken from Lake Sangchris in September 1975 (see Fig. 1 for sampling sites). Values underlined by the same type of line do not differ significantly from each other, each row taken separately. Values followed by the same letter do not differ significantly from each other, each column taken separately. All values tested by Duncan's multiple range test used $P < 0.05$.

Approximate Year of Deposition	Station					
	1	2	3	4	5	7
1975	0.25	0.15^{a}	0.12^{a}	0.11^{ac}	0.24^{a}	0.13^{a}
1974	0.09^{a}	0.44^{bc}	0.35^{b}	0.15^{b}	0.53^{ab}	0.12^{a}
1973	0.07^{a}	0.40^{b}	0.40^{b}	0.10^{ac}	0.34^{a}	0.13^{a}
1972	0.08^{a}	0.48^{c}	0.36^{b}	0.15^{b}	1.13^{cd}	0.17^{a}
1971	0.08^{a}	0.46^{bc}	0.37^{b}	0.13^{bc}	1.47^{c}	0.31^{a}
1970	0.10^{a}	0.43^{bc}	0.25^{c}	0.09^{ac}	0.57^{ab}	0.21^{a}
1969	0.09^{a}	0.39^{b}	0.27^{c}	0.08^{a}	1.05^{bcd}	0.23^{a}
1968	0.08^{a}	0.30^{d}	0.24^{c}	0.09^{ac}	0.57^{ab}	0.25^{a}
1967	0.08^{a}	0.25^{de}	0.16^{a}	0.09^{ac}	0.62^{abd}	0.22^{a}
1966	0.07^{a}	0.23^{de}	0.23^{c}	0.10^{ac}	0.47^{a}	0.21^{a}
1965	0.07^{a}	0.20^{ae}	0.24^{c}	0.27	0.83^{abcd}	0.23^{a}
Original soil	0.08^{a}	0.20^{ae}	0.23^{c}	0.33	0.55^{ab}	0.22^{a}

Table B3.—Cobalt concentrations (μg Co/g dry sediment) in sediment core sections taken from Lake Sangchris in September 1975 (see Fig. 1 for sampling sites). Values underlined by the same type of line do not differ significantly from each other, each row taken separately. Values followed by the same letter do not differ significantly from each other, each column taken separately. All values tested by Duncan's multiple range test used $P < 0.05$.

Approximate Year of Deposition	Station 1	2	3	4	5	7
1975	1.96^{a}	2.69^{ab}	3.16^{ab}	2.68^{ab}	0.92^{ab}	1.55^{a}
1974	1.49^{ab}	3.29^{a}	3.40^{a}	2.85^{a}	0.92^{ab}	1.38^{a}
1973	1.47^{ab}	3.03^{ab}	3.41^{a}	2.67^{ab}	0.91^{ab}	1.37^{a}
1972	1.25^{ab}	2.97^{abc}	3.05^{ab}	2.66^{bcd}	1.16^{ab}	1.85^{a}
1971	1.12^{b}	2.86^{abc}	3.07^{ab}	2.07^{bcd}	0.89^{ab}	1.85^{a}
1970	1.11^{b}	2.67^{abc}	3.15^{ab}	1.97^{cd}	0.85^{ab}	1.59^{a}
1969	0.78^{b}	2.70^{abc}	3.24^{a}	2.00^{cd}	0.99^{ab}	1.61^{a}
1968	0.92^{b}	2.54^{bc}	3.41^{a}	1.91^{cd}	0.84^{ab}	1.59^{a}
1967	1.13^{b}	2.19^{cd}	3.46^{a}	1.95^{cd}	0.79^{ab}	1.55^{a}
1966	0.91^{b}	1.47^{de}	2.41^{c}	2.14^{bcd}	0.67^{b}	1.48^{a}
1965	0.83^{b}	1.26^{e}	1.51^{d}	2.30^{abc}	0.79^{ab}	1.69^{a}
Original soil	0.76	1.14	1.66	1.51	0.84	1.31

Table B4.—Copper concentrations (μg Cu/g dry sediment) in sediment core sections taken from Lake Sangchris in September 1975 (see Fig. 1 for sampling sites). Values underlined by the same type of line do not differ significantly from each other, each row taken separately. Values followed by the same letter do not differ significantly from each other, each column taken separately. All values tested by Duncan's multiple range test used $P < 0.05$.

Approximate Year of Deposition	Station 1	2	3	4	5	7
1975	1.23^{a}	0.29	0.62^{a}	0.24^{ab}	0.99^{a}	0.58^{a}
1974	0.09^{a}	3.97^{ab}	3.45^{bce}	0.31^{a}	1.53^{a}	0.48^{a}
1973	0.09^{a}	3.83^{ab}	3.93^{ce}	0.19^{bc}	1.03^{a}	0.56^{a}
1972	0.08^{a}	5.11^{a}	3.29^{bc}	0.33^{a}	2.60^{b}	1.70^{ab}
1971	0.09^{a}	3.83^{ab}	3.19^{bc}	0.23^{ab}	2.51^{b}	3.67^{c}
1970	0.08^{a}	4.52^{ab}	2.63^{b}	0.07^{c}	1.05^{a}	2.85^{bc}
1969	0.09^{a}	4.20^{ab}	2.91^{b}	0.13^{bc}	1.85^{ab}	3.63^{c}
1968	0.08^{a}	3.61^{b}	3.00^{b}	0.11^{bc}	0.96^{a}	3.97^{c}
1967	0.08^{a}	3.99^{ab}	1.51^{a}	0.08^{c}	1.36^{a}	3.79^{c}
1966	0.07^{a}	4.21^{ab}	4.35^{de}	0.11^{bc}	0.98^{a}	3.53^{c}
1965	0.06^{a}	3.95^{ab}	4.95^{d}	3.79	1.24^{a}	3.36^{bc}
Original soil	0.09^{a}	3.81^{ab}	4.41^{de}	4.57	1.73^{ab}	3.68^{c}

Table B5.—Lead concentrations (μg Pb/g dry sediment) in sediment core sections taken from Lake Sangchris in September 1975 (see Fig. 1 for sampling sites). Values underlined by the same type of line do not differ significantly from each other, each row taken separately. Values followed by the same letter do not differ significantly from each other, each column taken separately. All values tested by Duncan's multiple range test used $P<0.05$.

Approximate Year of Deposition	Station 1	2	3	4	5	7
1975	1.80^{a}	0.79^{a}	0.95^{a}	0.70^{a}	0.62^{a}	1.08^{a}
1974	0.55^{a}	4.06^{a}	2.74^{abc}	0.79^{a}	0.89^{a}	1.09^{a}
1973	0.56^{a}	3.61^{a}	3.18^{bcd}	0.63^{a}	0.67^{a}	1.03^{a}
1972	0.57^{a}	4.65^{a}	2.52^{abc}	0.83^{a}	1.10^{a}	2.05^{ab}
1971	0.57^{a}	3.65^{a}	2.34^{abc}	0.61^{a}	1.23^{a}	1.45^{a}
1970	0.57^{a}	3.77^{a}	1.55^{ac}	0.56^{a}	0.78^{a}	3.05^{abc}
1969	0.58^{a}	3.79^{a}	1.70^{ac}	0.66^{a}	0.86^{a}	3.69^{bc}
1968	0.64^{a}	2.54^{a}	1.98^{ac}	0.53^{a}	0.75^{a}	4.10^{bc}
1967	0.59^{a}	3.45^{a}	1.28^{a}	0.55^{a}	0.93^{a}	4.62^{c}
1966	0.58^{a}	4.78^{a}	4.09^{bd}	0.49^{c}	0.97^{c}	4.39^{c}
1965	0.54^{a}	4.67^{a}	4.78^{d}	3.77	0.75^{a}	3.99^{bc}
Original soil	0.55^{a}	4.51^{a}	4.87^{d}	4.50	1.31^{a}	4.75^{c}

Table B6.—Mercury concentrations (μg Hg/g dry sediment) in sediment core sections taken from Lake Sangchris in September 1973 (see Fig. 1 for sampling sites). Values underlined by the same type of line do not differ significantly from each other, each row taken separately. Values followed by the same letter do not differ significantly from each other, each column taken separately. All values tested by Duncan's multiple range test used $P<0.05$.

Approximate Year of Deposition	Station 1	2	3	4	5	7
1973	0.043^{a}	0.054^{a}	0.053^{a}	0.054^{a}	0.017^{a}	0.037^{abcd}
1972	0.052^{a}	0.053^{a}	0.048^{a}	0.059^{a}	0.019^{a}	0.043^{abc}
1971	0.051^{a}	0.061^{a}	0.043^{a}	0.059^{a}	0.017^{a}	0.044^{abc}
1970	0.058^{a}	0.055^{a}	0.050^{a}	0.111^{a}	0.020^{a}	0.047^{a}
1969	0.072^{a}	0.058^{a}	0.050^{a}	0.094^{a}	0.015^{a}	0.040^{ab}
1968	0.067^{a}	0.050^{a}	0.051^{a}	0.041^{a}	0.045^{a}	0.041^{abc}
1967	0.063^{a}	0.053^{a}	0.036^{a}	0.029^{a}	0.041^{a}	0.044^{abcd}
1966	0.056^{a}	0.046^{a}	0.032^{a}	0.034^{a}	0.033^{a}	0.028^{bcd}
1965	0.051^{a}	0.040^{a}	0.029^{a}	0.022^{a}	0.033^{a}	0.040^{cd}
Original soil	0.037^{a}	0.020^{a}	0.030^{a}	0.035^{a}	0.027^{a}	0.021^{d}

Table B7.—Nickel concentrations (µg Ni/g dry sediment) in sediment core sections taken from Lake Sangchris in September 1975 (see Fig. 1 for sampling sites). Values underlined by the same type of line do not differ significantly from each other, each row taken separately. Values followed by the same letter do not differ significantly from each other, each column taken separately. All values tested by Duncan's multiple range test used $P < 0.05$.

Approximate Year of Deposition	Station 1	2	3	4	5	7
1975	4.23	5.34^{ab}	6.68^{a}	6.03^{a}	2.27^{ab}	2.78^{abcd}
1974	3.27	7.48	8.11	7.30	2.40^{ab}	2.60^{acde}
1973	3.24^{a}	7.01	7.78^{b}	6.57^{b}	3.36^{ab}	2.59^{acde}
1972	2.65	6.53	6.46^{ac}	6.38^{ab}	3.36	3.56^{b}
1971	1.99^{b}	5.66^{a}	6.23^{c}	5.03	2.59^{ab}	3.42^{ab}
1970	1.93^{bc}	5.26^{ab}	5.61^{d}	4.16^{c}	2.22^{b}	3.16^{ab}
1969	1.42^{bcd}	4.96^{bc}	5.40^{de}	4.06^{c}	2.71^{a}	3.17^{ab}
1968	1.45^{bcd}	4.62^{c}	5.39^{de}	3.39^{a}	2.20^{b}	3.07^{abc}
1967	1.66^{bcd}	3.97	5.03^{e}	3.18^{d}	2.25^{ab}	2.17^{de}
1966	1.31^{cd}	2.82^{d}	3.82	3.02^{d}	1.68^{c}	2.02^{de}
1965	1.24^{bd}	2.45^{de}	2.87^{f}	3.27^{d}	2.37^{ab}	2.26^{cde}
Original soil	1.05^{bd}	2.18^{e}	2.93^{f}	2.47	1.55^{c}	1.84^{e}

Table B8.—Zinc concentrations (µg Zn/g dry sediment) in sediment core sections taken from Lake Sangchris in September 1975 (see Fig. 1 for sampling sites). Values underlined by the same type of line do not differ significantly from each other, each row taken separately. Values followed by the same letter do not differ significantly from each other, each column taken separately. All values tested by Duncan's multiple range test used $P < 0.05$.

Approximate Year of Deposition	Station 1	2	3	4	5	7
1975	11.0^{a}	12.0^{af}	16.6	19.1^{a}	14.0^{a}	5.41^{a}
1974	7.65^{ab}	20.4^{b}	23.9^{a}	27.9^{bd}	16.9^{ab}	5.33^{a}
1973	7.80^{ab}	20.4^{b}	26.7^{bc}	28.9^{bd}	14.2^{a}	5.33^{a}
1972	7.90^{ab}	23.5^{cd}	24.7^{ab}	35.5^{c}	16.5^{ab}	10.6^{b}
1971	7.30^{b}	23.8^{cde}	27.4^{c}	30.9^{d}	19.6^{b}	10.5^{b}
1970	5.70^{bc}	26.4^{e}	28.3^{c}	24.1^{e}	12.7^{ac}	11.1^{b}
1969	4.59^{bcd}	24.6^{de}	27.7^{c}	38.3^{c}	13.6^{ac}	11.8^{b}
1968	2.87^{cde}	21.4^{bc}	27.9^{c}	20.1^{bd}	12.8^{ac}	12.0^{b}
1967	2.48^{cde}	16.7	23.1^{a}	26.4^{be}	13.5^{ac}	10.7^{b}
1966	1.60^{de}	12.9^{a}	13.7	22.9^{ae}	9.20^{c}	10.3^{b}
1965	0.99^{e}	9.93^{fg}	9.07^{d}	19.7^{a}	13.7^{ac}	11.3^{b}
Original soil	0.43^{e}	8.27^{g}	7.53^{d}	7.63	12.8^{ac}	8.80^{b}

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