

## HIGHLIGHTS IN THE HISTORY OF ENTOMOLOGY IN HAWAII 1778-1963

By C. E. Pemberton

HONORARY ASSOCIATE IN ENTOMOLOGY

BERNICE P. BISHOP MUSEUM

PRINCIPAL ENTOMOLOGIST (RETIRED)

EXPERIMENT STATION, HAWAIIAN SUGAR PLANTERS' ASSOCIATION

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#### INTRODUCTION

The following brief history of entomology in Hawaii is designed to place on record for ready reference purposes a narrative of the major immigrant insect pests in the Islands, the principal literature bearing on both the invading and native species and the extensive accomplishments in the fields of biological control of both insect pests and noxious plants. The history of plant quarantine is also of interest as it developed through the years.

Perhaps nowhere in the world has entomological science been given closer attention than in Hawaii. With a semi-tropical climate in the lowlands, a rich endemic flora and insect fauna, and great geographic isolation, the islands have offered a unique area for investigations by taxonomists and students concerned with the evolution and origin of the insect fauna. Great changes have occurred in the floral components of the lowlands below about 600 meters elevation. Vast plantations and the extensive development of cities, roads and housing sites during the past 75 years, have mostly obliterated the native flora in such regions with devastating effect and have even led to the extinction of some previously collected and described native insects. Beneficial insects imported for the control of invading pests and also the pressure of competing forms have also taken a toll of some native species. Even the mountain flora is undergoing an increasing change with the expansion of foreign tree planting for forest improvement, watershed protection, and the development of exotic trees for commercial timber uses. Introduced cattle, sheep, goats and various animals for sport hunting, have played havoc with much native vegetation. The endemic insect fauna has suffered heavily through the impact of such forces. For these reasons the extensive collecting and taxonomic work on the insect fauna and the comprehensive and successful achievements in the biological control of invading insect pests, offer information of definite historical and practical value, which for the convenience of future entomologists, would prove useful if documented in a single publication.

In this text it will be necessary to mention many individuals in connection with certain work undertaken. The present history however, is not a biography of entomologists, but rather an account of the insects of Hawaii. Consequently the names of many entomologists in the Islands are omitted and especially the younger ones who have come into the field in recent years.

## EARLY REFERENCES TO HAWAIIAN INSECTS

In E. C. Zimmerman's Introduction to "Insects of Hawaii" (1), he mentions a total of 3722 known endemic Hawaiian insects. Many more have since been found, especially owing to the work of D. E. Hardy on some of the Diptera. Thus there were at least from four to five thousand species in the Islands when the original Hawaiians first arrived. Having no written language at that time, there is no record of the particular species they encountered prior to the coming of Europeans. There is clear evidence, however, that fleas and head lice were of long residence in Hawaii, and undoubtedly came with the early Polynesian voyagers. This is suggested in their language by words for flea "Ukulele" and head louse "Uku-po'o." The fleas evidently came with dogs, and lice on the human heads. The presence of head lice is attested to in a report by C. S. Stewart (2) in 1828, in which he discussed in some detail the presence of head lice among the inhabitants, and their delousing efforts.

The first European observation of insects in Hawaii and recorded in writing was by William Ellis (3), who was assistant ship's surgeon on Captain Cook's ship when it reached Hawaii in 1778. He referred to hordes of flies bothering the natives. With no descriptions of the flies, it may be assumed that they were house flies and possibly other species.

Between 1815 and 1818, the Russian explorer Otto Von Kotzebue visited Hawaii. His physician and ship's surgeon Dr J. F. Eschscholtz collected a number of insects and published his findings in Berlin in 1821-22 (4). In this publication he mentions collecting the Oriental burrowing roach *Pycnoscelus surinamensis* (Linnaeus), which he named *Blatta punctata*. This is the first record of this roach in Hawaii. That other species of Blattidae invaded Hawaii at an early date is suggested in a publication by James Montgomery (5), who stated that upon arrival in Hawaii in 1822, his boat was swarming with cockroaches, though he did not mention the species or their characteristics. These were undoubtedly transported ashore with the ship's stores and other materials. In Eschscholtz's publication, the Kamehameha butterfly *Vanessa tameamea* Esch. is also recorded for the first time and described by him from specimens collected in the Islands.

The four species of mosquitoes in Hawaii are all invaders from other countries. The first record of a mosquito in Hawaii was given in 1826 by the Reverend William Richards, in charge of the mission station at Lahaina, Maui. As recorded by Van Dine (6), Richards reported that during 1826 the vessel "Wellington", from San Blas, Mexico, anchored at Lahaina and some time after its arrival the natives complained of an insect that sung in their ears at night. His investigations verified the presence of quantities of a night-flying mosquito. The natives had no previous name for such an insect, which suggested that it was new to the country. From then on the natives called it "Makika." This was undoubtedly our night-flying mosquito *Culex quinquefasciatus* Say, which must have emerged from fresh water casks aboard ship and spread over the Lahaina area. It is probable that other sailing vessels during this early period, also brought in this mosquito in the same manner. The entomologist Osten Sacken (7) has quoted remarks made to him by T. R. Peale, entomologist, who said that an old ship from Mazatlan, Mexico, was abandoned on the coast of one of the Hawaiian Islands in 1828, following which, night-biting mosquitoes became a nuisance in the area. Peale also told him that back in 1823 there were no mosquitoes in Hawaii to his knowledge.

During the 50 year period 1826 to 1876, there was a gradual increase in the Islands of

people immigrating from various countries. A fair number of insects were collected by some of these people and deposited in European museums, where they were described or referred to in entomological publications. No attempt will be made to list these. The systematic collection and study of Hawaiian insects on a large scale began in 1876 by an entomologist, the Reverend Thomas Blackburn. Though his obligations to the church occupied most of his time, he still found opportunity to collect insects on all of the main islands and at various elevations, giving particular attention to the endemic Coleoptera.

The Reverend Blackburn remained in Hawaii for six years. Upon returning to England, he collaborated with Dr David Sharp, noted English entomologist, in publishing a treatise on his collection of Coleoptera (8). This memoir included descriptions of many new species and genera of Hawaiian beetles, with 50 excellent illustrations, and a systematic catalog of the habits and habitats of each species. It covers 428 species of Coleoptera, representing 150 genera, of which 82 % were endemic. Blackburn collected many other insects which were described and discussed in various scientific journals by other specialists. He concluded that he had collected less than half of the Hawaiian Coleoptera present at that time. He can be justly called the "Father of Hawaiian Entomology."

Blackburn's pioneering work led to the systematic exploration of the Hawaiian insect fauna for ten years by R. C. L. Perkins, which began in 1892 and culminated in the publication of the "Fauna Hawaiiensis." Dr Perkins, an Oxford graduate, was engaged by a joint committee of the British Association for the Advancement of Science and the Royal Society of London, in collaboration with the Bishop Museum of Honolulu. It is estimated that Perkins collected over 100,000 specimens, most of which were sent to England for study.

The "Fauna Hawaiiensis" was published between 1899 and 1913 by the Cambridge University Press under the auspices of the above joint committee. It consisted of three elaborately illustrated volumes, comprising about 2,000 folio pages of descriptive matter, dealing mostly with the insects collected by Perkins. A large share of this work was undertaken by Perkins in collaboration with some 22 other specialists. According to Perkins, about 3,325 species of insects were described or catalogued in the Fauna, 82 % of which were endemic. His Introduction covers 220 pages of fascinating discussion on the habits and plant hosts of the phytophagous species, plus groups falling in other categories. He expressed particular concern over the disastrous effects on the native biota following the removal of lowland forests by man, with his grazing animals as a contributing factor, and the predation on the endemic insects by invading foreign insects, particularly the ant *Pheidole megacephala* (Fabr.). In his opinion many endemic insects became extinct due to this ant, especially the Coleoptera.

#### OTHER SOURCES OF INFORMATION ON HAWAIIAN ENTOMOLOGY

The *Planters' Monthly*, financed by the Hawaiian sugar planters and published regularly from 1882 to 1909, contains scattered records of historical interest for the period and especially between 1904 and 1909 when Perkins and Albert Koebele contributed a number of important items.

The Hawaii Agricultural Experiment Station of the Office of Experiment Stations, U. S. Department of Agriculture, was organized on a working basis by 30 June 1902. D. L. Van

Dine became the first entomologist. He was appointed in 1902 and remained until March 1909, to be followed by D. T. Fullaway, who held the office until 1913. During the period 1902-1913, Van Dine and Fullaway published many papers and bulletins on economic entomology in Hawaii, which appeared in *Bulletins and Annual Reports* by the Experiment Station. Following the transfer of Dr Fullaway in 1913 from the Experiment Station to the Hawaii Board of Agriculture and Forestry, no other entomologists were listed on the Experiment Station staff until 1938, after which the staff was slowly increased until at present a large staff of capable entomologists are actively contributing in many fields. It is of interest that the Experiment Station did not come under the joint supervision of the Federal Office of Experiment Stations and the University of Hawaii until about 1931.

The "Hawaiian Forester and Agriculturist", published monthly by the Board of Agriculture and Forestry from 1904 to 1925, quarterly thereafter until 1932, contains much information relative to economic insects in the Islands during that period, contributed mostly by entomologists of the Board.

In 1906, Van Dine (9) published "A Partial Bibliography of Hawaiian Entomology", containing 84 references to systematic papers and 69 to economic entomology up to 1905. This is an exceedingly useful paper in tracing the early history of many of the insects in Hawaii at that time.

The Hawaiian Entomological Society had its inception at a meeting of a small group of local entomologists on 15 December 1904. The first regular meeting of the Society was held 26 January 1905. Monthly meetings have been held to the present date and the membership has grown from 14 original members to over 120 at present. The minutes and papers presented at each meeting have always been carefully edited and published annually as "The Proceedings of the Hawaiian Entomological Society." This publication is now in its 18th volume and comprises, in all, several thousand pages of invaluable reference material. It is a storehouse of facts—both economic and taxonomic—on Hawaiian insects. The Society has come of age and the printed Proceedings are rated amongst the best of the entomological periodicals of the world. Dr L. O. Howard, former Chief of the U. S. Bureau of Entomology and Plant Quarantine, published a History of Applied Entomology in 1930. On page 411 appears the following statement: "An Entomological Society of Hawaii was founded in 1905 and it has published its Proceedings, which in many ways are the most interesting records of any entomological society in the world." The printing of the Proceedings has largely been made possible through financial aid from the Hawaiian Sugar Planters' Association, which continues to the present date.

On 21 April 1904, the Hawaiian Sugar Planters' Association established a Department of Entomology at their Experiment Station and secured the services of four capable entomologists and two consultants. These and others succeeding them have published 22 bulletins, 7 circulars and many papers in the *Hawaiian Planters' Record* between 1909 and 1950. These are both taxonomic and economic, with special reference to sugar cane insects.

Jacob Kotinsky (10), then Assistant Entomologist of the Hawaii Board of Agriculture and Forestry, published in 1906 a "History of Economic Entomology in Hawaii", which, though brief, contains much of historical interest.

One of the best historical records to Hawaiian entomology was published by J. F. Illingworth (11), Research Associate in Entomology of the Bishop Museum. This 63 page bulletin contains 224 references to publications on Hawaiian entomology, which were printed

between 1782 and 1906.

In 1928, the Hawaii Board of Agriculture and Forestry began printing Biennial Reports on the activities of its several departments. These continued through 1958, followed by Annual Reports to date. The entomological sections give precise and extensive data on the many beneficial insects imported into Hawaii by the Board's entomologists, together with much information on the work conducted by them on the economic pests in the Islands. The reports give the dates of beneficial insect importations, their origin, hosts and the species concerned. This information is of particular value for historical and other uses.

In 1925, O. H. Swezey (12) published a record of the many beneficial insect imported into Hawaii. It presents a long list of introductions between 1890 and 1924, giving the names, places of origin and hosts of each insect. Much data is included covering introductions which apparently failed to become established.

Of particular value to sugar planters in Hawaii and other countries, is a compilation by Francis X. Williams (13), Associate Entomologist of the HSPA Experiment Station. This 400 page book was published by the Hawaiian Sugar Planters' Association in 1931. With 190 clear illustrations, it offers an excellent account of not only the insects that attack sugar cane in Hawaii and their natural enemies, but also of a large number of other insects commonly found in Hawaii's cane fields.

An important reference book on Hawaiian insects by D. T. Fullaway and N. L. H. Krauss (14), entomologists of the Hawaii Board of Agriculture and Forestry, was published in 1945. This 228-page book deals with 335 common insects in Hawaii and 22 insect relatives, and is illustrated with 12 colored plates showing each of the insects discussed, as well as 16 figures of most of the insect relatives mentioned. The habits of each species are given, together with much information on the origin and early records in Hawaii of most of them.

A history of the Entomology Department of the HSPA Experiment Station from its inception in 1904 to 1945, was published by C. E. Pemberton (15). This account describes the insect pests of sugar cane in Hawaii, their history in the Islands and the procedures conducted for their control.

An ambitious project conceived in 1934 under the heading "Insects of Hawaii", was planned by Dr E. C. Zimmerman to constitute a manual of every known insect in the Hawaiian Islands, with notes on their origin, distribution, hosts, natural enemies and keys for identification. Through the joint financing by the Hawaiian Sugar Planters' Association and the University of Hawaii and sponsored by the Bernice P. Bishop Museum, the HSPA and the University of Hawaii, the first five volumes were published by the University of Hawaii Press in 1948. At this time Zimmerman was Associate Entomologist of the HSPA Experiment Station and Curator of Entomology at the Bishop Museum. Ensuing volumes have been made possible through financing by the National Science Foundation, and to date a total of ten volumes have been published by the University of Hawaii Press. These printed volumes form a remarkable and easily consulted reference work on the orders treated. Volumes are yet to be prepared dealing with the Coleoptera, Hymenoptera and Siphonaptera. The Lepidoptera and the Diptera are not quite completed.

Under the caption "Literature Consulted", the above volumes list hundreds of references to Hawaiian entomology. These offer a wide source of published information and will not be included in the present history.

An outstanding contribution on the insects associated with the flora of Hawaiian forests was published by O. H. Swezey (16) in 1954. During 1904-1933, while serving on the entomological staff of the HSPA Experiment Station and for many years thereafter as Consulting Entomologist, Dr Swezey spent a great deal of his spare time in Hawaiian forests investigating the insect fauna of their various floral components. This publication is rich in information on both the forest insects and the plants on which they occur.

In 1947, a committee of entomologists, then called the Insect Control Committee for the Pacific, under the newly formed Pacific Science Board of the National Academy of Sciences, met to formulate plans for exploration and study of the insects in the widely scattered Pacific islands known as Micronesia, and also to consider necessary action for the biological control of many serious economic insect pests within the area. A project under the heading "Insects of Micronesia" was thus born. Under direction of the Committee many entomologists made extensive insect collections amongst the islands by 1953, when the Bishop Museum took over the project. The work has been under the direction of J. Linsley Gressitt since 1951. These collections, together with others previously made, constitute an imposing array of material, upon which there has been printed by the Bishop Museum since 1954, a long series of papers by specialists in the various groups. This work continues and is important to Hawaii because of its geographic position in the Pacific.

In 1898, the Bishop Museum began a series of publications called "Occasional Papers", which have continued to date. Many of these papers deal with entomology. In 1922 the Museum began publishing Bulletins, a good number of which have appeared covering various entomological subjects.

In 1959, the Bishop Museum commenced the publication of a journal entitled "Pacific Insects", with Dr Gressitt as Editor. It is described as the organ of the program "Zoogeography and evolution of Pacific insects." Several volumes have appeared, as well as several "Pacific Insects Monographs" written by various specialists on different groups of insects. The data in these volumes have direct bearing on Hawaiian entomology. Much interest is given on the history of some economic Diptera in Hawaii by Hardy (17).

#### IMPORTANT IMMIGRANT INSECT PESTS AND BIOLOGICAL CONTROL

In 1948, Zimmerman (1) estimated the total number of insect species in Hawaii as close to 6,000, with about 3,722 being endemic. Since a few hundred more have since been added to the endemic list, we can assume that the adventive species, including harmful, beneficial and indifferent species now number well over 2,000. Many of the harmful species are only of moderate importance to our economy. Fullaway and Krauss (14) list about 211 species which are undesirable immigrants, many of which are pests of importance. By 1961, many additional immigrant insects have appeared in the Islands, of which about 85 can be placed in the category of pests; some potentially and some definitely so. From these records it is concluded that of the many adventive insects in Hawaii today, at least 296 lie within the status of pests. The following discussion will be confined only to those pests which have been of special concern to the State. In many cases, strenuous efforts have been made towards the control of these pests, often with success. As far as possible, species will be treated chronologically, rather than by family or host.

**Culex quinquefasciatus** Say

As previously mentioned, this mosquito apparently reached the Islands in 1826 on a vessel from Mexico. It was the first and one of the most serious insect pests to come to Hawaii. It spread to all the main islands and swarms of this night-biting species occurred wherever stagnant ground water was present. In 1900, Dr L. O. Howard (18) mentioned the importance of fresh water fish as predators of mosquito larvae and pupae. In 1902, Van Dine (19), who was appointed entomologist for the Hawaiian Agricultural Experiment Station in June 1902, considered the feasibility of introducing so-called top minnows into Hawaii. His influence resulted in the organization of a Citizens Mosquito Campaign Committee in Honolulu in 1904. Van Dine then personally discussed the problem with Dr David Starr Jordan of Stanford University, who was a noted authority on fishes of the world. Dr Jordan recommended the introduction of certain top minnows from Texas. He also recommended that Alvin Seale, Assistant to the U. S. Fish Commission, be hired for the work. The Citizens Mosquito Campaign Committee induced the Territorial Legislature to appropriate \$1,500 for the project. Seale went to Galveston, Texas, to obtain the fish and on 15 September 1905, arrived on the S. S. Alameda with a good supply of the little top minnow *Gambusia affinis* (Baird & Girard). These were liberated in fresh water at Moanalua, Oahu. They multiplied rapidly and stocks were distributed wherever needed. This fish greatly reduced the mosquito nuisance in many areas where stagnant water was more or less permanent and continue to do so. Temporary pools to which the fish cannot gravitate still present problems in control of this mosquito.

**Pheidole megacephala** (Fabricius)

This ubiquitous, tropicopolitan ant is an important immigrant pest. It is a household nuisance and a devastating predator on endemic insects, many of which have undoubtedly been exterminated by it according to Perkins. It also contributes largely to the development of many Coccidae and Aphididae. However, it is useful as a predator on both the house fly and fruit flies. It was in the Islands several years prior to 1879, when Frederick Smith (20) identified it from material collected by Blackburn, as *Pheidole pusilla* Heer. Blackburn (21) stated that it was one of the most common ants on Oahu and elsewhere at the time he was in Hawaii.

**Cryptotermes brevis** (Walker)

Because of its destructiveness to dry wood of buildings and their contents, this termite is one of the most serious insect pests in Hawaii. Costs to the householder have been heavy in efforts to eradicate the pest or check damage done by it. Expensive fumigation of buildings by termite exterminators is today the most effective method of control. The date of its arrival in Hawaii is not clearly documented. Zimmerman (22) expresses the opinion that it came to Hawaii prior to 1869. In 1883, Robert McLachlan (23) discusses this termite under the erroneous name *Calotermes marginipennis* Latr., as being abundant and destructive to wooden buildings in Honolulu. This could only have been *C. brevis*, which must have arrived in Honolulu many years previous to 1883. It was not until about 1917 that entomologists discovered that the head of the soldier of *C. brevis* differed from that of the lowland dead tree termite *Kalotermes immigrans* Snyder, with which it was confused. A few years later D. T. Fullaway sent specimens of *brevis* to Dr Thomas E.



Snyder, who pronounced the species *Cryptotermes brevis*, and finally established its correct identity. At that time (1920), its known distribution was given by Snyder as South and Central America, the West Indies and Key West, Florida.

#### **Rhabdoscelus obscurus** (Boisduval)

This weevil, commonly known as the sugar cane beetle borer, has been a pest of first importance in Hawaii. Its recorded history began when Dumont d'Urville collected it on New Ireland in 1827 during the voyage of the corvette *Astrolabe*. The corvette returned to Marseilles on 25 March 1829, and cases of scientific material collected during the voyage were deposited in the Museum in Paris. Buck (24) has published an account of this voyage. Specimens of the weevil were evidently included in the donation to the Museum and described in 1835 by Boisduval (25) under the name *Calandra obscura*. In 1849, Fairmaire (26) discussed this species as found by M. Vesco in Tahiti. The beetle probably came to Hawaii in 1854, when Captain Edwards of the American whaleship *George Washington* brought a bundle of choice sugar cane from Tahiti and gave it to Consul Chase of Lahaina, Maui, who planted it in his garden and later distributed cuttings to others. It came to be known as the variety Lahaina. The Honorable D. D. Baldwin (27) reported that cane in the Lahaina area was damaged by this weevil as early as 1865. This cane was ultimately distributed throughout Hawaii. The borer undoubtedly accompanied this distribution.

Though now widespread in the Pacific where it attacks both sugar cane and palms, this borer is considered native to New Guinea and adjacent islands. Pemberton found it in split or broken sugar palm fronds in North Celebes and scanty evidence of it in sugar cane. This may not be within the range of its nativity. Curiously, it has not been recorded in Java, the Philippines or further west in Southeast Asia.

Work on the biological control of this pest began in 1907, when Frederick Muir began a long search for natural enemies of this or related borers occurring from the Malay Peninsula to New Guinea. This culminated in the discovery of the tachinid parasite *Microceromasia sphenophori* Vill., which was first found developing in the beetle larvae in sago palms in Amboina, and later in sugar cane in New Guinea. Through great difficulties, this parasite was finally brought to Hawaii from New Guinea on 16 August 1910, reared in the laboratory, and established in Hawaiian cane fields. Muir and Swezey (28) have published a complete account of this classic investigation. The parasite brought about a material reduction in borer damage to the cane. Muir, and later Pemberton, introduced a number of predators found attacking larvae of related borers in the Malay Archipelago, but they failed to become established. Research on this project by F. A. Bianchi continues. During 1963 he succeeded in the introduction of the mymarid egg parasite *Patasson calandrae* (Gahan), which, on the U. S. Mainland, develops in the eggs of certain pill bugs. Laboratory tests in Honolulu indicated that this parasite can develop in the eggs of *R. obscurus*. Many have been reared and liberated in cane fields. Results are yet to be determined. Bianchi has also made an extensive survey of *R. obscurus* in the Trust Territory of the Pacific Islands, where it commonly occurs on sugar cane and coconut palms. No promising parasites or predators were discovered, though further study is needed.

#### **Spodoptera exempta** (Walker)

This armyworm invaded Hawaii some time prior to 1873. Chamberlin (29) described

the denudation of pasture grass on the central plain of Oahu during that year which was so extensive that cattle died of starvation. His description of the moth egg-masses establishes without question the identity of the species. The first entomological record of the species in Hawaii is by Arthur G. Butler (30), in which he lists it under the name *Prodenia ingloria* Walker and stated that it was probably collected by Blackburn. Through the years it has been a periodic and prominent defoliator of young sugar cane and pasture grasses. Until 1938 it was erroneously named *Spodoptera mauritia* (Boisd.) until Swezey (31) pronounced it *Laphygma exempta* (Walker). Finally in 1958, under a new combination, Zimmerman (32) restored the genus to *Spodoptera* and it now stands as *S. exempta*.

Much work has been conducted on the biological control of this moth. The first record of a larval parasite in Hawaii was by Perkins (33) in 1892. This is the large, gray tachinid *Chaetogaedia monticola* (Bigot). It is not known how or when it reached Hawaii from the western U. S. Mainland, where it parasitizes a number of lepidopterous caterpillars. The second parasite observed was *Trichogramma minutum* Riley, which Koebele (34) first reared from the moth eggs in 1900. It also probably came from the Mainland as an immigrant. The first intentionally introduced parasite was the ichneumonid *Pseudamblyteles koebelei* (Swezey), which Koebele obtained in California about 1899. This internal, larval parasite became well established but has never been abundant. About 1898 or 1899 Koebele is believed to have introduced the tachinid larval parasite *Achaetoneura (Frontina) archippivora* (Williston) from California. It is widespread in the Islands, has a number of lepidopterous hosts and has been useful in checking *S. exempta*. Eggs are laid on the surface of the caterpillars, and upon hatching the maggots penetrate the body.

In April 1923, Herbert Osborn, Assistant Entomologist at the HSPA Experiment Station, introduced the eulophid *Euplectrus platyhypenae* Ashmd. into Hawaii from Mexico. Its larvae develop in mass on the surface of the caterpillar. It became well established and played a definite part in further checking the armyworm (35). In February 1924, Osborn introduced from Mexico the large, blackish and gray tachinid *Archytas cirphis* Curran. From the few fly puparia he sent, nine adults emerged and were liberated in Honolulu (36). From these few the parasite multiplied rapidly and spread throughout the Islands with good results. This parasite has the interesting habit of depositing its maggots on leaves where armyworms are feeding and from there they move to and penetrate the caterpillar's body. In September 1923, Osborn also shipped from Mexico a consignment of the large carabid beetle *Calosoma blaptoides* Putz subspecies *tehuacanum* (Lapouge). He found this beetle feeding on armyworms and other caterpillars at Cuernavaca. Thirty adults were liberated on pasture land on the island of Hawaii. It is of interest that this beetle was not seen again until 24 years later, when it appeared in abundance in the original area of liberation at a time when there was an outbreak of armyworms (37).

In 1925 the ichneumonid parasite *Hyposoter exiguae* (Vier.) appeared in the Islands. It was not intentionally introduced but could have come from California where it is known. It was found to parasitize a number of lepidopterous hosts but particularly *S. exempta*. Its larvae develop internally in the caterpillars. Then in 1926 the scelionid egg parasite *Telenomus nawai* Ashm. was found heavily parasitizing the eggs of this armyworm in Honolulu. It was spread rapidly over Hawaii by HSPA entomologists and added still more to the complex of natural enemies of the armyworm. In Fiji, whence it probably came to Hawaii (38), it parasitizes the eggs of *Prodenia litura* (Fabr.).

Though the above parasites effected a considerable control of *S. exempta*, moderate but disturbing outbreaks continued to occur in the cane fields from time to time and attention was turned to the American armyworm *Laphygma frugiperda* (S. & A.). R. A. Vickery (39) had reported a number of parasites of this armyworm at Brownsville, Texas. F. A. Bianchi, then Assistant Entomologist of the HSPA Experiment Station, was sent to Brownsville in 1942 to investigate these parasites. He succeeded in introducing several to Hawaii, four of which became established in the cane fields and two species proved to be of great importance. These were the braconid larval parasites *Apanteles marginiventris* (Cresson) and *Meteorus laphygmae* Vierick. During the same year a sarcophagid fly, only recently identified by Dr C. R. Joyce as *Helicobia morionella* (Aldrich), was observed heavily parasitizing both the armyworms and certain other lepidopterous larvae in Hawaii. It is not known how it came to Hawaii but it proved of great value as an enemy of the armyworm. After 1942, the combination of the several parasites above mentioned, particularly the last three, have effected a remarkable control of this armyworm which has not reappeared in quantity anywhere in the Islands.

#### **Icerya purchasi** Maskell

The notorious cottony-cushion scale first appeared in California on a species of *Acacia* imported from Australia about 1869. It was recognized as a serious pest in California by 1872 and was known in Hawaii by 1894, probably coming from California on one or more imported plants some years previously.

It was during 1888 that Koebele introduced the famous coccinellid *Rodolia cardinalis* (Mulsant) into California from Australia with astonishing benefit, especially to the citrus growers. Koebele then introduced it into Hawaii in 1890 followed by remarkable control which persists to the present date. The first published record of this introduction into Hawaii was by Perkins (40), and in a later paper (41) he states that the introduction from California was by Koebele. This is the first beneficial insect purposely introduced into Hawaii.

#### **Adoretus sinicus** Burmeister

The first recorded reference to this ubiquitous beetle in Hawaii was by C. V. Riley and L. O. Howard (42). They reported that the Honorable I. Marsden, Commissioner of Agriculture and Forestry of Hawaii, had sent them specimens of the insect in 1893, with the statement that it was "rapidly becoming a most serious pest and was first noticed about two years previously." This would date the first appearance of the beetle in Hawaii at about 1891. Riley and Howard identified it at that time as *Adoretus umbrosus* L. For many years thereafter it was considered to be *Adoretus tenuimaculatus* Waterh., a species known in Japan and China. For this reason it was commonly called the Japanese Beetle in Hawaii. However, in 1912, F. Ohaus (43) clarified its identity and pronounced it *Adoretus sinicus* Bur., a species known in China, Java and Formosa. In Hawaii it is now called the Chinese rose beetle. It probably came to Hawaii in the larval stage in soil with imported plants from the Orient.

Because of the heavy defoliation of many economic and ornamental plants by the adult, much attention has been given towards its control by parasites. During 1915-16, F. Muir, F. X. Williams and H. T. Osborn introduced two scoliid parasites from the Philippines

for control of *Anomala orientalis* (Waterhouse). These were *Campsomeris marginella modesta* Sm. and *Tiphia segregata* Crawford. They became established on *Anomala* grubs and in time were also found to parasitize the *Adoretus* grubs. Control by these parasites has been only lightly effective. It is of interest that the *Tiphia* became established from the liberation of six females and a few males, which emerged from cocoons sent to Honolulu from the Philippines by Dr Williams in April 1917, and released on Oahu; but it was not until August 1934, that it was recovered in the field after which it appeared over much of Oahu.

A number of other *Adoretus* parasites are known in Formosa, Japan and the Philippines. Special efforts have been made to establish these in Hawaii but all have failed. Work on this project was undertaken by Muir, Williams, Osborn, F. C. Hadden and R. H. Van Zwaluwenburg. The most comprehensive attempt was made by Hadden in 1931-32, when he shipped to Hawaii about 24,000 parasitized *Adoretus* grubs from the Philippines consisting mostly of the scoliid *Tiphia lucida* Cwfd. From this material a large number of adult *Tiphia* was reared and liberated, but without establishment.

#### **Peregrinus maidis** (Ashmead)

The corn leafhopper is a destructive pest of maize in Hawaii, not only because of the wilting effect on the plant through mass feeding, but also through its agency as a vector of a serious disease known as corn mosaic. In July 1888, W. H. Ashmead (44) observed it on maize and grasses in his garden in Florida and described it under the name *Delphax maidis*, stating that it was new to the country. It is widely distributed in the tropics, but how or when it came to Hawaii is not known. G. W. Kirkaldy (45) stated that Perkins obtained a single specimen in Hawaii in 1892. Zimmerman (46) states "that there is reason to believe that the species was established in the Islands about 1880." In 1904, Van Dine (47) reported that some of the sugar planters had informed him that they had known of the corn leafhopper in Hawaii for the past 15 or 20 years.

When the egg-feeding mirid bug *Tytthus mundulus* (Bredd.) was introduced into Hawaii in 1920 from Australia and Fiji for control of the sugar cane leafhopper *Perkinsiella saccharicida* Kirk., it became well established in the cane fields and was also found feeding on the eggs of the corn leafhopper some years later. Another enemy of the sugar cane leafhopper introduced into Hawaii from Australia in 1904 by Koebele and Perkins, develops readily in the eggs of the corn leafhopper. This is the minute mymarid *Anagrus frequens* Perkins. It seems to prefer the latter. Another mirid bug *Cyrtorhinus lividipennis* Reuter, which feeds on the eggs of this leafhopper, was introduced from Guam in 1939 and in 1952 by the Board of Agriculture and Forestry. Board entomologists reported it well established by 1959.

#### **Hedylepta blackburni** (Butler)

The coconut leafroller is perhaps the only endemic insect that is an important insect pest in the Hawaiian Islands. On the windward sides of the Islands the coconut fronds are sometimes almost completely defoliated. But they recover, following the development of some 13 different parasites. The most efficient of these is the ichneumonid larval parasite *Trathala flavo-orbitalis* (Cameron), which at times will parasitize the majority of the moth larvae. It is not known how this parasite reached Hawaii. It was first noticed in 1910.

Damage by the leafroller was even conspicuous on the leeward sides of the Islands until this parasite became widespread; but by 1921 and thereafter, damage was greatly diminished. The parasite is widely distributed through the Oriental and Australian regions and was introduced into the United States from Japan in 1932 for control of the European corn borer *Ostrinia nubilalis* (Hubner).

#### ***Aedes albopictus* (Skuse)**

This day-biting mosquito whose larvae develop particularly in small containers of fresh water such as tin cans, old auto tires, tree holes, large leaf axils, roof gutters, etc., has long been a public nuisance in Hawaii. It has been especially abundant in wet forest areas, and has been credited as a vector of dengue fever, which has appeared in Hawaii several times since 1903. It occurs in many parts of the Pacific, the Orient and Africa, but was not noticed in Hawaii by Perkins when he first began collecting in the forests in 1892. He states in his Introduction to the "Fauna Hawaiiensis" that it did not come to his attention during the earlier days of his collecting, inferring that it appeared a few years later. The species is cosmopolitan within the tropics.

#### ***Aedes aegypti* (Linnaeus)**

Like *A. albopictus*, this mosquito has similar breeding habits, but is inclined to be more closely associated with human habitations. In Perkin's reference to the two species it can be concluded that *aegypti* was the first to appear in Hawaii and probably predates the former by at least a few years. Being a known vector of both yellow fever and dengue fever, it is recognized as a dangerous member of our insect fauna. It is widespread in the tropical and sub-tropical parts of the world.

A few attempts have been made to control the two species of *Aedes* in Hawaii through the introduction of predatory mosquitoes of the genus *Toxorhynchites*. The adults are incapable of biting, but their larvae are predatory on larvae of other mosquitoes occurring in water containers above ground. *T. inornatus* (Walker) was introduced from New Britain in 1929, *T. brevipalpus* Theobald from Africa in 1950 and *T. splendens* (Wiedemann) from the Philippines in 1954. There is evidence that the latter two species are established but it is doubtful if they are contributing any measurable control.

Persistent and systematic sanitary work by the Mosquito Control section of the State Department of Health, has greatly reduced these two day-biting mosquitoes and *A. aegypti* has not been seen for a number of years.

#### ***Siphanta acuta* (Walker)**

Commonly called the torpedo bug, this green, flatid hopper was first observed in Hawaii by Perkins about 1898, but must have reached the Islands some years earlier because he states (48) that by 1900 it was so numerous in the forests of Oahu, that it was destroying certain native trees and damaging coffee and other cultivated plants. Guava is also a favored host. This insect is of Australian origin and may have come to Hawaii on some imported plant.

From a pest of first importance, the torpedo bug has been reduced to one of little significance owing to the introduction of the platygasterid egg parasite *Aphanomerus pusillus* Perk. from Australia by Perkins and Koebele in 1904. It can now be found on various plants,

but usually in small numbers.

#### **Saccharicoccus sacchari** (Cockerell)

Because of its color, this mealybug is commonly called the pink sugar cane mealybug. It occurs in every country where sugar cane is grown. The first account of its presence in Hawaii is apparently by Koebele (49). His description of the species in 1896 leaves no doubt of its identity. It undoubtedly came to the Islands on imported sugar cane cuttings many years previously; the principal importations being from Australia about 1880 or 1881 and from Mauritius about 1884. There was no plant quarantine service in Hawaii then. Because of the extent to which this mealybug masses on the cane stalk, particularly beneath the leaf sheaths, and because of its profuse secretion of sticky honeydew and abundant production of wax, it has long been of concern to the sugar planters. Though measurable damage to the cane has not been determined, there is undoubtedly an insidious and detrimental effect to the plant and loss of sugar when infestations are heavy.

Efforts towards biological control of the pest have been made with some success. On his second trip to Australia in 1891-92, Koebele collected and shipped the ladybird *Cryptolaemus montrouzieri* Mulsant to California. He considered it a valuable predator on mealybugs. It proved useful in California and Koebele recommended its introduction into Hawaii. Accordingly it was introduced in 1894, apparently from California. Upon establishment it proved useful against a number of mealybug species, particularly the pink sugar cane mealybug. Control was, however, not entirely satisfactory during the ensuing years. In 1930, F. C. Hadden, HSPA entomologist, investigated this mealybug in the Philippines and found it well parasitized by the encyrtid internal parasite *Anagyrus saccharicola* Timberlake. This was introduced into Hawaii the same year and liberated in quantity in the sugar cane fields. Establishment resulted in a material reduction of this mealybug. However, in some areas control was not satisfactory and two other promising introductions were made. The first was by Pemberton, who in 1931 sent from the Malay Peninsula consignments of the ladybird *Pullus apiciflavus* (Motsch.), which he found destroying this mealybug on the Peninsula. It was reared extensively in the laboratory in Honolulu and widely liberated; but there has been no evidence of establishment. The second and most recent effort has been the importation of the ladybird *Hyperaspis trilineata* Mulsant from Barbados, West Indies, during February 1963, through the aid of the Entomology Research Branch of the U. S. Agricultural Research Service. This has been reared in quantity at the HSPA Experiment Station and released widely in cane fields. It is too early to know the results.

#### **Pulvinaria psidii** Maskell

This coccid offers a spectacular case in the biological control of an insect pest in Hawaii. Its origin or time of introduction to Hawaii is not recorded. Though not a native of Hawaii, it was originally described from material collected in these Islands. Zimmerman (50) lists a dozen or more host plants, including guava, citrus, coffee, gardenia and avocado. It was once particularly destructive to coffee. When Perkins visited Kona, Hawaii in 1892, he reported (51) that many of the coffee trees were literally festooned with masses of this pest and appeared on the point of being totally destroyed. Following the liberation of the ladybird *Cryptolaemus montrouzieri*, the situation soon changed as reported by Koebele. In his comments in the Report of the Minister of the Interior to the President of the Republic

of Hawaii for the Biennium ending 31 December 1897, Koebele stated this coccid was shockingly abundant on coffee in North Kona, Hawaii, in February 1894, but that on a recent visit to the same area, all of this had changed owing to the predation by the *Cryptolaemus* ladybird. It is also of interest that through the years from 1905 to date, *P. psidii* is rarely mentioned in the annual issues of the "Proceedings of the Hawaiian Entomological Society", and then only in incidental plant host recordings.

#### **Dacus cucurbitae** Coquillett

The melon fly is one of the most destructive immigrant insects ever to invade Hawaii. Though widespread in India, Ceylon, South China and Indo-Malaya, its origin is assumed to be India. In spite of the serious damage by its larvae to cucurbitaceous and other truck crops in the above areas, it was not named until 1899 when D. W. Coquillett published a description of it (52) from four specimens collected by George Compere in Honolulu and sent to Dr L. O. Howard, Entomologist, U. S. Department of Agriculture. The first record of its appearance in Hawaii was noted in 1898 (*The Hawaiian* 1 (27): 6) by Byron O. Clarke, Secretary and Commissioner, Hawaii Bureau of Agriculture. This newspaper was published only during 1898. Mr Clarke first noticed the fly in the Kalihi District of Honolulu in October 1897. He then found it abundant at Pearl City, Oahu two months later, and information was at hand to indicate that the fly was also doing much damage on the island of Hawaii by August 1898. From such data it is generally assumed that the fly came to Hawaii with produce brought by immigrants from either Japan or China around 1895.

Efforts to control this pest through biological methods have been made by entomologists sent out from Hawaii. Dr Fullaway succeeded in finding and introducing the braconid larval parasite *Opius fletcheri* Silv. from India in 1916. It became well established and has effected a considerable control of the fly where it infests the small fruits of the balsam apple *Momordica balsamina* L., particularly where the plant occurs in waste areas. This parasite, however, has given little control in melons, cucumbers, squash, tomatoes and other host fruits. During 1949, N. D. Waters investigated the melon fly in Northern India. He sent a large number of melon fly puparia to Honolulu from which emerged a new braconid parasite, described by Fullaway under the name *Opius watersi*. This bred readily on melon fly larvae in the laboratory and many were liberated in the field, but there is no evidence of establishment.

Intensive work by entomologists of the University of Hawaii on the artificial control of this fly has presented a method of control developed only after a thorough study of its ecology in vegetable gardens. It was noted that gravid females come to the host plants to lay their eggs, but that they rest or "roost" on other vegetation in the near vicinity of the food crops. By planting a "roosting" plant such as maize around the gardens, and treating these plants with an insecticide with good residual qualities such as DDT, an excellent kill of the females has been reported. By this method no poison contaminates the food plants and the opiine parasite, if present, is not poisoned.

E. A. Back and C. E. Pemberton (53) conducted extensive studies of the melon fly in Hawaii between 1913 and 1917, resulting in the publication of Bulletin No. 491, U. S. Department of Agriculture, 30 June 1917. With 24 plates and 10 figures, the bulletin covers the salient features in the life history and general habits of the pest.

**Longiungis sacchari** (Zehntner)

Though occurring on several host plants, sugar cane is preferred by this aphid. There is a long record of complaints by Hawaiian sugar planters regarding mass outbreaks, especially on young cane on all of the plantations. Though not described and named until 1897 by Zehntner (54), it must have been in Hawaii many years previously. It is now widespread over the world where sugar cane is commercially grown. The first published record of the insect in Hawaii was by Koebele in a report (55), dated 6 Oct. 1896. He mentioned a heavy infestation on young cane at Kilauea Plantation on Kauai and also referred to its presence on the island of Maui. Perkins did not mention it in the "Fauna Hawaiiensis" but it must have been in Hawaii prior to his arrival in 1892 because of its distribution by 1896.

The most important enemy of this aphid is the ladybird *Coelophora inaequalis* (Fab.), which Koebele introduced into Hawaii from Australia in 1894. As it feeds upon many species of Aphididae in Hawaii, substantial populations are constantly maintained. The earliest report of its value is found in Koebele's report on "Insect Pests" cited above, in which he refers to the almost complete elimination of a heavy outbreak of the aphid at Kilauea Plantation, Kauai, by this ladybird, misnamed by him as *Coccinella repanda*. During years up to the present time, outbreaks of the aphid have erupted on various plantations but have become gradually limited to smaller areas of infestation, owing primarily to predation by *C. inaequalis*. Other useful coccinellid predators are *Platyomus lividigaster* Muls. and *Scymnus notescens* Blackburn, which Koebele introduced from Australia in 1894. Another predator established in the cane fields is the hemerobiid *Micromus vinaceus* Gerst., which F. X. Williams introduced from Australia in 1919. An additional and interesting aphid enemy is the braconid internal parasite *Lysiphlebus testaceipes* (Cresson), introduced into Hawaii from California in 1923 by P. H. Timberlake. It is well established. There are now several other natural enemies of the cane aphid in Hawaii. The combined work of the complex would seem to account for the reduced importance of this aphid in the cane fields.

**Oxya chinensis** (Thunberg)

The Chinese grasshopper is first mentioned in Hawaiian literature by Perkins (56), wherein he stated that in 1892 it was confined to Oahu and Kauai and that it had not been reported on the other Hawaiian islands. It was not recorded on Maui until 1918, nor on the island of Hawaii until 1925, though it undoubtedly reached these two islands at earlier dates. Because of its presence on Oahu and Kauai in 1892, it certainly reached the State many years previously, probably as egg pods in soil accompanying imported plants from the Orient. By 1928 it caused concern amongst sugar planters because of extensive defoliation of sugar cane. This was particularly the case at the then Waianae Plantation on Oahu, where some cane fields were badly stripped of their leaves.

During 1930-31, Pemberton investigated natural enemies of this grasshopper on the Malay Peninsula, which resulted in the finding and introduction of the scelionid egg parasite *Scelio pembertoni* Timberlake. It became thoroughly established in all areas where the grasshopper was prevalent. Within a few years, this grasshopper became insignificant in the cane fields and has thus remained so.



***Nipaecoccus nipae* (Maskell)**

The first record of this mealybug in Hawaii was by Perkins in 1902 (57), in which he refers to "the white *Eriococcus* of the alligator pear, guava and other trees" and considered it the most injurious insect pest of the avocado in Hawaii at that time. A year later Van Dine (58) discussed what he called "The Mealybug or Pear Blight of the Alligator Pear", and in 1906 he called it "The Avocado Mealybug" (59). It was commonly known by this name thereafter. As an indication of its importance, Van Dine discussed and illustrated insecticidal efforts underway to check the mealybug on avocado trees. In a paper by Perkins (60), he states that he accompanied Koebele on a trip to Arizona and Mexico in 1897 in search for some natural enemy of this mealybug, which by that time had become "an unsightly pest" and that it had appeared in Hawaii since the earlier days of his collecting, which began in 1892.

For over 22 years this mealybug continued to be conspicuous on avocado trees, banyans, guavas, edible figs, breadfruit and other host plants. A noticeable and annoying situation prevailed under large banyan trees where dripping honeydew from the insects, kept park benches under the trees sticky and soiled with accompanying black sooty mold.

This problem was completely solved following the introduction of the encyrtid parasite *Pseudaphycus utilis* Timberlake from Vera Cruz, Mexico, in April-May 1922, by H. T. Osborn, then Assistant Entomologist, Experiment Station, HSPA. He also introduced the coccinellid *Hyperaspis silvestrii* Weise, which also became established, but the parasite proved to be the major factor in control. Within two years the mealybug approached a point of almost extermination by this parasite and has been rarely seen since. This has been one of the most spectacular cases in the biological control of an insect pest in Hawaii.

***Syagrius fulvitaris* Pascoe**

The Australian fern weevil was first seen in Hawaii in 1900, when it was found infesting maidenhair ferns in greenhouses in Honolulu, as reported by Perkins (61). He stated that this and a number of other insects observed by him in 1900, were unknown to him in 1897. This seems to place the date of entry shortly before 1900. It undoubtedly came to Hawaii in imported ferns from Australia. Pemberton found it common in greenhouses in Sydney, Australia in 1921, and also in ferns in eastern Australian forests. Fullaway and Krauss (62) state that F. W. Terry found it established on Pacific Heights, Honolulu, in November 1903, and Swezey (63) reported that it was abundant in the stipes of the common fern *Sadleria cyatheoides* in the same area nearly up to the forest in May 1905. It spread rapidly into the forests of Oahu and by the summer of 1912, Swezey (64) observed an area in Makiki Valley, Oahu, where all of the *Sadleria* ferns had been killed by the weevil.

The beautiful *Sadleria* ferns form an important element in Hawaii's forests, especially in the dense native forests on the island of Hawaii, both because of their aesthetic value and of their protective influence in the maintenance of other native flora. In 1908, Brother Mattias Newell found this weevil in ferns at the Shipman House in Hilo, Hawaii, as reported by Swezey (65). *Sadleria* ferns are very common both in the waste lands and forest areas from Hilo into the upland and the weevil spread easily over the Island. At a meeting of the Hawaiian Entomological Society on 2 October 1919, W. M. Giffard stated that he and Fullaway observed a severe infestation by this weevil in *Sadleria* ferns at 29 miles,

Olaa, Hawaii, which is in the splendid fern forest area near the Kilauea volcano and that about seven acres of the ferns were badly damaged. There was consternation over this development and strenuous efforts were made to eradicate the weevil, but without success. By 1922 it had also reached the island of Maui, so that some form of biological control was strongly indicated.

During April–May, 1921, Pemberton visited forest regions in New South Wales, Australia in search of the weevil. It was readily found in virgin forests rather lightly affecting several species of ferns and parasitized by the braconid, external, larval parasite *Doryctes syagrii* (Fullaway). About 60% of the larvae were parasitized. A good quantity of cocoons and developing larvae of this parasite were sent to Honolulu during May and emerging adults were liberated on Oahu and Kilauea, Hawaii, thus resulting in establishment. It has proved to be useful in checking the weevil but more natural enemies are still needed. Further studies in Australia might reveal other parasites or possible predators. This work was documented by Pemberton (66).

#### **Dysmicoccus brevipes** (Cockerell)

The so-called pineapple mealybug was first identified in Hawaii by Jacob Kotinsky and E. M. Ehrhorn and recorded by Kotinsky (67) as *Pseudococcus bromeliae* Bouche. With many host plants, it is widespread over most of the tropical world. Because of the extensive culture of pineapple in Hawaii, this mealybug assumed the position of one of the most serious economic pests in the Islands because of its role in causing the devastating malady now called mealybug wilt of the pineapple. This wilt disease was first recognized and reported in Hawaii by L. D. Larsen (68) under the name "pineapple wilt." Larsen stated that at that time (1910) this wilt disease was known in all parts of the world where pineapples were grown. By 1910, however, the disease in Hawaii had not apparently assumed alarming proportions. J. E. Higgins (70) stated that "with the exception of a few fields (the wilt) had not caused great damage." But the disease evidently gained rapid headway and J. F. Illingworth (71) in discussing the problem in 1931, stated that as early as 1920, whole fields in certain instances were wiped out by this disease. In the same paper he presents information tending to incriminate *D. brevipes* as the responsible agent in the spread of the disease.

Beginning about 1930, elaborate studies by Walter Carter and associates, convincingly demonstrated proof of the relation of the wilt disease to the presence of this mealybug, and the influence of ants, particularly *Pheidole megacephala*, as a contributing factor in its spread. This information resulted in the development of artificial methods of mealybug control with consequent enormous financial savings to the industry.

Much exploration has been undertaken in foreign lands in search of suitable predators or parasites of this pest. Some have been found and established in Hawaii. The cecidomyiid fly *Lobodiplosis pseudococci* Felt was introduced from Mexico in 1930 by Fullaway. C. T. Schmidt has reported it well established in some fields. A few other predators and one or two parasites are also established, but their effectiveness is evidently insufficient to obviate the continuance of field protection by artificial measures.

#### **Perkinsiella saccharicida** Kirkaldy

The sugar cane leafhopper is another insect with a spectacular history in Hawaii, both

because of its positive threat to the very existence of the sugar industry and the final and dramatic control with imported natural enemies. It was unrecorded in entomological literature at the time of its first appearance in Hawaii, and was named and described by G. W. Kirkaldy (72) in 1903.

It was first observed in Hawaii in 1900 by Perkins (73), who stated that "In the latter half of the year 1900 I first observed and collected specimens of the leafhopper of the cane." According to Swezey (74) these were collected by Perkins at a light in his room at Waialua, Oahu. In January 1902, Koebele (75) reported that a year previously E. G. Clarke had noted this leafhopper at the HSPA Experiment Station in Honolulu as abundant on cane. This would be late in 1900 or early in 1901 and established the fact that the insect was a pest of sugar cane. By 1903 it had spread to all of the main islands and was recognized as a very destructive insect. Perkins (76) concluded that this leafhopper was introduced into Hawaii two or three years prior to 1900. On page 7 in the same bulletin, he mentions finding the eggs and young of apparently the same leafhopper in packages of imported cane cuttings received from Queensland, Australia, which he destroyed. It undoubtedly entered Hawaii in uninspected cane cuttings from Australia before Perkins began plant inspection work as a Consultant for the Territorial Board of Agriculture and Forestry.

To illustrate the devastation to sugar cane by this insect, Swezey (77) stated that at the Hawaiian Agricultural Company at Pahala, Hawaii, "damage was so extensive that whole fields of great area were practically killed outright, and the plantation, which had a sugar crop of 18,888 tons in 1903, was reduced to crops of 1,621 tons in 1905 and 826 tons in 1906. This represented a loss of over a million dollars each year." Heavy damage was also reported on other Hawaiian plantations, and as early as 1903 it was estimated that sugar plantations suffered sugar losses amounting to 70,516 tons.

The HSPA Experiment Station was established in 1895, but it was not until August 1904 that a division of entomology was established. Four thoroughly qualified entomologists, R. C. L. Perkins, O. H. Swezey, G. W. Kirkaldy and F. W. Terry, were employed. Two other entomologists, Alexander Craw and Albert Koebele, were appointed to serve as Consultants. The serious nature of the leafhopper problem prompted the HSPA to establish this division.

Before Perkins joined the HSPA Experiment Station in 1904, he corresponded with Mr James Clark of Cairns, Queensland regarding possible leafhoppers in Australian cane fields. Clark responded by sending Perkins four specimens of a leafhopper he had found in a cane field and which proved to be the same as the one in Hawaii. Perkins and Koebele then departed for Queensland on 11 May 1904. Early in June they found this hopper in cane, though not abundant, and Koebele promptly discovered mymarid egg parasites of the pest. One of these, later described by Perkins as *Paranagrus optabilis*, was dispatched to Honolulu. Several shipments were made. In those days transportation by ship was slow and the first consignments failed, but one, arriving 14 December 1904, arrived satisfactorily and Swezey succeeded in rearing it in the laboratory and making liberations in the cane fields. It became established and accomplished good control of the leafhopper in many areas, but not on plantations where the annual rainfall is usually heavy. Another mymarid egg parasite, named by Perkins *Anagrus frequens*, was also introduced about the same time as *P. optabilis* and became established, but it proved much less effective than the latter.

Exploration for more parasites was continued by Koebele and F. Muir, who joined the

Experiment Station 1 September 1905. Koebele successfully introduced the tetrastichine egg parasite *Ootetrastichus beatus* Perkins from Fiji in 1905, which he found destroying the eggs of a related leafhopper *Perkinsiella vitiensis* Kirk. At the same time he introduced the dryinid parasite *Haplogonatopus vitiensis* Perkins from Fiji which parasitizes the young hoppers, and which also was successfully established. In 1906 Muir found the dryinid parasite *Pseudogonatopus hospes* Perkins in China parasitizing adult hoppers of the species *Perkinsiella sinensis* Kirk. This was introduced and liberated in 1907, but it was not until 1916 that it was found established. Muir continued his explorations for leafhopper enemies and in 1916 found the egg parasite *Ootetrastichus formosanus* Timberlake in Formosa. This was introduced the same year and reared in quantity in the laboratory and liberated in cane fields. It also became established. Though the above parasites accomplished a considerable control of the leafhopper on many of the plantations, control remained unsatisfactory in the rainy districts, particularly on the island of Hawaii, and Muir continued his search for natural enemies that might thrive in these districts.

In 1920, Muir returned to Australia to resume his search. At that time he observed the mirid bug *Tytthus mundulus* (Breddin) piercing and sucking out the contents of eggs of this leafhopper in Queensland. He brought a few to Honolulu on 21 June 1920. Laboratory tests indicated that the bug could only survive if given eggs of the leafhopper and that it could not live on sugar cane free of hopper eggs. A few surviving individuals were then liberated in a cane field on Oahu and Pemberton immediately went to Fiji, where this mirid had been recorded in cane fields there, and sent three large shipments of the bug to Honolulu during September, October and November, 1920. These were liberated and quantities were also bred in the laboratory and widely spread to all of the islands. It proved so effective that by 1923 the hopper populations were definitely on the wane on all plantations, including those in wet areas. Within a few years the leafhopper became scarce and has remained so to the present day. This is a classic case in the remarkable biological control of an important economic insect pests.

#### **Anomala orientalis** (Waterhouse)

For several years after 1900, no new serious insect pests were reported, but in October 1908, Dr H. L. Lyon, then Pathologist of the HSPA Experiment Station, examined failing or dying sugar cane at Honolulu Plantation, Oahu and found large numbers of grubs in the soil about the cane roots. The entomologists concluded that these were the larvae of the Chinese rose beetle *Adoretus sinicus* Burm. which had been known in Hawaii since 1896. Again in October 1910, Dr Lyon examined the same areas and reported increased damage and that affected cane covered some two acres. On 18 June 1912, Muir reported grub infestation in the same region now covering over a square mile of cane land. He succeeded in collecting adults of the insect which proved to be *Anomala orientalis*, a Japanese species. It thus seemed probable that the insect had come to Hawaii in imported plants with soil sometime before 1908. These details were discussed by Muir (78) in November 1912.

The entomologists determined that the grubs of this insect ate the cane rootlets and bored into the root-stocks sufficiently to weaken the cane and often kill it outright. A serious problem confronted the planters for the beetle continued to spread widely in the Pearl Harbor area. Many years later it advanced across the Island through cane and pineapple

lands to Waialua. Damage to pineapple roots also became a problem because of the very limited root system of this plant. Various attempts in chemical control of the pest proved unsatisfactory. Natural enemies were badly needed.

Muir departed for the Orient on 28 March 1913 to search for parasites or other natural enemies. Of special interest at the time was a scoliid parasite of the genus *Tiphia* which Muir found parasitizing the grubs of *A. orientalis* in Japan. Two successful shipments were made by him during October and November 1913, and a third was made in October 1914. From these a total of 117 adults were liberated, but establishment was not successful. In July 1915, he also succeeded in shipping 74 adults of a large carabid *Craspedonotus tibialis* Schaum, which he considered a valuable predator of white grubs in Japan. These were liberated but also failed to become established.

Though *A. orientalis* is not known in the Philippines, other related species with somewhat similar habits to *orientalis* are common, and it was assumed that natural enemies of these might be more adaptable to Hawaiian conditions than species normally occurring in the temperate to cold climate of Japan. Muir visited the Philippines in late July 1915. In the vicinity of Los Baños, Luzon he soon observed a very abundant scoliid wasp in the cane fields, then known as *Scolia manilae* Ashm. He was able to demonstrate that it readily parasitized grubs of certain *Anomala* and *Adoretus* species. H. T. Osborn and F. X. Williams of the HSPA Experiment Station, went to Los Baños to help Muir with the introduction of this parasite into Hawaii. During the summer of 1916, a total of 2164 adults were successfully obtained and liberated on Oahu. Shipments from Los Baños arrived either as adult wasps or in the cocoon stage. By September 1916 the parasite was found to be well established, and within four months it had become exceedingly abundant and had effected an excellent control of the pest. By the middle of 1919 the *Anomala* beetle was rather scarce in the cane fields.

Another scoliid parasite *Tiphia segregata* Crawf. was introduced from the Philippines by Williams in March 1917. Six females and a few males survived the last shipment after 14 previous consignments had failed. These few were liberated in April 1917, but there was no evidence of establishment until August 1944, over 17 years after release, at which time it appeared in fair numbers in the cane fields. Both the *Tiphia* and the *Scolia* (now known as *Campsomeris marginella modesta* Sm.) parasitize the grubs of both *Anomala orientalis* and *Adoretus sinicus* in Hawaii.

Control of the *Anomala* beetle remained perfect until about 1930, when it reappeared in quantity in certain cane fields on Oahu in spite of extensive parasitism. This was only temporary but it persisted for four or five years and more efforts were made to obtain additional natural enemies. In 1932 Pemberton introduced the tropical American toad *Bufo marinus* (Linn.). This quickly became well established and fed at night on most insects at ground level. It is doubtful if it contributed much in *Anomala* control. In Puerto Rico, where the toad was collected, it was given credit as an important enemy of certain beetles in cane fields. During 1932-34, F. A. Bianchi and F. X. Williams studied *Anomala* and related beetles in Guatemala and successfully shipped to Honolulu many scoliid parasites of these beetles, the parasites arriving in the cocoon stage. Some 1522 adult wasps were reared from these cocoons; they were then mated and liberated, but did not become established. Bianchi returned to Guatemala in 1941 and shipped large numbers of the grub-feeding wireworm *Pyrophorus rufus* Champion. Though liberated there was no evidence

of establishment.

During this repercussion period R. H. Zwaluwenberg and H. A. Wadsworth conducted elaborate studies of soil conditions favoring or inhibiting *Anomala* development, and established proof that many Hawaiian cane soils are unacceptable for *Anomala* grubs whereas others have the opposite effect. By their classification, it can be reliably assumed where the beetle may spread in the future and where it may not be able to thrive.

To date there has been no further damage to cane by this beetle, and at times it is even difficult to find it in fields where it was once epidemic.

#### ***Coptotermes formosanus* Shiraki**

The destruction to buildings in Hawaii by this subterranean termite has been so great during the past 30 or 40 years, that it may be justly classed as one of the worst insect pests in the State. Vast sums have been expended in eradication measures against it and termite exterminators take a heavy but justified toll from householders in the constant war against this pest.

The first definite record of its presence in Hawaii, was announced by Dr Swezey (79). On 18 December 1913, Swezey reported finding an extensive infestation in the floor timbers of the Kamehameha School Chapel in Honolulu close to the site of the Bishop Museum. The termite had evidently been in Hawaii for some time previous to Swezey's observation. Zimmerman (80) states that Perkins discovered it in Honolulu in 1907 or earlier, without identifying it. By 1926 it was found established on the island of Hawaii at Hilo, as reported by Fullaway (81). Then on 13 January 1928 he found it at the Hanalei landing on Kauai. It was not until April 1963 that C. J. Davis reported an infestation by this termite in buildings at Wailuku, Maui. It is thus widespread in Hawaii, though we have no records of it on the island of Molokai.

Apart from the predation by the ant *Pheidole megacephala*, which is by no means sufficient, the termite has no other natural enemies in Hawaii. Control is only by barrier construction in buildings and the use of fumigants and other insecticides.

#### ***Ceratitis capitata* (Wiedemann)**

The Mediterranean fruit fly was first seen in Hawaii on 21 June 1910, when D. T. Fullaway caught a living specimen at the U. S. Agricultural Experiment Station, then on Punchbowl, Honolulu. It had evidently been on Oahu for some time previous to this date. E. M. Ehrhorn (82) stated that a Honolulu resident had submitted to the Experiment Station three years previously some oranges showing blemishes typical of fruit fly attack. By September 1910 it had become common in the Punchbowl area and a year later it was found on the island of Kauai. By early 1912 it had spread to Molokai, Maui and Hawaii. In view of its early discovery over such a wide area, it is evident that this fly had been in the Islands some years prior to Fullaway's finding, and the year 1907 or perhaps a little earlier may be concluded as the probable date of introduction. It is certain that the fly came to Hawaii from Australia, where it was established about Sydney and Western Australia between 1897 and 1907. Before 1910, entomologist George Compere, while traveling between Australia and Honolulu, observed *C. capitata* larvae emerging from fruits stored on the deck of his steamer. The history of these facts will be found in a bulletin by E. A. Back and C. E. Pemberton (83).

Consternation prevailed amongst horticulturists and the general public because of the heavy larval infestation of mangoes, oranges, guavas and many other fruits, totaling about 72 different kinds. The fear that the fly would reach California resulted in the repeal of the California Quarantine Law enacted 11 March 1899, and the passage of a new quarantine law on 2 January 1912, which prohibited the entry of fruits susceptible to fruit fly attack. Then on 20 August 1912 the Federal Government passed the Federal Plant Quarantine Act, to be enforced by the Federal Horticultural Board, which was established in the fall of 1912. This Act included Item 2, relating particularly to the Mediterranean fruit fly and puts a stop to any fruit shipments from Hawaii to the mainland excepting pineapples and green bananas.

Following the establishment of the Federal Horticultural Board, Dr E. A. Back of the U. S. Bureau of Entomology was sent to Hawaii in September 1912, and C. E. Pemberton in March 1913, to undertake studies of this fly and the melon fly *Dacus cucurbitae*, with particular duty to enforce the Plant Quarantine Act as it related to the shipment of bananas to California. This required the inspection and certification of every bunch of bananas consigned for California. As long as banana bunches consisted only of sound, green fruit, they were passed for shipment. In spite of the fruit fly, a thriving industry was thus permitted to continue operating. As an indication of the magnitude of the industry at that time, 256,319 bunches were shipped from June 1914 to June 1915.

Artificial control of this pest seemed hopeless in those days and biological methods were resorted to by the Hawaiian Board of Agriculture and Forestry. Professor F. Silvestri of Portici, Italy was engaged to explore for parasites in Africa. He began work in West Africa in July 1912, and concluded his investigations in March 1913 in South Africa. He found a number of fruit fly parasites. He left Africa with living material of five different parasites and added another which he obtained in New South Wales in Australia. He arrived in Honolulu on 16 May 1913, with all six species still alive. Of special interest were the two braconids *Opius humilis* Silv., which he obtained at Cape Town, South Africa, and *Opius tryoni* Cameron, which he collected in New South Wales. Of *O. humilis*, only two females and three males were still alive and active. Laboratory breeding did not prove promising. A single additional female was reared with a few more males. Fearing to lose the colony, the three females and a few males were taken to Kona, Hawaii, where coffee was heavily infested by the fly. These were liberated on 12 June 1913, and by October 1913 surveys in Kona showed that this parasite had multiplied rapidly and had already become widespread in the coffee region thus contributing a heavy parasitism of fruit fly larvae in the district. Likewise the opiine *Opius tryoni* survived the trip from Australia in very small numbers, there being only four females and three males. These were taken to the Kona coffee plantations on June 12th and liberated and by October 1914 this parasite was also found to be well established. Both species greatly reduced the fly infestations in coffee. It is of special interest that these two braconids were successfully established following the release of only three females in one case and four in the other, together with a few males.

When Silvestri returned to Honolulu he also brought back approximately 300 adults of the proctotrupid *Galesus silvestrii* Kieffer and about 500 adults of the chalcid *Dirhinus giffardii* Silv., both of which were found to be parasites of fruit fly pupae in Africa. Many were reared in the Honolulu laboratory and liberated. The *Dirhinus* became established

but has not proved important. A report by Silvestri (84) gives a full account of his work on this project.

Besides the parasites Silvestri successfully introduced to Hawaii, he contributed much information on other parasites of fruit flies found in Africa, with particular reference to the braconid *Opius fullawayi* Silvestri and the eulophid *Tetrastichus giffardianus* Silv. Dr Fullaway and J. C. Bridwell then left for West Africa in June 1914 to obtain these and other parasites if possible. Fullaway returned to Honolulu 27 October 1914, with living material of both species. These were readily reared in the laboratory and liberated, resulting in their establishment. Owing to illness, Bridwell was forced to discontinue work on the project.

The Silvestri-Fullaway-Bridwell expeditions thus resulted in the establishment of three opiine larval parasites, one eulophid larval parasite and one chalcid which parasitized the fly pupae. As announced by Fullaway (85), a great reduction in fruit fly damage in the Kona coffee district had followed the establishment of the three opiines, amongst which there was heavy competition, resulting in the possible elimination of *Opius humilis*. There was some decline in fruit infestation over the whole State by 1915. For many years thereafter, U. S. Department of Agriculture entomologists kept quantitative records on the extent of fruit fly infestation and the degree of parasitization. This is well summarized by H. F. Willard and A. C. Mason (86), covering the period 1914-1933. Their data indicate a general decline of fruit infestation, especially in the lower elevations. *Opius tryoni* appeared to be the dominate parasite.

The Mediterranean fruit fly underwent a remarkable and permanent subsidence in the lowlands, following the invasion into the Islands about 1945 of the Oriental fruit fly *Dacus dorsalis* Hendel and the establishment of *dorsalis* parasites imported from June 1948 through September 1950. Of these parasites, *Opius longicaudatus* (Ashm.) and *Opius oophilus* Fullaway appear to be factors in the decline. These were imported in small numbers from the Philippines in 1947 by Q. C. Chock and L. B. Uichanco, and in quantity from the Malay Peninsula by N. L. H. Krauss during the summer of 1948. D. W. Clancy (87) demonstrated that *O. longicaudatus* readily parasitizes *C. capitata* larvae. This parasite became abundant in the field by 1949. Though *Opius oophilus* was not recognized as an egg-larval parasite when originally introduced, it proved to be a parasite of both *D. dorsalis* and *C. capitata*. Bess (88) states that large numbers of *oophilus* have been recovered in Hawaii from *capitata*.

It seems probable that some of the parasites introduced for control of the Oriental fruit fly, plus some unexplained competition between *dorsalis* and *capitata*, accounts for the amazing reduction of the latter almost to the point of elimination in the lowlands of Hawaii. The Mediterranean fruit fly now appears to survive almost solely in the cool uplands.

#### **Tarophagus proserpina** (Kirkaldy)

Following the recognition of the Mediterranean fruit fly in Hawaii in 1910, a number of additional foreign insect pests became established in the Islands, but were not of special economic importance and during the ensuing 20 years no new or serious pest appeared until December 1930 when O. H. Swezey and D. T. Fullaway found the taro leafhopper abundant and heavily damaging taro in the Waianae district of Oahu in December 1930. The first printed record of their finding was by Fullaway (89), who stated that "toward



the close of 1930 there was brought to our attention a new leafhopper pest on the taro plant." In view of its abundance it must have been in Hawaii for a year or more. At that time, taro and its widely used product *poi* were important foods and they are still obtainable in the local markets. Strenuous efforts by the Board of Agriculture and Forestry to eradicate the insect failed and it spread to all areas on Oahu where taro was grown. By September 1947 it was found on the islands of Kauai and Hawaii, and in October 1951 it had spread to Maui.

This hopper is widespread in the Pacific, including Australia, Java and the Philippines. It is also known in Samoa and Fiji. It is of record that 16 varieties of taro were introduced into Hawaii in 1928 from the south seas. It seems most probable that the insect accompanied one or more of the plants introduced at that time. By September 1937 it was evident that eradication measures had failed, and a local committee of entomologists recommended that natural enemies of the insect be sought. Accordingly, Fullaway investigated natural enemies of the hopper in the Philippines, and by the close of the year had found and shipped to Honolulu the mirid bug *Cyrtorhinus fulvus* Knight, which fed on the hopper eggs, and two species of hymenopterous egg parasites. These were reared in the laboratory and released in taro patches. More shipments were made by him in 1938. Outstanding results attended these liberations, particularly through the predation on hopper eggs by the mirid. According to Fullaway (90) the increase and spread of this bug was astonishing. The hopper was soon brought under good control and the taro crop was restored to its former state of productivity. Since then there have been occasional repercussions of the leafhopper, but again suppressed by the mirid bug.

#### **Anacamptodes fragilaria** (Grossbeck)

J. W. Beardsley (91) stated that through the period 1937-1961, about 400 species of insects and other terrestrial arthropods of accidental introduction were found established in the Islands for the first time. Some of these were conspicuous pests. It was during World War II that there was a particular rash of introductions owing the mass movement of men and materials in and out of Hawaii, and to the virtual breakdown of plant quarantines. *A. fragilaria* was one of the first conspicuous pests to arrive during this period.

This geometrid first appeared at Pearl Harbor in August 1944, when a dozen adults were caught in a light trap operated by the Navy. By February 1945 it was found widespread over most of Oahu up to 500 m elevation. Being fairly large and a good flyer, this moth quickly spread to all of the main Hawaiian Islands. The looper caterpillars were found defoliating some 30 different plants, many of which were of ornamental or other economic value. The important forage tree *Prosopis pallida* (Willd.) was particularly affected.

The moth is a native of California, where it is inconspicuous. During December 1945, and January 1946, N. L. H. Krauss investigated the insect in Southern California and introduced the braconid larval parasite *Apanteles praesens* Muesebeck. It was reared in the Honolulu laboratory and liberated, but there is no evidence of establishment. Although no additional enemies of this moth were intentionally introduced, it is of interest that two eumenid wasps came accidentally to Hawaii at about the same time or shortly after *Anacamptodes* reached the Islands. These were *Eumenes latreillei petiolaris* (Schulz) and *Eumenes pyriformis philippinensis* Bequaert. The former comes from New Guinea and was first collected in Honolulu 6 August 1944, as reported by Dr Henry Townes (92). The latter was

first collected at Hickam Field, Oahu, by K. L. Maehler (93) on 17 October 1946. The extent to which these large and active wasps store *Anacamptodes* caterpillars in their mud nests, would appear to account for the very great subsidence in the populations of this moth. Both wasps are now widespread in the State. They undoubtedly immigrated to Hawaii as larvae or pupae in their mud nests attached to barges, ships and other materials arriving at the Pearl Harbor area from the Philippines and New Guinea.

#### ***Polydesma umbricola* Boisduval**

On 4 June 1945 Dr Swezey identified a number of caterpillars and pupae of this agrotid moth, which were submitted to him by a resident of Kaimuki, Oahu. It was another new pest in the Islands. The following day HSPA entomologists visited the residence and found more of the same larvae at the base of monkey-pod trees, *Samanea saman* (Jacq.) Merr. Investigations showed that the caterpillars fed voraciously on the terminal branches and destroyed the tender leaf buds. This resulted in the death of the terminal twigs and branches. Leaf buds were repeatedly destroyed, limbs died and in some cases whole trees perished. Immediate surveys during the next few days established the fact that the insect was well established over most of Honolulu and even some 25 km west of the city. The moth is large and a strong flyer. A month later it was found on monkey-pod trees at Lahaina, Maui, and during October 1945 it appeared on Kauai and Niihau and on the island of Hawaii by June 1946. The caterpillars were found on a few other plants but the monkey-pod proved to be the favorite host in Hawaii. This is the finest shade tree in Hawaii and it was not long before many of the trees were completely defoliated.

During the first two years of this epidemic, residents spent much money hiring exterminators to power spray their trees with insecticides. The Board of Agriculture and Forestry also became heavily involved in the spray program. Entomologist Fullaway (94) stated that "a spray program was started on June 8, 1946, by the Department of Public Parks and Recreation of the City and County of Honolulu and the Board of Agriculture and Forestry", and that "during the campaign, 1,819 trees were sprayed." Some spraying continued for a few years thereafter, but by June 1950, Fullaway (95) reported that the moth had become generally controlled by natural enemies.

No parasites or predators were imported for control of this pest, but a number of lepidopterous parasites in the Islands were soon found attacking the caterpillars. R. H. Van Zwaluwenberg (96) mentions the egg parasite *Trichogramma minutum* Riley and the larval parasites *Hyposoter exiguae* (Viereck), *Eucelatoria armigera* (Coq.) and *Chaetogaedia monticola* (Bigot) as natural enemies in Hawaii. By far the most aggressive and important of these was *E. armigera*, then considered a tachinid. It was not until 1963 that Dr C. R. Joyce clarified the identity of this parasite and pronounced it the sarcophagid *Helicobia morionella* (Aldrich). It is a U. S. mainland species and was first seen in Hawaii in April 1942. It is probable that this parasite had more to do with the subsidence of the moth than any other factor. Occasionally some trees are now reported damaged by the caterpillars, but most monkey-pod trees in the State have fully recovered and little damage is now seen.

This moth occurs in Africa, Madagascar, India, Ceylon, Burma and on through the Pacific to Tahiti and Guam. Swezey (97) reported that in 1936 it was quite common in Guam. It probably came to Hawaii from Guam during World War II a year or more be-

fore June 1945.

### **Dacus dorsalis** Hendel

Another major insect epidemic in Hawaii may be ascribed to military operations in the Pacific during World War II. On 10 May 1946, Mabel Chong, entomologist with the Hawaii Board of Agriculture and Forestry, reared this fruit fly on fruits collected in Honolulu. The fly was identified by Dr Gonzalo Merino of the Philippine Bureau of Science, who was in Honolulu at the time and familiar with the fly. Dr F. X. Williams agreed with Merino that the fly was the above species. Subsequent to this, some 25,000 fruit flies in a collection reared from fruits collected in Honolulu by O. C. McBryde between April and July 1945 were examined by him and a single specimen of *dorsalis* was found. Then W. C. Look examined a collection of fruit flies made on the island of Hawaii in November 1945, in which the same species was represented. McBryde had previously reared about 50,000 flies from fruits collected in Honolulu between November 1942 and April 1945, with no *dorsalis* appearing. This sets the probable date of entrance into Hawaii as about the summer of 1944. As much troop and other military movement occurred about this time between Hawaii and Saipan, where the fly occurred, this new pest could have come from the latter island.

By 1946 it was present on all of the main Hawaiian islands. It proved more destructive than the Mediterranean fruit fly and great concern was felt over its presence. The flies even entered houses in quantity. The writer was called to examine a new house at Waikiki, where the interior walls had been freshly stained by a pungent liquid. This fly was evidently attracted to the odor of the stain and positive swarms were on the walls.

Owing to the large number of host fruits in Hawaii and particularly the extent of wild guava thickets in the uplands, artificial repressive measures were considered futile. Dr J. H. Beaumont, Horticulturist at the Agricultural Experiment Station, University of Hawaii, was especially insistent that biological control methods be resorted to. He called many meetings with local entomologists to consider the matter. As the fly was known to occur from India through the Malay Archipelago, including the Philippines, Formosa and the Mariana Islands, plans to search for parasites in these areas were ultimately made by Beaumont's Committee. Q. C. Chock was sent to the Philippines in 1947. L. B. Uichanco cooperated with him in the work. They found and shipped four larval parasites, but they were not propagated in Honolulu satisfactorily and only a few were liberated. Then in April 1948 the Board of Agriculture and Forestry sent Mr. Krauss to the Malay Peninsula. Within a year's time he sent large quantities of *D. dorsalis* puparia to Honolulu, from which about 19,000 adult parasites representing about 14 different species were reared, some being the same as those introduced by Chock and Uichanco. These were reared in quantity in Honolulu and released.

In 1948 the project was organized on a cooperative basis between the Hawaii Board of Agriculture and Forestry, the Federal Bureau of Entomology and Plant Quarantine, University of Hawaii Agricultural Experiment Station, The Hawaiian Sugar Planter's Association and the Hawaiian Pineapple Research Institute. In July 1949 the University of California also participated, and under this organization, 14 entomologists engaged in the exploration for parasites in the Malay Peninsula, Africa, India, Australia, New Caledonia, New Britain, the Philippines, Formosa, South China, Mexico and even Saipan. Their work

covered the period June 1948 to October 1950. About 465 shipments of fruit fly material were received in Honolulu and were studied at the cooperative fruit fly laboratory at the University of Hawaii. Any parasite deemed suitable for release was then passed on to the entomologists of the Board of Agriculture and Forestry who undertook to mass breed and liberate each parasite. About 106,000 parasites were processed, representing some 40 different species. Some were readily reared on *D. dorsalis* larvae. Others imported from various countries failed to parasitize *dorsalis* in the laboratory and were discarded. Large numbers shipped by Krauss from Malaya in 1948 were liberated by the close of the year.

Without discussing the problems involved with the identity of some of the parasites that bred on *dorsalis* in the laboratory, it may be stated that three opiine parasites believed to have been sent by Krauss from Malaya in 1948, became well established. These consisted of *Opius longicaudatus* (Ash.), *Opius vandenboschi* Fullaway and *Opius oophilus* Fullaway. Of these three species, *O. oophilus* became dominant in 1950 and according to Van Den Bosch and Haramoto (98), parasitization by this species in *dorsalis* larvae in wild guavas averaged about 64% on Oahu during the last five months of 1950. It has continued to be the most effective parasite. Perhaps through some additional control by the other two parasites a very substantial subsidence in damage by the Oriental fruit fly has resulted. It is no longer in an epidemic status. Van den Bosch and Haramoto (98) discovered in May 1950 that *Opius oophilus* oviposits in the fruit fly eggs and that development is completed in the fly larva. It is thus described as an egg-larval parasite.

A general account of the entire project, covering the explorations for and importations of parasites, was published by D. W. Clancy, P. E. Marucci and E. Dresner (99), all being Federal entomologists assigned to the work.

Though the Oriental fruit fly continues to infest fruits in Hawaii, sometimes in fair quantity, the overall population is tremendously less than formerly and definite economic benefit has attended the establishment of at least three of the imported parasites.

#### **Spodoptera mauritia acronyctoides** (Guenée)

Following the arrival of the Oriental fruit fly in Hawaii, about 8 years elapsed before another serious foreign insect pest appeared. In December 1953, a moth new to the Islands was caught in a light trap near Barber's Point, Oahu. The trap was operated by the HSPA Experiment Station. Identified as above, it is known as a widespread tropical species, the caterpillars of which are grass feeders. Zimmerman (100) gives the distribution from the Red Sea to India, Ceylon, Malaya to Australia and many Pacific Islands. It was not until 10 September 1954 that it proved to be another injurious insect in Hawaii. At a meeting of the Hawaiian Entomological Society on 13 September 1954, Dr Y. Tanada reported observing heavy damage to a lawn of manienie grass, *Cynodon dactylon* (L.) Pers., in Honolulu by the larvae of this moth. Being a strong flyer it spread rapidly after first appearing at Barber's Point, and soon thereafter, complaints were frequent by many home owners in Honolulu over denudation of their lawns by this armyworm. Lawns were rendered almost completely bare in many cases, and hence it came to be known as the lawn armyworm. During the next few years residents spent large sums of money employing insect exterminators to spray their lawns. By 1958 the moth had spread to the islands of Kauai and Maui, and was reported on the island of Hawaii as early in 1959.

As lawns are indispensable in the landscaping of homes in Hawaii, there was much

demand for suitable control methods and entomologists gave the problem close attention. A complete summary of the life history, habits, growth stages, host plants and natural enemies was published by Y. Tanada and J. W. Beardsley (101). In this paper several grasses, three small sedges, and very young sugar cane seedlings were listed as host plants, but manienie (Bermuda) grass lawns were greatly preferred. Of special interest were the natural enemies listed, which included a polyhedrosis virus on the caterpillar, a number of predators, with the giant toad *Bufo marinus* (L.) and the mynah bird *Acridotheres tristis* heading the list, but parasites seemed to be of the greatest importance.

All of the parasites found attacking the caterpillars are species previously known in Hawaii. No new ones were introduced for this pest. Two are the scelionid egg parasite *Telenomus nawai* Ashmead, and the trichogrammatid egg parasite *Trichogramma minutum* Riley. Three braconid parasites were found developing on the larvae. These are the egg-larval parasite *Chelonus texanus* (Cresson), *Meteorus laphygmae* Viereck and *Apanteles marginiventris* (Cress.), all three having been introduced into Hawaii by Bianchi in 1942 for control of the sugar cane armyworm. The *Apanteles* seemed to be the most efficient of the three braconids. Two tachinid flies *Chaetogaedia monticola* (Bigot) and *Achetoneura archippivora* (Williston), and the sarcophagid *Helicobia morionella* all attack the caterpillars. It is now generally felt that the *Helicobia* is the most important of all of the natural enemies of this pest in Hawaii. At present the lawn armyworm is less conspicuous than during the first few years of its residence in Hawaii. The above battery of natural enemies must be accountable for the change, but the insect is by no means under full control at all times.

#### ***Nezara viridula* var. *smaragdula* (Fabricius)**

Records of new chance insect immigrants into Hawaii, are published annually in the "Proceedings of the Hawaiian Entomological Society." Following the arrival of the lawn armyworm, first seen in December 1953, about 142 new species were reported in the Islands up to 1 October 1961. Some were entomophagous and some phytophagous but none appeared to be economically important. However, on 15 October 1951, Frank Haramoto found the southern green stinkbug feeding on various truck crops and other plants at the University of Hawaii. Because of its history as a plant pest in several parts of the world, it was recognized as an undesirable addition to Hawaii's insect fauna. Eradication measures failed and within a month it was found in other parts of Honolulu. Between January and April 1962 it was discovered in various parts of Oahu beyond Honolulu, and by August it was on Kauai. Within another year it was found established on all of the main islands, including Lanai. As this insect is known in Guam and Samoa but not in California, it possibly came from one of those islands.

In an unpublished report by State Entomologist C. J. Davis, of 12 August 1963, some alarming facts were given covering the economic importance of the bug on Oahu by that time. He stated that "commercial plantings of string beans and soybeans have been a total loss where the bug is well established", that "the 1963 crop of Haden mangoes was rendered unmarketable from attacks by the bug" and that "*Vanda* hybrids and *Dendrobium* orchid plantings for cut flowers suffered almost a complete loss." He further stated that a survey of commercial truck crop growers on Oahu, producing snap beans, mustard cabbage, daikon, watercress, corn, broccoli, eggplant, soybeans and spinach, showed a loss of such produce, up to June 1963, of 27,000 pounds. Its attack on macadamia nuts renders

the nut unfit for consumption. Hawaii has a thriving and expanding macadamia nut industry. Great concern is felt over the probable invasion by the bug into the large macadamia orchards in areas of the Hawaiian Islands where the tree is being commercially planted.

In cooperation with the Hawaii Agricultural Experiment Station, the State Department of Agriculture has attempted insecticidal control of the pest with some success. However, owing to the wide range of both cultivated and wild hosts of the bug, eradication or satisfactory control with insecticides does not appear to be feasible.

The most practical approach towards *Nezara* control is with natural enemies. It first appeared in Australia in 1916. In 1933 the Western Australian Department of Agriculture introduced the scelionid egg parasite *Telenomus basalis* Wollaston from Egypt. It became thoroughly established and was later moved to all Australian areas where the bug occurred, where it proved to be of great value. Wilson (102) stated that "This is regarded as one of the outstanding biological control successes in Western Australia." Through correspondence with Dr Douglas Waterhouse, Chief, Division of Entomology, C. S. I. R. O., Canberra, Australia, Mr Davis received a shipment from Australia of this parasite on 6 February 1962, consisting of some 2,000 specimens. Releases and subsequent laboratory rearing of the parasite resulted in the establishment of the species with 100% of the stinkbug eggs sometimes found parasitized.

In Florida and the West Indies the tachinid *Trichopoda pennipes* F. has long been known as a parasite of adult stinkbugs. Through correspondence between Mr Davis and Dr F. D. Bennett of the Commonwealth Institute of Biological Control, Imperial College of Tropical Agriculture, Trinidad, the latter sent several consignments of puparia of this fly from Trinidad and Montserrat between March and December 1962. From these a large number of adult tachinids were reared and liberated. By March 1963 it was definitely known to be established, and by the summer of that year it was very abundant in the release areas. Mr Davis stated on 12 August 1963, that approximately 75% of adult stinkbugs in those areas were parasitized by this tachinid.

By September 1963, as a result of the work of these two parasites, an encouraging subsidence of the stinkbug has been noted in many areas in Hawaii, due to the intense and spectacular attack by these parasites. A slightly different color form of *Trichopoda pennipes* was also received from Florida and has been found established. At present it is felt that it is basically the same species as the one from the West Indies. The parasitic checking of the stinkbug again demonstrates how practical, permanent, and generally inexpensive the biological control of many insect pests in Hawaii has been.

There are many insect pests in Hawaii which have not been included in the present paper. An attempt has been made to discuss in some detail only those over which there has been public concern or substantial economic losses.

#### BIOLOGICAL CONTROL OF NOXIOUS PLANTS

Hawaii has led the world in the control of noxious plants through biological methods, and is apparently the first country to undertake such work. Pest plants such as insect pests have many natural enemies. Of particular importance are insects that attack them in their native habitats. When these can be imported into new regions such as Hawaii,

and when their feeding habits proven to be specific on the plant requiring control, much benefit can generally be expected. Such insects if imported without their own natural enemies, may sometimes multiply prodigiously and greatly diminish the vigor or abundance of the pest plant.

#### ***Lantana camara* var. *aculeata* Moldenke**

In the "Flora of the Hawaiian Islands" by William F. Hillebrand, page 342, 1888, it is stated that lantana, a native of sub-tropical regions of South America, was introduced into Hawaii in 1858 as an ornamental garden plant. The aromatic berries of lantana are greatly sought as food by the lace-necked dove *Streptopelia chinensis chinensis* (Scopoli) and the mynah bird *Acridotheres tristis* (Linn.). Their droppings of the undigested seeds have played a large part in the widespread dissemination of lantana in the lowlands of Hawaii. In a bulletin by R. C. L. Perkins and O. H. Swezey (103), Perkins states that the introduction of both the Chinese dove and the mynah bird can be held responsible for the spread of lantana in Hawaii and that without these birds "the plant would never have increased and spread to the extent that was subsequently reached." The mynah was introduced from India in 1865; the dove was also an early introduction, but we find no record of the date. Perkins also states that the dove preceded the mynah in Hawaii. A note in the Hawaiian Almanac and Annual for 1881, under the heading "Game Laws and Game of the Hawaiian Islands", mentions on page 40 that "stock doves make the town echo with their cooing at early morn." This could only have been the Chinese dove. Thus, through the agency of these birds, lantana became an important pasture pest throughout the Islands.

Perkins reported on page 2 of the above bulletin that by 1902 "very large areas were occupied by lantana" and that "Many of these dry areas are said to have afforded good pasture during the wet season before the coming of lantana." He further stated that "When one looked over miles of country covered with almost continuous growth of the plant, one might well doubt whether anything could be done to check a growth that had already acquired so strong a hold on the land."

During 1902, Albert Koebele, then an entomologist under the Commissioner of Agriculture of the Provisional Hawaiian Government, was sent to Mexico to investigate insect enemies of lantana, with the object of introducing into Hawaii insect species that he considered safe for trial. This was apparently the first time the control of noxious plants with insect enemies was ever attempted anywhere in the world. In Koebele's report to the Hawaii Board of Agriculture and Forestry, written early in 1903, and included in the above bulletin (103), he makes frequent mention of the comparative paucity of this plant in Mexico, which suggested the probable importance of the many insects attacking it there. Koebele found a large number of insects variously attacking the lantana flowers, seeds, flower stalk, leaves, stems, terminal branches and roots. By the close of 1902, he had shipped to Hawaii 23 different species. Many were found heavily parasitized upon arrival. Of those liberated, eight species became established in the vicinity of Honolulu and from there were spread to the other islands.

Of the insects established from Koebele's introductions, the lycaenid butterflies *Strymon bazochii gundlachianus* (Bates) and *Strymon echion* (Linn.) feed upon the flowers in the caterpillar stage, the tingid bug *Teleonemia scrupulosa* Stal attacks the leaves and to some

extent the flowers, the tortricid moth *Epinotia lantana* (Busck), whose larvae bore in the tender shoots, the flower heads and the fruits, the plume moth *Lantanophaga pusillidactyla* (Walker), the larvae of which feed in the flower heads, the lantana leaf miner *Cremastobombycia lantanella* Busck, the stem gall fly *Eutreta xanthochaeta* Aldrich, whose larvae form prominent galls in the twigs, and finally the lantana seed fly *Ophiomyia lantanae* (Froggatt), which places its eggs in the pulp of the green lantana berry and the larvae destroy the pulp and sometimes the embryo of the seed itself. Swezey states on page 72 (103), that by 1905 these insects were generally spread throughout the Islands, and by 1924 the area occupied by lantana was much less than formerly. Since that time, however, lantana has continued to be a pasture problem in certain areas, although not as seriously as in the early days.

In 1952 the Hawaii Board of Agriculture and Forestry resumed the search for additional lantana insect enemies; most of the work being conducted by the Board's indefatigable entomologist, N. L. H. Krauss, who has continually explored various countries in search of insects inimical to lantana and other noxious plants in Hawaii. Of important introductions by Krauss, should be mentioned the noctuid *Catabena esula* Druce, imported from Southern California and liberated in April, 1955; the pyraustid *Syngamia haemorrhoidalis* Guenée from Cuba and Florida, which was liberated in 1956; and the noctuid *Hypena strigata* F. from Kenya, East Africa, which was released in 1957. These are all leaf defoliators and have proved to be of definite importance. Davis and Krauss (104), state that following the establishment of these defoliators, "never in the history of lantana in Hawaii has it been under such attack by introduced enemies as observed during the past four years." Krauss introduced other insect enemies, some of which are established and in time may also prove effective. It can be said that lantana will no longer be feared as a serious pasture pest owing to the persistent attack by the several imported natural enemies.

#### **Pamakani, *Eupatorium glandulosum* Humboldt, Bonpland & Kuntli**

This branching composite shrub, considered a native of Mexico, was apparently introduced into the island of Maui about 1879 for medicinal purposes or possibly as an ornamental because of its showy clusters of white flowers, according to Pope (105). A member of the thistle family, the seeds are equipped with structures which enable them to drift through the air. It spread rapidly over pasture lands on Maui and in time completely occupied some 25,000 acres of good pasture land to the almost complete exclusion of grasses and other plants. It also reached the islands of Lanai, Molokai and Oahu.

During 1923-24 H. T. Osborn, then Assistant Entomologist of the HSPA Experiment Station, investigated this plant in Mexico. He (106) listed a large number of insects which he found living on this plant, and also stated that pamakani was never found in a cultivated field or pasture and that it was of no economic importance in Mexico. None of the insects were introduced into Hawaii at that time, but Osborn's work formed the basis for a later valuable introduction. In July 1944 Mr Krauss went to Mexico to study the plant there and possibly introduce one or more of the insects reported by Osborn. Between January and July, 1945, he made frequent shipments of a trypetid fly *Procecidochares utilis* Stone, the larvae of which develop in the terminal shoots of the plant, form conspicuous galls which prevent the formation of flowers and seeds and also weaken the stems. Liberations were made on Maui in May 1945, and on Oahu prior to that date. It quickly became established.



Within a few years, results were astonishing. Pemberton (107) visited the infested area on Maui on 28 April 1950. The shrub was found dying out over thousands of acres, and the ranch was engaged in re-establishing pasture grasses where formerly nothing but pamakani grew. Where living plants could be found they were, without exception, heavily damaged by the fly.

#### The Prickly Pear Cactus, *Opuntia megacantha* Salm-Dyck

According to Pope (108) the prickly pear cactus is believed to have been brought to Hawaii from Acapulco, Mexico by Don Marin, probably a little before 1809. It is a tropical American species and has spread to all the main Hawaiian islands. Being highly adaptable to Hawaiian conditions, it ultimately assumed pest proportions in pasture lands, particularly on the island of Hawaii. Entomologist Q. C. Chock (109) reported in 1945 that "As long ago as 1930, some of the ranchers were very much alarmed over the rapid spread of the prickly pear and in some of the older cactus areas it was not only difficult but in many places impossible for the cowboys to drive cattle through it." This was particularly the case on the great Parker Ranch on the island of Hawaii and on the adjacent Kahua Ranch. By 1945 thousands of acres of good pasture land on these ranches were rendered useless by the ever expanding cactus.

Australia has had a similar problem with cactus species, notably *Opuntia inermis* DC and *Opuntia stricta* Haw. By 1925 these species occupied some sixty million acres in Queensland and New South Wales. Between 1921 and 1935, 48 insect species that attack cactus in North and South America were imported into Australia, about a dozen of which became established. Of this lot, the phycitid moth *Cactoblastis cactorum* (Berg), which was obtained from Argentina, proved the most effective and devastating to the cactus. It was introduced in 1925 and by 1928 vast areas of cactus had collapsed and the lands were permanently restored for pasture purposes. A modern review of this work was given by Wilson (110). The results in Australia prompted the Hawaii Board of Agriculture and Forestry to undertake a similar attack against the cactus in Hawaii. A study of the problem began in 1943 but no direct action was taken until 1949.

Several cactus feeding insects were imported from California and Texas between 1949 and 1951, but these proved unsuitable. It was then felt that the cactus insects which were so successful in Australia, might be worth trying in Hawaii. Through the cooperation of the Commonwealth Prickly Pear Board, the mealybug *Dactylopius confusus* (Cockerell) was imported from Australia on 29 June 1949, and released on the island of Hawaii the following August. It proved highly adaptable to *Opuntia megacantha* and was widely spread on the two large ranches on Hawaii. It multiplied prodigiously, especially in the lowlands where the cactus was rampant, and within a few years the cactus died out in these areas. About the only evidence of previous cactus infestation was the remains of dead cactus stumps.

Then on 6 February 1950, a consignment of eggs of the phycitid moth *Cactoblastis cactorum* was received from Australia and a second lot some time later. In April 1950 this species was approved for liberation on the Parker Ranch on the island of Hawaii. This large, strong flying moth spread rapidly after initial establishment and heavily damaged the cactus over a large area. In time it spread to all of the main Hawaiian islands. The moth larvae mass inside the cactus pads and cause their complete collapse, having an effect in either eradicating or reducing the development of cactus in very large areas.

The third insect imported from Australia is the large cerambycid borer *Archlagocheirus funestus* (Thoms.), the larvae of which bore in the main cactus stems or trunks. It was introduced into Australia from Central Mexico in 1935. It was received from Australia on 26 November 1950, and 15 September 1951. Screening tests in the laboratory against various plants proved negative. It was successfully reared on cactus in the laboratory and adults were released on the Parker Ranch during 1951 and 1952, resulting in establishment.

In the report of the Board of Commissioners of Agriculture and Forestry for the Biennial Period Ending 30 June 1958, it is stated that the three cactus insects imported from Australia "continue to increase their range and are doing good work in the control of this pest plant on the ranches. Large areas formerly overrun with cactus have been reclaimed and grass planted on many ranches", and that "these areas were of little value for cattle grazing prior to the introduction of the cactus insects." Much of the above information has been taken from an unpublished report prepared late in 1952 by Dr Fullaway, who was in charge of most of the work, and to whom much credit is due.

Other work is being done by the Board towards the biological control of undesirable plants with some promising results. Special mention should be made of success in control of the pasture weed pest *Emex australis* Steinh. with a stem-boring weevil *Apion antiquum* Gyllenhal, introduced by Krauss from South Africa in January 1957.

#### THE GIANT AFRICAN SNAIL *ACHATINA FULICA* BOWDICH

This large African snail came to Hawaii late in 1936 in two importations. Eight living adults were received through the mail from Japan by a Maui resident on 30 November 1936; also about the same time, a woman returning from Formosa, brought in two living adults to Honolulu. Both importations escaped detection at the port of entry. This snail had been advertised in Japan as a valuable food for medicinal purposes. It was not until early in April 1938 that the Hawaii Board of Agriculture and Forestry learned of these importations, and by that time progeny from the two lots had escaped confinement by the owners. Every effort was made by the Government to eradicate the snail in the escape places, but without success, and the snail spread widely over Oahu and parts of Maui. It has also gained a foothold on Kauai and the island of Hawaii. Its early history has been discussed by Pemberton (111).

It was early recognized that Hawaii had a new and distressing problem. The record of this snail as a pest and general nuisance covers a long story beginning about 1803 in its movement by man from Africa to Mauritius, Madagascar, India, Ceylon and Indo-Malaya. During World War II, it was generally spread over the Pacific by the Japanese as a possible emergency food. With omnivorous food habits, including both dead and living plant material, all attempts at eradication failed. It attained great notoriety in Hawaii and clamors for control have been frequent by the general populace.

Though not strictly an entomological problem, control naturally fell into the hands of the entomologists and a great deal of their time has been spent on biological methods to restrain its development and spread in the Islands. This began with studies and possible natural enemies in East Africa by Dr F. X. Williams in December 1947, under the auspices of the Pacific Science Board, National Research Council, National Academy of Sciences. He concluded his work in June 1948. Though he found certain predatory beetles attack-

ing the snail, he concluded that carnivorous, streptaxid snails, notably *Gonaxis kibweziensis* E. A. Smith, appeared to be the most important natural enemy.

Williams returned to Honolulu on 24 June 1948 with living specimens of *Gonaxis*, together with some predatory beetles. The *Gonaxis* snails were studied in the laboratory by Dr Yoshio Kondo, malacologist of the Bishop Museum, who demonstrated their value as predators of young *Achatina* snails and otherwise harmless to vegetation. To test the habits of this *Gonaxis* in the field before release in Hawaii and elsewhere, it was decided to establish it first on Agiguan, an isolated island in the Mariana Islands, where the African snail was very abundant. R. Tucker Abbott, then Associate Curator, Division of Mollusks, U. S. National Museum, went to East Africa in April 1950, and obtained a quantity of *G. kibweziensis*, 300 of which were liberated on Agiguan by R. P. Owen on 1 June 1950. For the next few years teams of investigators visited Agiguan and finally concluded that the *Gonaxis* was apparently responsible for a great decline of the giant snail on the island.

The results on Agiguan prompted the Hawaii Board of Agriculture and Forestry to send Krauss in 1951 to Africa to obtain *Gonaxis* for liberation in Hawaii. He succeeded in shipping many living specimens to Honolulu, which were released on Oahu in June 1952. More were obtained from Agiguan during 1954 and 1955 and released on Oahu and Maui. A final lot was obtained in East Africa by Krauss in 1957. This work resulted in the thorough establishment of the *Gonaxis* in Hawaii, where it was credited in a considerable control of the snail in some areas.

A second predator *Euglandina rosea* (Ferrusac) was obtained by Krauss in Florida and introduced into Hawaii in November 1955. Following liberations on Oahu it multiplied and spread rapidly and is believed to be successful. A third, and important predator is *Gonaxis quadrilateralis* (Preston), which Krauss collected in East Africa and shipped to Hawaii in 1957 and released in June of that year. It is somewhat larger than *G. kibweziensis*. It spread very well where liberated. Davis and Krauss (112) state that by December 1961, *G. quadrilateralis* "now appears to be the most effective predator of the African snail." Both species of *Gonaxis* prey heavily on newly hatched *Achatina* snails. The snail now appears to be greatly reduced in some areas where it was formerly very abundant.

About 20 other snail-feeding predators were brought to Hawaii from Africa, the Philippines, Ceylon, Cuba, Japan and California between 1952 and 1959, with little or no success following liberation.

Dr A. R. Mead, Professor of Zoology, University of Arizona, has conducted elaborate studies of a possible disease of the snail, symptoms of which he found in all Pacific and Ceylon regions examined, including Hawaii. It is now reasonably expected that the three main predators established in Hawaii will ultimately reduce the snail to a fairly uneconomic level, and, according to Mead, other factors may also play an important part in the decline of the pest.

#### PLANT QUARANTINE IN HAWAII

By 1890, many destructive insects had invaded Hawaii and it was deemed necessary to establish quarantine laws against future invasions. Under King Kalakaua, Chapter 2, Sections 2 to 6, "Laws of the Hawaiian Islands", 1890, was enacted which related to the prevention of introduction of any plant disease, whether blight or insect pest, and to the ex-

termination of any already established. In 1892 an additional law was enacted in Chapter 81, Section 4, "Laws of the Hawaiian Islands", which established the Bureau of Agriculture and Forestry with more provisions for guarding against invading insect pests, but these laws did not provide for the employment of inspectors to enforce them. It was not until 1902 that Perkins became a consultant to the Bureau of Agriculture and Forestry and undertook actual inspection of imported plant material. Under Act 44 of the Territorial laws of 1903, approved 25 April 1903, the Board of Agriculture and Forestry was organized, and the act provided for a building and apparatus for quarantine and disinfection of fruits and for the obtaining and distribution of beneficial insects. The act also authorized the appointment of a Superintendent of Entomology and an assistant. Thus on 18 May 1903, Albert Koebele was appointed Superintendent of Entomology with Dr Perkins as Assistant Superintendent. Perkins continued to serve officially as a plant inspector until he and Koebele left for Australia on 11 May 1904 in search of parasites of the sugar cane leafhopper. Perkins was appointed Superintendent of Entomology at the HSPA Experiment Station in August 1904, and the plant inspection work for the Board of Agriculture and Forestry was taken over by Alexander Craw, who was appointed 12 August 1904. Prior to his appointment, Craw was Horticultural Quarantine Officer for the State of California.

Mr Craw died 28 June 1908, and was succeeded by Jacob Kotinsky, who served as Chief Plant Inspector until the appointment on 1 October 1909, of E. M. Ehrhorn who served both as Superintendent of Entomology and Chief Plant Inspector for the Board of Agriculture and Forestry. Ehrhorn also came from California, where he was Horticultural Quarantine Officer for the State. Under Craw and Ehrhorn the Territorial plant inspection service expanded to a fair degree of efficiency and when Ehrhorn retired, the inspection staff consisted of nine regular and six Honorary Inspectors. D. T. Fullaway became Territorial Entomologist on 1 September 1926, with the additional title of Chief Plant Inspector, with L. A. Whitney as Assistant Plant Inspector. Upon Fullaway's retirement on 1 June 1948, William C. Look was appointed Inspector in Charge of Plant Quarantine on 1 September 1948, and serves in that capacity to the present date. Q. C. Chock succeeded Fullaway until retirement on 31 December 1960. Chock was then succeeded by C. J. Davis, who was given the title of State Entomologist. During the regimes of Fullaway, Chock and Davis the plant inspection service was taken over entirely by Mr Look with advisory aid from the Chief Entomologists.

Federal participation in plant quarantine work in Hawaii began with the enactment by Congress on 20 August 1912 of the Federal Plant Quarantine Act and the establishment of the Federal Horticultural Board in September 1912. The threat of the Mediterranean fruit fly and the melon fly to fruit and vegetable industries on the mainland resulted in the Horticultural Board sending Dr E. A. Back to Hawaii in September 1912, to establish a Federal Plant Quarantine station in Honolulu. Back was joined by Pemberton in March 1913. Apart from biological studies of fruit flies in Hawaii, their principal duties involved inspection and certification of bananas for shipment to California, which was a large business at that time. Back remained in charge of the Federal Station through 1915, and was succeeded through the years by Pemberton, H. F. Willard, A. C. Mason, Richard Faxon, C. L. Ritchie, K. L. Maehler, Ivan Rainwater and G. W. Dyson.

There has been close cooperation in the plant quarantine service between the Federal and Hawaiian offices. On 12 December 1949, the Federal service assumed quarantine in-

spection of overseas (foreign) ships and planes, plus the interception of fruit flies and other insects on ships and planes, both domestic and foreign, leaving Hawaii for the U. S. mainland. In spite of the annual invasion of new insects into Hawaii, large staffs of both State and Federal quarantine agencies are operating as intensively and effectively as possible, and without this service many more insect pests would be in Hawaii than at present.

In the light of our past history it is inevitable that additional pests will become established in Hawaii, some of which may seriously affect our economy. However, it is reassuring to know, as summarized in this paper, that Hawaiian entomologists have generally succeeded in effecting a reasonable, and sometimes remarkable, control of many of our most destructive insect pests. I anticipate similar results in our warfare against future invasions.

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