Brown planthopper migration

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The growth of populations of *Nilaparvata lugens* and *Sogatella furcifera* in Japan starts from immigrants transported from the south by a warm and humid maritime air mass. Inflow of the air mass is induced by a depression or depressions traveling northeastwards along the frontal system, which appears in the rainy season called *bai-u* in the Far East. When a depression emerges in the Chinese continent between 25 and 35°N and proceeds rapidly northeastward along the Japan Islands, a mass immigration of *N. lugens* and *S. furcifera* occurs. There are more *S. furcifera* than *S. lugens* in most cases. When the route digresses to the north or south, a minor immigration of only *S. furcifera,* or of *S. furcifera* accompanied by *N. lugens,* occurs.

Migration surveys on the East China Sea, in which three net traps were set up on a boat, showed that of more than 60 species of small insects that were traveling in the rainy season, *S. furcifera* was the most numerous, followed by *N. lugens* then by *Laodelphax striatellus,* the small brown planthopper. All the insects were concentrated within 200 to 300 km south or north of the front where southwest winds prevail.

A general survey of the immigrant density was carried out soon after a typical mass immigration in 1969, which covered the whole of Japan. An insect net sweep of 50 strokes was taken as a sampling unit. The density in logarithmic scale decreased linearly with distance from the west coast of Kyushu Island.

Among various traps tested, a parallel use of a net trap and a yellow-pan water trap was the most adequate for estimating the time and the density of immigration. Catches of 10 *N. lugens* by a net trap and 50 by water trap are tentatively designated as the threshold above which hopperburn will appear within two to three generations.

THE BROWN PLANTHOPPER (BPH) *Nilaparvata lugens* (Stål) is an important pest of the rice plant. It is characterized by its high migratory ability and its high reproductivity on modern, susceptible rice varieties. Many small insects, such as aphids, leafhoppers (Jassidae), and flies, can be carried over long distances by wind; but the planthoppers (Delphacidae) have higher migratory ability. Among the planthoppers that infest rice and other cereal crops or gramineous

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weeds, *Sogatella furcifera* seems to have the highest migratory ability, *N. lugens* the next highest. Immigrant masses of *S. furcifera* sometimes invade fields of young seedlings and injure them seriously, but their offspring rarely cause damage later. *S. furcifera* is not sedentary enough to build up populations that injure rice as does *N. lugens.*

The growth of BPH population begins with immigrants. In the rapid increase of population that follows, the short-winged form plays an important role. When a certain population density is attained, the host plant withers (Kisimoto 1976a, b). Immigration–over a long distance or a short one—depends on the flight of the long-winged adult. Several processes constitute the migratory phenomenon: takeoff, traveling, landing, and short-distance flying before settling down to a preferred habitat. Techniques for collecting flying insects or estimating the density of migrating insects are also important in the study of migration.

LONG-DISTANCE MIGRATION

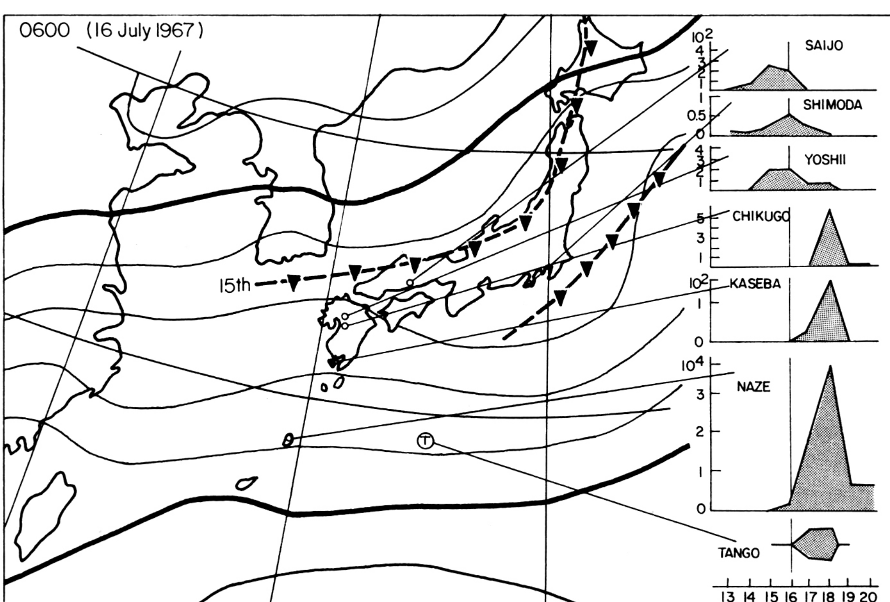
Whitebacked planthopper and BPH infest rice grown in tropical Asia, in temperate Asia up to the northern region of the Chinese continent, and in Korea and Japan. The whitebacked planthopper is much more widely distributed than BPH; it covers areas northeast of China, Vladivostok, U.S.S.R., and Hokkaido, Japan.

There has been long-standing disagreement about the modes of overwintering of the two species. In Japan the species have no apparent resting state in which to survive a severe winter after the rice plant dies and no alternative host plant. Yet, in the rainy season they suddenly appear in light traps or paddy fields, sometimes in large numbers. Until recently, the features of their migration were not understood, partly because their small size renders visual observation difficult, and partly because most surveys have used light traps, which function only on calms. But Tsuruoka's observations opened a new dimension in the discussion (Asahina and Tsuruoka 1968), and the many facts that have accumulated show that planthoppers migrate long distances—several hundred kilometers or more.

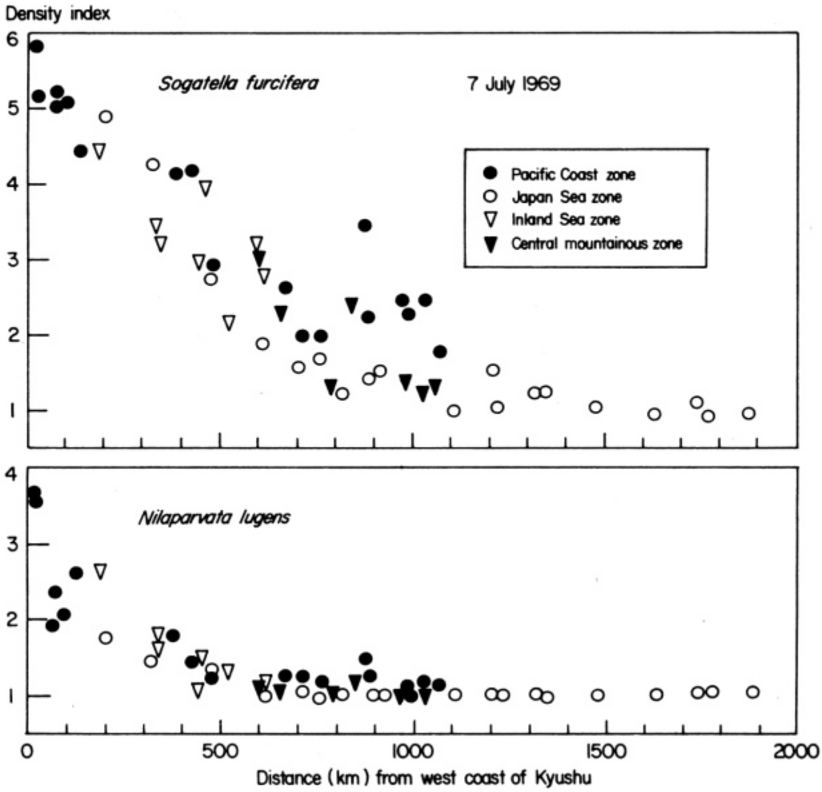
At Tango, an ocean weather station 135°E, 29°N, about 500 km south of the Japanese mainland, Asahina and Tsuruoka (1968) reported that two whitebacked planthoppers flew into a light on board the ship on 15 July, and several thousands the next day. Throughout the day of 17 July the weather ship was in the midst of masses of swarming *S. furcifera* and a small proportion of BPH. The swarms were observed until 0600 on 18 July, when the wind, until then southwesterly, became west-northwesterly or northwesterly and the number of planthoppers apparently decreased. Tsuruoka supposed that the air at the station at 2100 of 16 July came from south of 20 N, east of the Philippines. However, light trap records in western Japan showed distinguishable catches from 13 to 14 July (Fig. 1). Catches were much larger in western Japan, particularly in Kyushu and the southern islands, but interestingly catches were obtained 2 to 3 days earlier in the central Pacific coast zone than in Kyushu or at Tango. It seems plausible that those widely separate catches came from the same mass of migrating planthoppers.

In Chikugo, a southwesterly south wind started to blow at 1100 of 13 July and lasted until 1900 of 17 July, mostly at speeds of 20 to 30 km/hour, making light-trapping unfeasible. A distinguishable catch was then obtained on the calm night of 18 July. A cold front over the northern part of the Japanese mainland slowly moved southward and approached the Japanese islands on 15 July. The broad weather pattern seemed associated with light-trap catches of planthoppers moving stepwise from north to south, and Tango seemed to be the midst of such movement on 16 to 17 July.

In 1968, Tsuruoka (Asahina and Tsuruoka 1968) observed several hundred planthoppers, most of them BPH between 2130 and 2230 of 6 July at Tango, when a southwesterly wind, 24.2 to 24.6°C, blew at 4 to 7 m/sec. After the passage of a cold front at 2230, the temperature dropped 1 C and the number of planthoppers suddenly decreased. Distinguishable light-trap catches, mainly of BPH were observed in the central and western Pacific Coast zone; they were particularly large in southern Kyushu on 5 and 6 July. In 1969, Kisimoto



1. Synoptic map for 16 July 1967, when a mass of planthoppers was found at the Ocean Weather Station, Tango (T). Light trap records showing simultaneous catches at various stations are shown on the right. The broken line shows the front's position on 15 July



2. Relationship of prefecture's average density index to prefecture's distance from the west coast of Kyushu. Density index: 1 = no planthoppers; 2 = 1–5; 3 = 6–25; 4 = 26–125; 5 = 126–625; 6 = more than 625.

(1976b) reported a large-scale immigration of whitebacked planthopper and BPH on 25 and 26 June.

All facts strongly suggest that an area stretching more than 2,000 km from west to east is involved in the planthopper migration assuming the nearby continent to the west to be the migration source.

A general survey covering the whole of Japan, coordinated by the Section of Plant Protection, Ministry of Agriculture and Forestry, was carried out on 7 July 1969. Three typical immigration peaks, all involving whitebacked planthopper and BPH were observed from 25 June to 7 July (Kisimoto 1976b). Depending upon the number of pest-forecasting inspectors, 50 to 150 fields were sampled in each prefecture. Fifty sweeps with a 36-cm-diameter insect net were made on each paddy field. The planthopper densities were categorized on a logarithmic scale according to the number of insects collected (Fig. 2). The average density index for each prefecture is shown along with the distance of the prefecture's medium point from the west coast of Kyushu. Each prefecture was categorized as belonging to one of four zones: the Kyushu and Pacific coast zone, Japan Sea coast zone, inland sea zone, and central mountainous zone. All the Tohoku and Hokkaido districts were placed in the Japan Sea coast zone because the wind favoring the immigration of planthoppers in these areas seemed to come through the Japan Sea. Nagano, Gifu, and Kyoto prefectures, wide and heterogeneous, were each divided into two zones, and Hokkaido into four.

It is apparent from Figure 2 that the density index for both whitebacked planthopper and BPH decreases linearly with distance from the west Kyushu coast. That of BPH for a given locality is about one-half or one-third that of the whitebacked planthopper which means that actual populations of BPH are 1/25 to 1/125 those of the whitebacked planthopper. A few whitebacked planthoppers were collected as far as north as Hokkaido, and BPH as far as Yamagata and Ibaragi, which an autumn survey had shown to be the eastern limit of hopperburn-injury zone. From 26 June to 5 July 1969, Mochida (1974) collected 2,669 whitebacked planthoppers and 2,739 BPH on the East China Sea—almostthe same numbers. The migratory ability of the white-backed planthoppers appears to be much higher than that of BPH.

In a second general survey of the same type carried out 16 to 17 July, the same linear relation between distance and density index was found for both species, but the density of BPH was much lower than that in the previous study because substantial immigration of BPH had ended by 5 July (Kisimoto 1976b).

Tsuruoka also collected many planthoppers at Tango from August to October in 1967 and 1968 (Asahina and Tsuruoka 1968). The planthoppers were believed to be carried by north or northwest winds converging in the autumnal fronts that appear in the transitional period from summer to autumn in temperate East Asia. Itakura (1973) confirmed that by observation at Tango in 1973. In these cases, the planthoppers and other small insects were considered to have emigrated from western Japan.

COLLECTION OF MIGRATING INSECTS ON THE EAST CHINA SEA

Since 1969 survey voyages for collecting migrating insects have been made during the rainy season in the East China Sea. *S. furcifera* and *N. lugens* were the most numerous of the insect species collected (Table 1). Insects were caught in three 1-m-diameter tow nets 1.5 m deep; those flying into lights were collected by an aspirator. The third largest catch was that of *Laodelphax striatellus,* the small brown planthopper which is distributed widely in subtropical and temperate Asia, but in the Philippines is found only in mountainous areas (Kisimoto 1975). *Nilaparvata muiri* is distributed on the Chinese continent, Japan, and Korea. The densities of several predaceous mirid bugs, particularly *Cyrtorhinus lividipennis* and *Tytthus chinensis,* were comparable, but the density of *Tytthus chinensis* in tropical Asia seemed extremely low (R. Kisimoto,

Table 1. Migrating insects collected on the East China Sea.

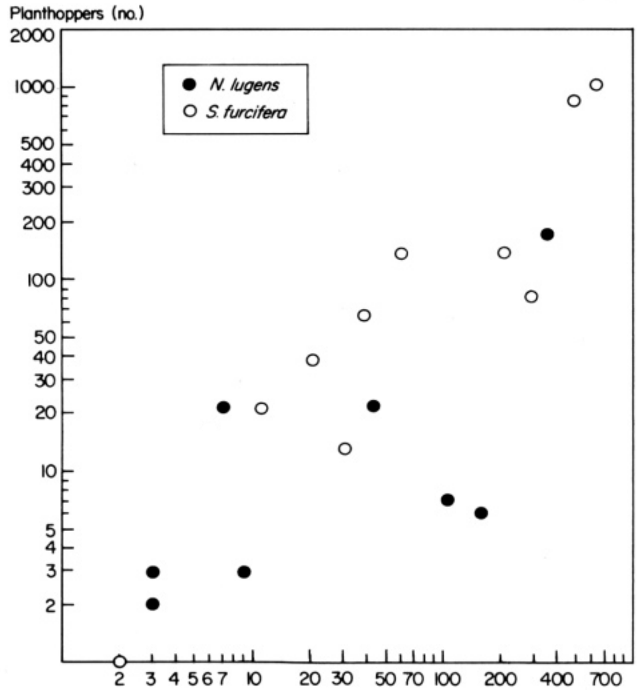
Species	Insects collected (no.)		
	9–18 July 1969 (R. Kisimoto)	22 June– 2 July 1971 (R. Kisimoto)	25 June– 1 July 1973 (T. Iijima)
S. furcifera	2010	98	618
N. lugens	650	10	129
L. striatellus	96	45	46
S. panicicola	61	11	64
N. muiri	9	0	0
P. propinqua	2	0	5
Other delphacids	4	0	2
Cyrtorhinus lividipennis	47	6	41
Tytthus chinensis	25	0	28
N. cincticeps	6	0	0
N. virescens	0	0	2
Other jassids	22	4	0
Others	161	12	53
Total	3093	186	988

unpubl.). Only a few *Nephotettix cincticeps* and other *Nephotettix* species were collected, although they multiply widely on rice in the area from which they were believed to have migrated. *Nephottetix* species seem to have a weaker migratory ability.

The correlation between numbers of whitebacked planthoppers or BPH caught in the East China Sea and on Chikugo by tow nets during the same period is shown in Figure 3. Catches showed large yearly fluctuations but were highly correlated.

METEOROLOGICAL FACTORS INDUCING IMMIGRATION

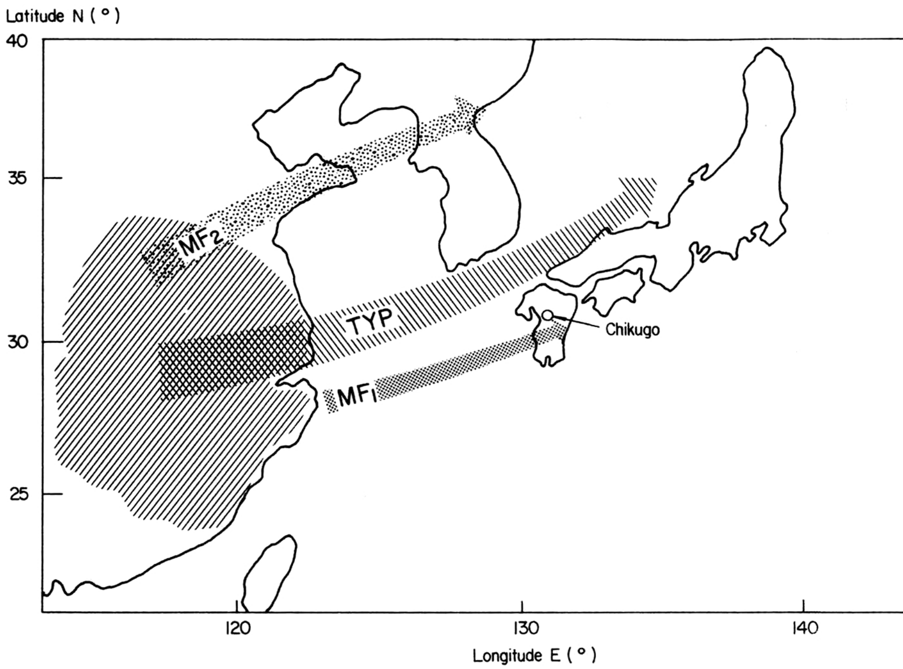
Kisimoto (1976b) analyzed broad weather patterns inducing long-distance immigration into Japan. The inflow of warm and humid air from the south favored the sudden appearance of planthoppers. The air flow was associated with the passage of a depression along the frontal zone called *bai-u* in temperate East Asia. The 40 immigration peaks of planthoppers from 1967 to 1972 were categorized into mass or minor immigrations according to the density of the trapped insects. Seven categories of broad weather patterns were used in the analysis (Kisimoto 1976b). Most immigrants were induced by a depression or successive depressions that emerged from the central part of the Chinese continent between 25°N and 35°N and proceeded eastward through a range between the observation point at Chikugo and about 600 km north (Fig. 4). This route was categorized as typical. Warm and humid southwest winds blew 19.3 hours at an average speed of 32.9 km/hour. When the route digressed a little to the north or south, minor immigrations occurred. In the final stage of the rainy season, southwesterly winds sometimes lasted 3 or 4 days, and in most cases inducing minor immigrations, but sometimes mass immigrations



3. Correlation between simultaneous planthopper catches (male and female) on the East China Sea and on land (Chikugo) during rainy seasons. 1960–72

as in 1967. Only the whitebacked planthopper appeared in one-half of the minor immigrations. Maximum wind speed averaged 23.1 km/hour for minor immigrations of both planthoppers and 16.6 km/hour for those without BPH. The latter type of immigration tended to occur at the beginning of the immigration season when temperatures were lower.

Typical mass catches by the tow net at sea or on land, or collections by aspirator at sea were often observed in a warm sector, 200 to 300 km south of a cold front (Kisimoto 1971) (Fig. 5, 6). But north of the frontal zone planthoppers were often collected as far as 400 to 500 km away. Itakura (1973) analyzed the relation between frontal systems and migrating insects at Tango, and found that during the *bai-u* season insects were at points within 100 km south and 400 km north of a front, and in autumn 100 to 400 km north and 300 km south. Unstable air currents, showers, and turbulence in the frontal system seem to induce the landing of insects traveling along with the air mass.



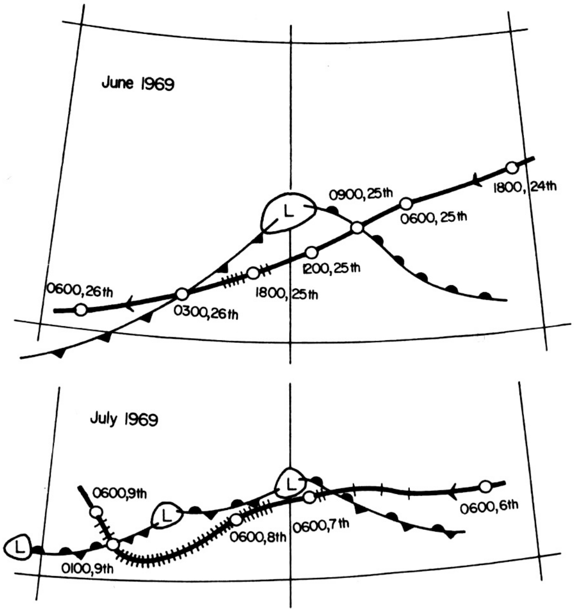
4. Paths of depressions associated with typical mass immigrations (TYP) and with minor immigrations of both *S. furcifera* and *N. lugens* (MF_2) and of *S. furcifera* alone (MF_1).

FLIGHT BEHAVIOR OF PLANTHOPPERS

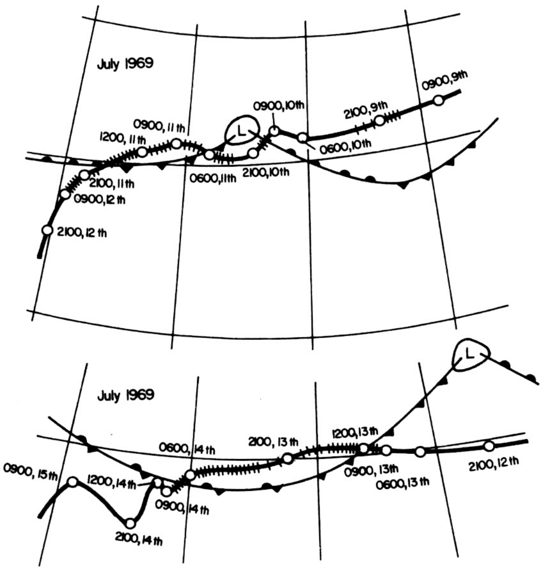
After a teneral period of 22 to 23 hours at 27.5°C (Ohkubo 1973), long-winged adults of *N. lugens* tend to take off spontaneously. An insect ready to take off, goes up to the top of a host-plant leaf, then takes off and flies upward. If wind is blowing, it drifts. This flight behavior seems to be quite different from the sporadic flight of the insect when disturbed (Ohkubo and Kisimoto 1971).

Takeoff periodicity surveyed by a Johnson-Taylor suction trap showed a typical crepuscular bimodal curve during summer and early autumn. Takeoff was most frequent at light intensities of 1 to 200 lux, with the maximum observed at 100 lux. This light intensity occurs within a quarter of an hour of sunset or sunrise. Takeoff frequencies were fundamentally the same at dawn and at dusk and were unaffected by temperatures above 20°C.

When temperatures went down in autumn, the bimodal curve was modified; when they were higher than 22°C, the bimodal peaks were found at 50 to 1,000 lux. When the dawn temperature was 13°C, takeoff was observed only at dusk at 18°C and at 50 to 4,000 lux. In late autumn, when dawn temperature was 13°C and dusk temperature was 12°C, takeoff was observed only in the daytime. The temperature threshold for takeoff was estimated as 17°C. Winds higher than 11 km/h in the open air inhibited takeoff.



5. Position of observation point Chikugo in relation to the frontal system. Good catches by tow nets are indicated by short bars on the track showing the position of Chikugo moving westward. Numbers on open circles mean the hour and date when Chikugo was located. O-O-O = position of Yoko-maru, [frontal symbol] = frontal system.



6. Position of the survey ship Yoko-maru relative to the frontal system on the East China Sea.

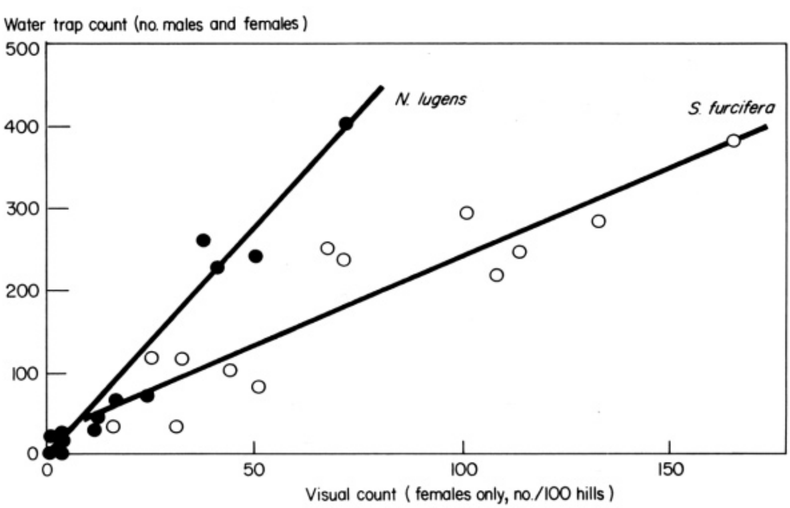
Takeoffs of *N. cincticeps* formed a unimodal distribution pattern at dusk; dawn takeoff was sporadic. Light intensity for takeoff was 0.1 to 20 lux—much lower than that for BPH (*N. cincticeps* is considered to be an unlikely long-distance migrant). Winds higher than 12 km/h clearly inhibited takeoff.

In tethered flight in the laboratory, a few BPH began continuous wingbeating at 10°C, and one-half of the individuals, both male and female, started to do so at 16.5°C. The temperatures are much higher than those for aphids. Winds do not favor the continuation of wingbeating, which decreased linearly with increased wind velocity. No wingbeating was expected at 5.6 m/second. In a series of velocity-increasing experiments, 15 individuals stopped wingbeating at 5.5 m/second; on the average in a velocity-decreasing series, they started to do so at 5.1 m/second.

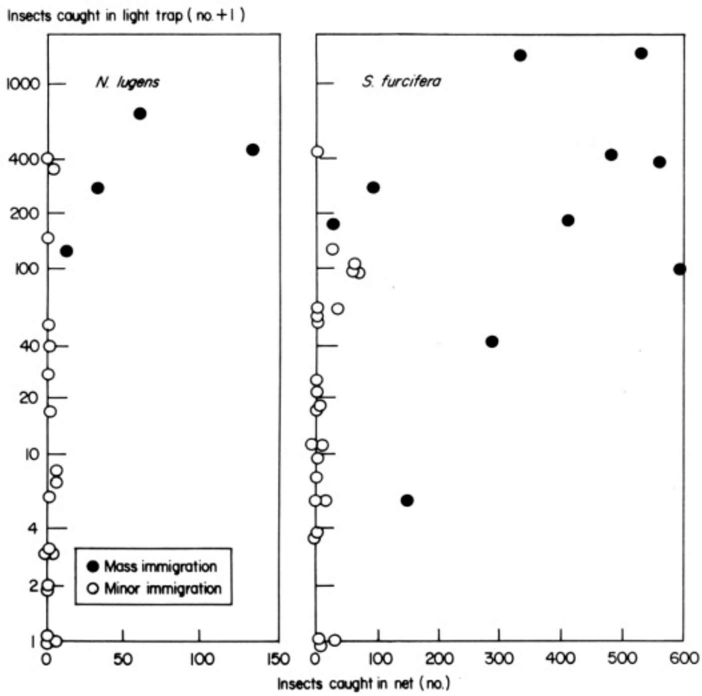
High humidity favors a longer flight period, as well as the ability to endure longer fasting. Most BPH in the experiment kept up wingbeating for more than 10 hours at 85% relative humidity; the longest wingbeating lasted 23 hours. The period of wingbeating was about one-half as long as the life span without food. Wingbeating clearly induces a decrease in body weight in the first 2 to 3 hours; in 5 to 6 hours it consumes 20% of the original body weight in both male and females.

VARIOUS TRAPS FOR ESTIMATING PLANTHOPPER DENSITY

In addition to visual counting in the paddy field, the light trap, the yellow-pan water trap, and the tow net have been used to help estimate insect densities.



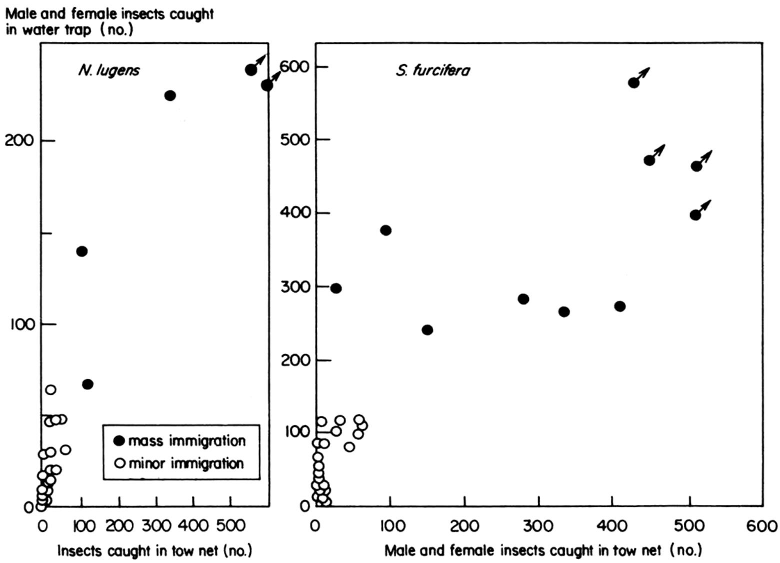
7. Correlation between number of females per 100 hills recorded from a visual count and number of males and females caught by a water trap set in the same paddy field within 3 days of the count.



8. Correlation between planthopper catches in two net and in light trap for each immigration peak, 1968–72

Traps depend on insect flight behavior and different ones may give different results. The tow net seems to be the most direct method of collecting flying insects, but it functions only when wind is blowing. Density estimated by the tow net shows the average trend of immigration in a relatively broad area. Low cost and easy handling favor its extensive use in wild or remote areas, or at sea. The yellow-pan water trap is also easy to handle, and has yielded fairly good correlation between the number of females counted visually and the number of planthoppers caught by water trap (Fig. 7). The correlation coefficient is very high. Efficiency of the pan-water trap is higher with BPH than with whitebacked planthopper and in both species but particularly in BPH the male is much more attracted to the trap than is the female (Kisimoto 1976a,b).

The light trap is one of the most widely used tools in estimating insect density, but it functions only on calm night. Catches by net and by light trap are not linearly correlated (Fig. 8). On the whole, the combined use of the net and the water trap seems to provide the best estimates of immigrant density. Catches of more than 10 BPH individuals by net and of more than 50 by water trap should be considered evidence of an important immigration that will ordinarily cause hopperburn after the crop's heading stage (Fig. 9).



9. Correlation between catches in tow net and in water trap. ♂ means that the actual figure is far from where it should be but is placed there to shorten the scale.

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