12. LONG DISTANCE MIGRATION OF PLANTHOPPERS, *SOGATELLA FURCIFERA* AND *NILAPARVATA LUGENS*

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Introduction

Migrations of small insects have been analyzed by various methods and many valuable results have been accumulated (Johnson, 1969). However, migrations themselves are not always seen and records of observations by volunteers are much less frequent than those of butterflies, moths and other large insects. Migrations of small insects are spoken of as in voluntary, or as passive transportation by winds. Their importance, however, is not at all inferior to that of large insects.

Overwintering of the white back planthopper, *Sogatella furcifera,* and the brown planthopper, *Nilaparvata lugens,* is unknown; Murata (1941) failed to present a simple possibility of overwintering under usual conditions of winter within Japan Mainland. He and other workers failed to show overwintering at any stages and low cold hardiness, no special hibernating stages and complete withering of rice plant, which had been considered to be the sole food plant of the two planthoppers in natural conditions, are the main reasons of lack of overwintering. All the planthoppers kept under observations in laboratory or natural conditions died before severest season in February. However, several workers insisted on the possibilities of overwintering within Japan under certain circumstances and made trials in various localities of artificial overwintering. On the other hand, the two planthoppers invade into paddy fields soon after the transplantation of rice plant every year, number of invading insects varying with year or locality.

These complicated situations as to the real state of overwintering are recently nearing a complete solution because survey navigations into the Pacific Ocean and East China Sea as well as continuous tow net collections on land indicate that there is, instead, long distance migration.

Biology of *Sogatella Furcifera* and *Nilaparvata Lugens*

The two planthoppers feed on the rice plant and cause severe damage that results in complete withering when hundreds of nymphs and adults crowd on a single hill of rice plant. Miserable famines recorded in Japanese history are considered to be induced mainly by infestation of these planthoppers. They do not transmit virus diseases in Japan though *N. lugens* transmits the virus of grassy stunt disease in the Philippines.

The two species are widely distributed in Southeast Asia. *S. furcifera* extends a little farther northwards in Saghalien and Siberia than *N. lugens.* No considerable populations of *N. lugens* are found in the northern Japan, Tohoku and Hokkaido, but *S. furcifera* is commonly found even in Hokkaido. They feed and breed only on rice plant in Japan. Miyake (1966) and others reported breeding experiments on *Echinochloa crus-galli, Poa annua, Zizania latifolia, Leersia japonica, Leersia sayanuka,* and other

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species, but no reliable observations of such breeding on natural conditions have been obtained. Kisimoto (1965) made breeding experiments using several species of *Oryza*, not endemic in Japan, as hosts as well as several proposed endemic plants. With *N. lugens* *O. perennis* and *O. sativa* var. *spontanea* showed the best results, comparable to those using *O. sativa*, followed by *O. latifolia*, *O. stapfii* and *O. alta*. Very high mortalities, during nymphal development occurred on seven other species of *Oryza* and *Zizania* and two species of *Leersia*.

Processes of populations growth in the paddy field were studied by Suenaga (1963), Kisimoto (1965) and Kuno (1968). The density of *S. furcifera* immigrants is much higher than with *N. lugens*, and therefore cause damage by feeding and tearing plant tissue for oviposition. Young plants are often withered completely in years of heavy immigration, particularly in the southern Japan. The next two generations appear after about a month at the end of July to early August and in the middle to the end of August. Feeding by nymphs and adults induce injuries such as yellowing, dwarfing and finally withering at the tillering stage of rice plant. Therefore, *S. furcifera* is called also the summer planthopper. Density of immigrants of *N. lugens* is not so high as to cause damage directly. The next generation appears from the end of July to August, most females are brachypterous and show patchiness in spatial distribution. Population density increases almost exponentially during another two generations. After the heading stage of the rice plant a typical damage of round withering occurs often involving scores or even hundreds of hills when a certain population level is attained. This concentration was found to derive from the brachypterous females that had become established in these areas two generations earlier. *N. lugens* is called also as the autumn planthopper.

N. lugens shows two wing-forms, brachypterous and macropterous, in male and female, but in *S. furcifera* there is no brachypterous form in the male. Factors controlling the appearance of the two wing-forms were studied by Kisimoto (1965) and the role that polymorphism played in the population growth was discussed. Brachypterous females of *N. lugens* occur much more frequently than those of *S. furcifera*.

In Japan, at least two closely related species of *Nilaparvata*, that is, *N. muiri* and *N. bakeri*, are often confused with *N. lugens* when specimens are collected by light trap. These two *Nilaparvata* spp. breed on *Leersia japonica* and *L. sayanuka*, producing the brachypterous form much more frequently than the macropterous form in both male and female, even under crowded condition on the food plant. This fact suggests that the two species are much less migratory than *N. lugens*. They overwinter as diapausing eggs in the tissue of overwintering stems of the host plant, which is perennial.

Possibilities of Overwintering within Japan Mainland

Possibilities of overwintering within Japan mainland seem to be based on several prepositions. The presence of food plants other than rice plant was insisted by several workers. Miyake and Fujiwara (1962) proposed complicated life cycles of *S. furcifera* and *N. lugens* including rice plant and other weeds, *Poa annua* and *Echinochloa Crus-galli*, in addition to egg diapause. Okumura (1963) studied the conditions inducing egg diapause by low temperatures. Takezawa (1961) tried overwintering eggs under sophisticated circumstances with *N. lugens*. None of these experiments, however, have been endorsed by the discovery of overwintering populations under natural conditions, except some limited cases of overwintering near a hot spring where rice plants survived the winter.

Findings of planthoppers, particularly *S. furcifera*, in mountainous regions, as high as 2,000 m above the sea level, several tens of kilometers distant from the paddy field area, after August have suggested the possibilities of overwintering in mountainous regions; but no affirmative results have been obtained by further studies, only leaving a suggestion of high migratory ability of planthoppers in the autumn when the insects tend to produce the macropterous form.

Surveys on Immigration by Light Trap and the Possibilities of Long Distance Migration

Although no substantial overwintering populations, or those of the following generation before the immigration season, have been found, the two planthoppers appear every year, more or less, regularly. Appearances of immigrants have been mostly

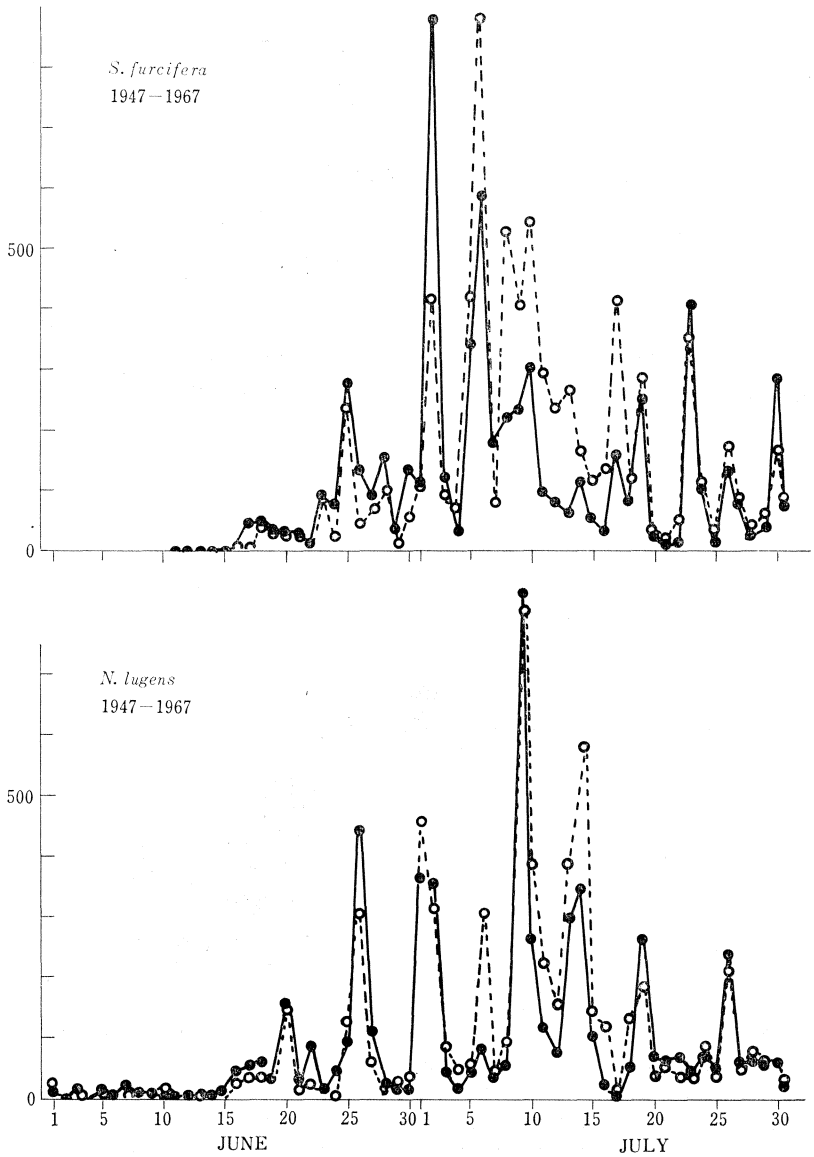


Fig. 1. Catches of *Sogatella furcifera* and *Nilaparvata lugens* by a light trap summed up for each calendar date from 1947 to 1967 at Chikugo.

sporadically. In Amami and other southern islands, however, mass flights into light traps are often observed as early as in May. Substantial mass flights occur usually from the middle of June to July. Light trap catches accumulated in Kyushu Agr. Exp. Sta., Chikugo, Fukuoka, since 1947 are summed up simply on the calendar date as Fig. 1.

The scale of mass flights, so far as light trap catches are concerned, is much larger in southern Japan, particularly in the western coast region of Kyushu, than in any other part of Japan. Light trap records obtained in various Prefectural observatory stations in Kyushu were ranked and shown in Fig. 2. Daily catches were

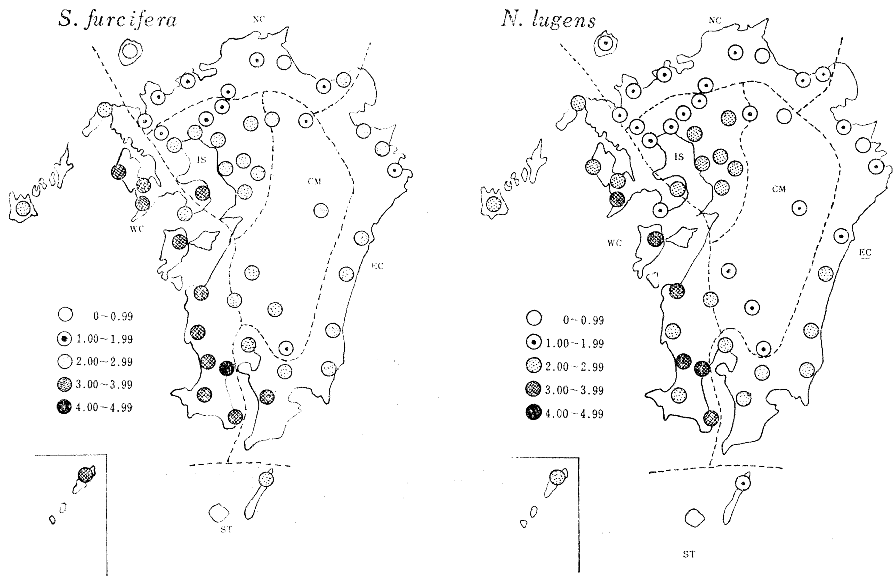


Fig. 2. Averages of yearly total catches in logarithmic scale by light trap at various Prefectural Observatory Stations until July 20. Faint lines mean climatic areas; western, eastern and northern coastal and inland sea area, central mountainous area and subtropical area.

summed up from the beginning to July 20, which date was tentatively fixed as the end of immigration season, as after then adults of the next generation often appear. Yearly total catches were transformed into logarithmic scale and averaged. Large catches were exclusively found in the western coast region up to the northern extreme of Kyushu, followed by catches in the eastern coast region or central mountainous region even in the southern part of Kyushu. Catches were very low in the northern coast region. Even this fact alone suggests continuous influxes of planthoppers from the west or south west.

Meteorological conditions associated with mass flight into light traps of the two planthoppers have long been pointed out. Yokoo (1952) reported that the mass flights were observed when there were warm air masses in the upper atomosphere over west Japan and cyclones, troughs or fronts were approaching. Kuwabara (1950, 1956) pointed out that mass flights of *S. furcifera* were usually observed when the front of the Bai-u season lay on the southern coast region of Japan and those of *N. lugens*, generally occurring a little later than in the former, were observed when depressions were located in the midst of Japan Sea and a cold front passed east. A warm SW wind flew continuously for a considerable period before the mass flights. These findings with other facts mentioned above, strongly suggested long distance migration but most authors thought rather at overwintering or of short distancce immigrations only from the southern part of Japan.

Findings of Transoceanic Migration of Planthoppers

In 1967, Tsuruoka made a epoch-making observation on the weather ship 'Ojika' at the Ocean Weather Station 'Tango', 29°N and 135°E, 500 km south of Japan Mainland (Fig. 3), of a mass of planthoppers flying into lights or flying at day time around

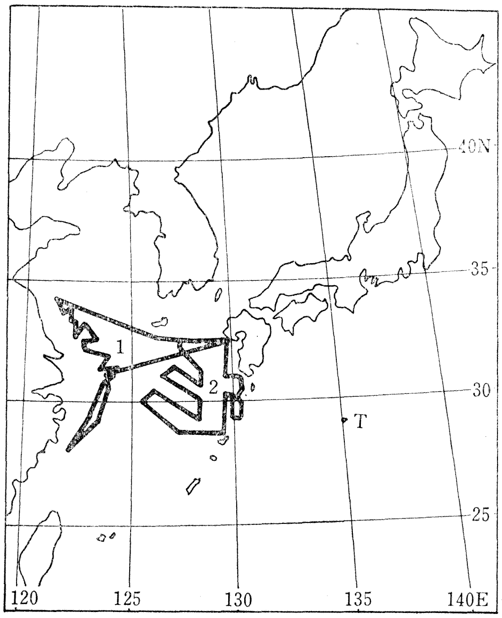


Fig. 3. Navigation route No. 1 and 2, in 1969 in the East China Sea and the Ocean Weather Station "Tango" (T).

the ship. At the beginning, 2 *S. furcifera* were caught flying into light at 2:40 J.S.T. of July 15 and about 10 at 20:30 of July 16, followed by sudden increase of more than 1000 after 23:00. Many dead specimens were found on the deck and on wet walls the next morning. On July 17, the ship was in the midst of masses of planthoppers throughout the day; planthoppers were flying up and down around the ship like snowflakes or alighting on and taking off from the sea surface or from shipboard. The mass flights were observed until 06:00 of July 18, when the wind, until then SW, veered to WNW to NW and planthoppers decreased. He estimated that the air of 21:00 on July 16 at the station came from south of 20°N, east of the Philippines. Most of the planthoppers were identified as *S. furcifera* and 32 *N. lugens* were included in those caught at 21:00 to 23:00, July 17 (Asahina & Tsuruoka, 1968). Santa (1968) also collected migrating insects including *S. fucrifera* and *N. lugens* on the same station from June 22 to July 8, 1968.

The planthoppers were collected also in August, September and October at the same station though fewer than in June to July, and were supposed to be carried by north winds.

Mass Immigrations of Planthoppers Surveyed on Land

To estimate the density or occurrence of pest insects, light traps and sweeping have been used widely in Japan, but they have their own handicaps. Kisimoto (1969) employed large tow nets to catch flying insects throughout the day. Tow nets of 1 m diameter and 1.5 m depth, made of polyester organzy were set at 10 to 15 m high above the ground in the midst of paddy fields in Chikugo, Fukuoka, throughout the season. Many insects, including aphids, flies, small coleopteran insects and spiders as well as various planthoppers and leafhoppers were caught.

Numbers of *S. furcifera* and *N. lugens*, caught by tow nets at a height of 15 m until the end of July in 1968, 1969 and 1970, are shown in Fig. 4, 5. The numbers of

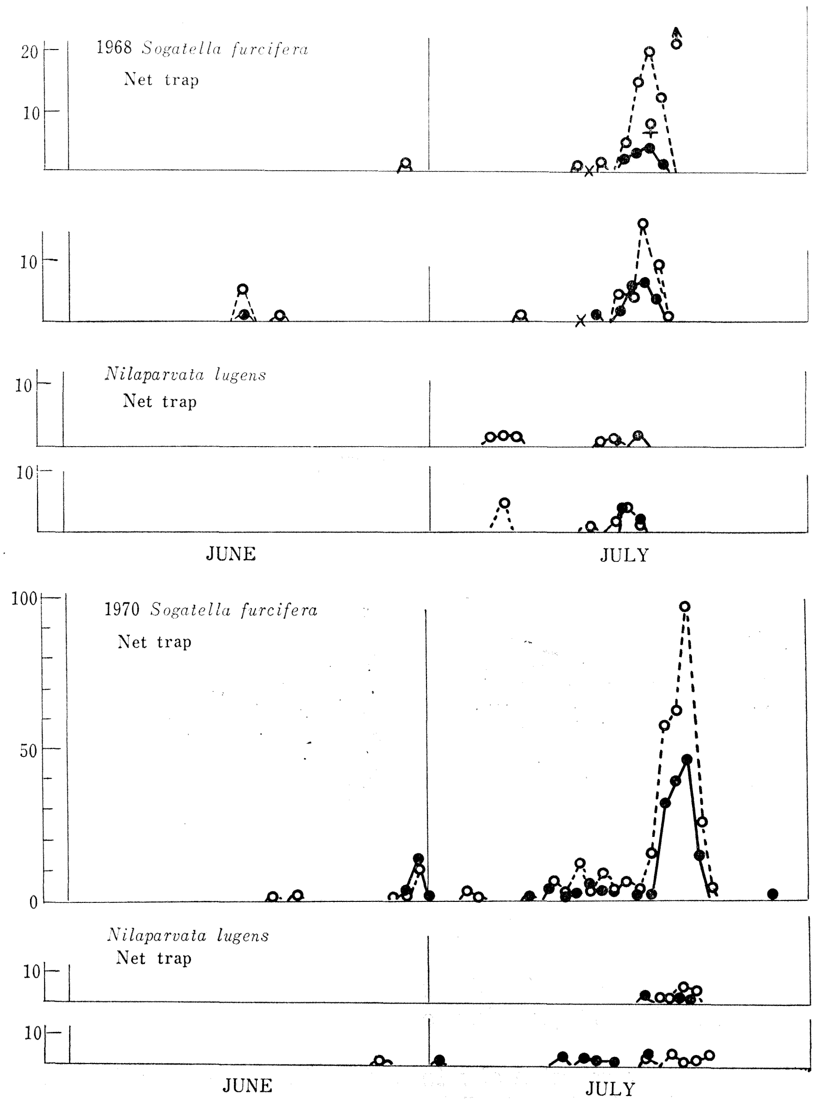
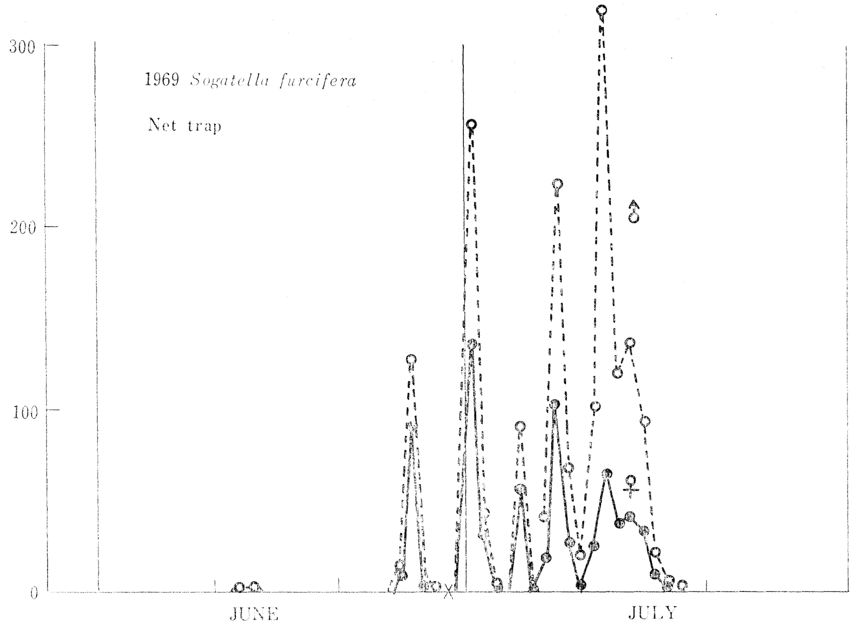


Fig. 4. Catches by tow net of 15 m high in 1968 and 1970.



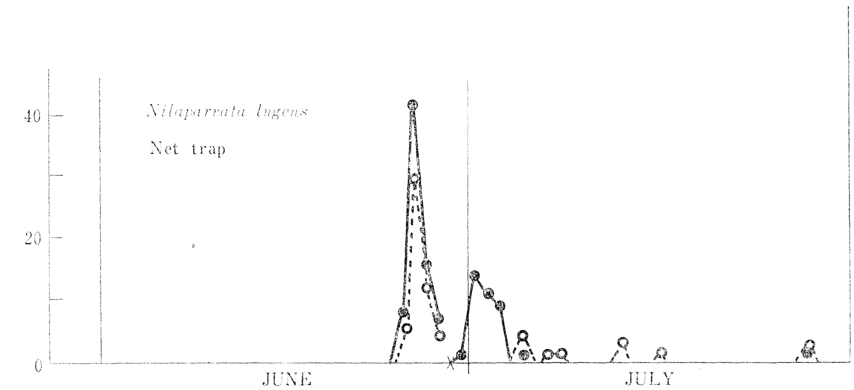


Fig. 5. Catches by tow net of 15 m high in 1969. Cross on a abscissa means no record.

planthoppers caught each day usually did not exceed 10 to 20 in 1968 and 1970, but heavy immigrations occurred several times in 1969.

One of the typical mass immigration was observed in the evening of June 25, 1969. A depression moved north-east from the northern East China Sea through the Korean Channel to the Japan Sea. At 9:00, J.S.T., June 25, a warm front passed over Chikugo and warm stable SW wind began to blow at speeds of 25 to 33 km/hr throughout the day until a cold front passed over at 3:00, June 26, when the wind speed decreased and the temperature fell. Showers of 0.5 to 1.5 mm/hr occurred from 19:00, June 25 to 12:00, June 26. Under these weather conditions mass flights were first recognized at 16:00, June 25. The insects were alive when caught and it was supposed that the catching had started not so long before then. Insects continued to be caught until 20.00, on the same day, when catches suddenly ceased. At a maximum about 90 *S. furcifera* and about 20 *N. lugens* were caught per an hour. These catches are surely extraordinary high. No *S. furcifera* and *N. lugens* were caught in the preceding several days. Even in *Laodelphax striatellus* which breeds widely on wheat and barley and is easily caught by the same tow net from the end of May to June, the highest catches were usually 250 to 300 per day in 1968 and 60 to 100 in 1969.

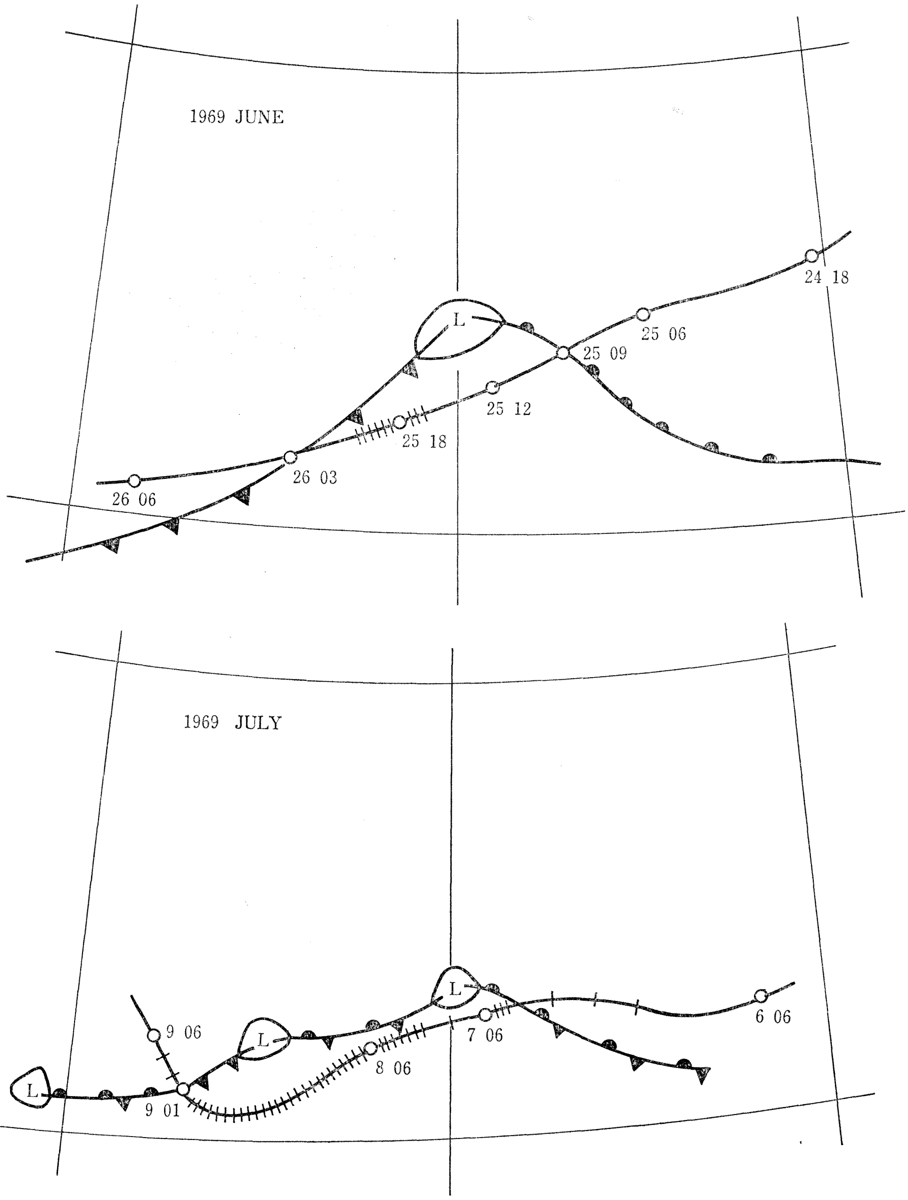


Fig. 6. Schematic presentation of interrelation between frontal system and the observatory point, Chikugo, in which the point is to move west crossing the stational frontal system. Figures show the date and time (Japanese Standard Time) in 1969. Cross bars mean mass flight caught by tow nets. Lines of latitude and longitude are in a scale of 10°.

In June 25 night, mass flights into light traps were recorded in many observatory stations in Kyushu, Chugoku and Shikoku area, and in eastern areas as far as Ibaraki Pref. the mass flight was recorded in June 26 night. Presumably the mass immigration covered at least the western half of Japan at the same time. Some of the planthoppers caught alive were kept in laboratory and found to be unmated.

The similar type of mass flight but for much longer period was observed from July 7 to 9, 1969. In this case, three depressions moved east successively and the

Table 1. Catches of planthoppers by tow nets of 15 m high and meteorological elements at Chikugo, Fukuoka, 1969.

Date	Time	Temp. (°C)	Wind direction	Wind run (km/hr)	*Sogatella furcifera*				*Nilaparvata lugens*			
					Net No. 1		Net No. 2		Net No. 1		Net No. 2	
					♀	♂	♀	♂	♀	♂	♀	♂
June 25	06	19.4	E	4.5								
	08	19.9	N	4.8								
	10	22.2	S	6.3								
	12	23.6	SW	27.1								
	14	23.6	SW	31.0								
	16	23.6	SW	24.5	10	12	20	22	8	5	12	11
	18	23.5	SW	22.7	20	38	25	44	9	9	13	10
	19	23.1	SW	25.9	33	53	39	54	13	11	7	11
	20	22.4	SW	32.5	25	19	26	39	12	4	12	7
	21	22.0	SW	31.8	0	1	1	0	0	0	0	0
26	01	21.2	SW	15.4	6	9	6	8	2	1	1	3
	06	19.7	SW	7.3	2	2	4	3	0	2	0	0
	08	21.9	SW	4.3	2	0	0	0	0	0	1	0
	16	25.3	SW	24.0	3	3	4	0	6	3	7	4
July 7	08	26.0	SW	10.2	7	9	10	19	0	0	0	0
	21	24.4	S	17.5	12	31	2	4	0	1	0	0
	24	25.5	SWS	22.8								
8	06	25.4	SW	36.8	46	103	59	150	0	0	0	0
	08	25.5	SW	21.6	21	37	21	49	0	0	0	0
	10	25.4	SW	30.0	6	23	10	22	0	0	0	0
	12	25.5	SW	23.4	16	12	14	17	0	0	0	0
	14	25.0	SW	19.8	6	17	6	16	0	1	0	0
	16	24.0	SW	31.5	7	31	20	27	0	0	0	0
	18	22.7	SWS	32.5	0	11	9	27	0	0	0	0
	22	21.9	SWS	24.0	18	40	21	50	0	0	0	0
9	01	21.5	W	1.1								
	04	20.7	NE	3.9								
	06	20.6	NEN	9.8	2	9	4	3	0	0	0	0
	16	24.2	NEN	9.0	8	6	13	44	0	0	0	0

Wind runs present those during the preceding one hour. Catches of planthoppers comprise the total catches from the preceding observation time.

(Meteorological observation was made by Kyushu Agr. Exp. Sta. Laboratory of Agr. Meteorology observation station was situated in the warm sector for considerably long period. Showers of 0.5 mm/hr were observed from 22:00, July 7 to 3:00, July 8 (Fig. 6).

Interrelation between mass immigrations and large scale weather conditions are schematically shown in Fig. 6, in which the observation point is shown as if it were moving south-west across a stationary frontal system, neglecting minor changes of the frontal system during the period concerned. It is shown that mass flights are mainly found within the warm sector but near the cold front. In the case of July 6 to July 9, some catches were obtained in the northern area of the frontal system but this seems to depend on complexity of the frontal system or a kind of contamination due to the preceding immigrations. Actual data of the mass immigrations are shown in Table 1.

Surveys on the East China Sea

Stimulated by the findings of transoceanic migrations mentioned above, surveys on the East China Sea were planned covering several parts of the Sea. Three tow nets made of synthesized yarn, much thicker than those used on land, were flown at the mast of Fisheries Research Vessel 'Yoko-maru' 213 tons, about 8 m above the sea level, throughout the following navigation routes (Fig. 3). Insects caught were removed from the nets every 3 hours, or intermittently during mass flights.

At the first navigation, Mochida, O., Kyushu Agr. Exp. Sta. collected 1468 *S. furcifera,* 1056 *N. lugens* and 136 *L. striatellus* and also other insects from June 26 to July 5, 1969. At the second, Kisimoto, R. collected 1851 *S. furcifera,* 472 *N. lugens,* 90 *L. striatellus* and others, from July 9 to July 18, 1969. In 1970, similar surveys were carried out from April 28 to May 6 by Kisimoto, R., from May 13 to May 20 by Okada, T. and from July 5 to July 18 by Mochida, O. In the first two surveys no planthoppers and leafhoppers, but many aphids, flies and others were collected. Mochida, O. collected 865 *S. furcifera,* 322 *N. lugens,* and 39 *L. striatellus.*

Interrelations between navigation route and the frontal systems in the second navigation in 1969 were shown in Fig. 7. It was found that catches were mostly made at or near a frontal system moving north or south on the East China Sea in the Bai-u season. Winds at times when planthoppers were successfully caught were usually SW to SWS, at Beaufort 4 to 5, with often showers and fogs. Insects caught in the rain were sometimes damaged probably due to impact on a wet net but some were alive and undamaged. They produced offsprings successfully in breeding cages. When the ship went south into the Pacific high pressure, weather became very fine, winds changed to SSE to S and no insects were caught.

Categories of Mass Immigrations in Relation to Synoptic Situation

Based on the typical immigrations in 1969, the frontal system moving north or south in the Bai-u season seems to play the most important role. Similar analyses were made with the sporadic immigrations that usually occurred at the beginning of the immigration season. In these cases, as shown in Fig. 8, 9, depressions pass near or south of the observation station, with a less well-developed frontal system. Sometimes occlusion of a depression was found. In these situations, little invasion of warm SW wind is to be expected. Sporadic immigrations of *S. furcifera* are most usual, possibly due to the higher density of migration and stronger flying ability of this species than of *N. lugens.*

Another type of synoptic situation was found in the case of immigration on July 20 to 23, 1970 and July 16 to 18, 1967. In the latter case, no catches by tow net were made, but catches by yellow pan water traps (Kisimoto, 1969) clearly showed the immigration of similar type to the former as shown in Fig. 10. This immigration seems to correspond with that observed by Tsuruoka (1968) at the Ocean Weather Station.

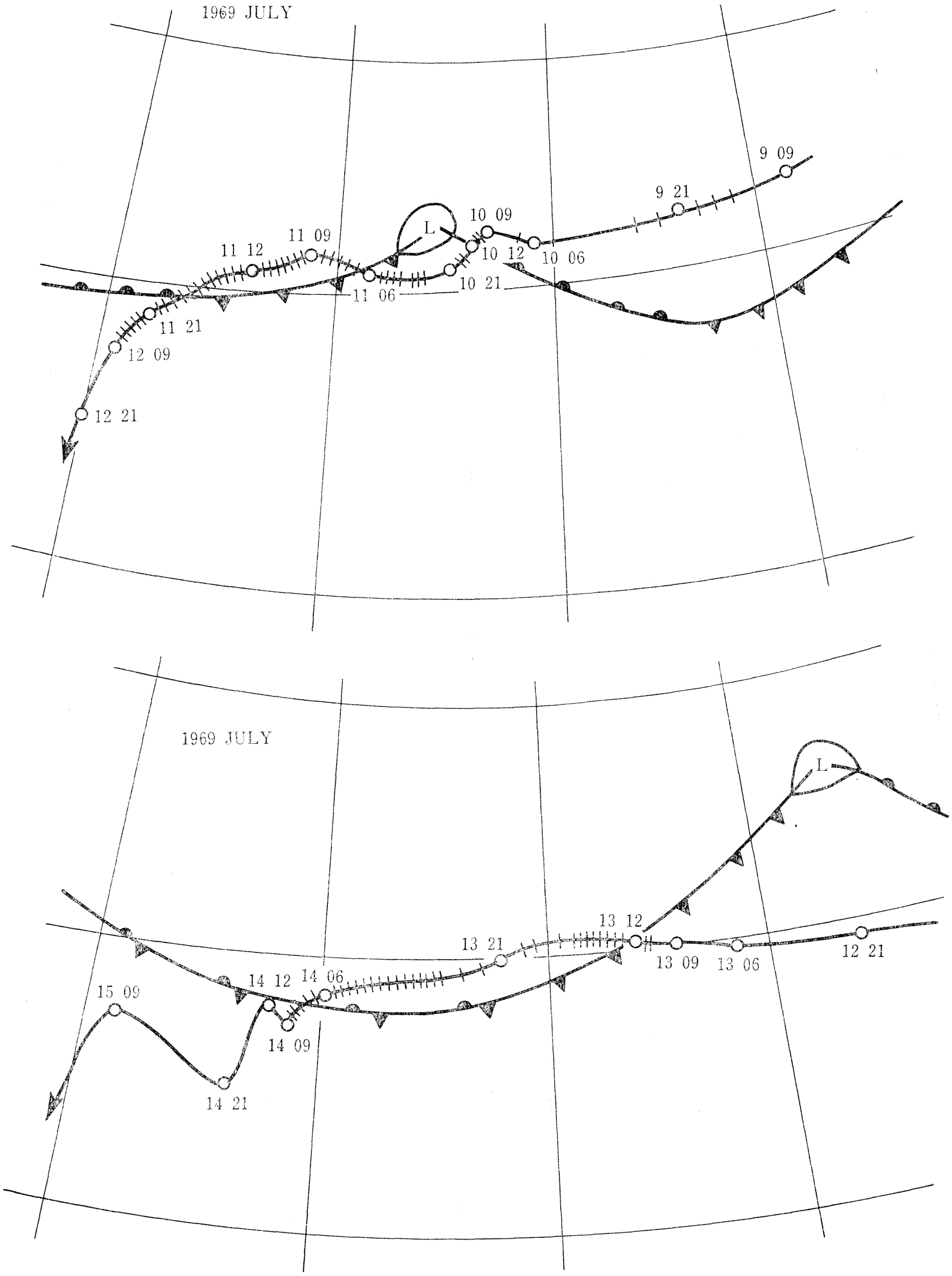
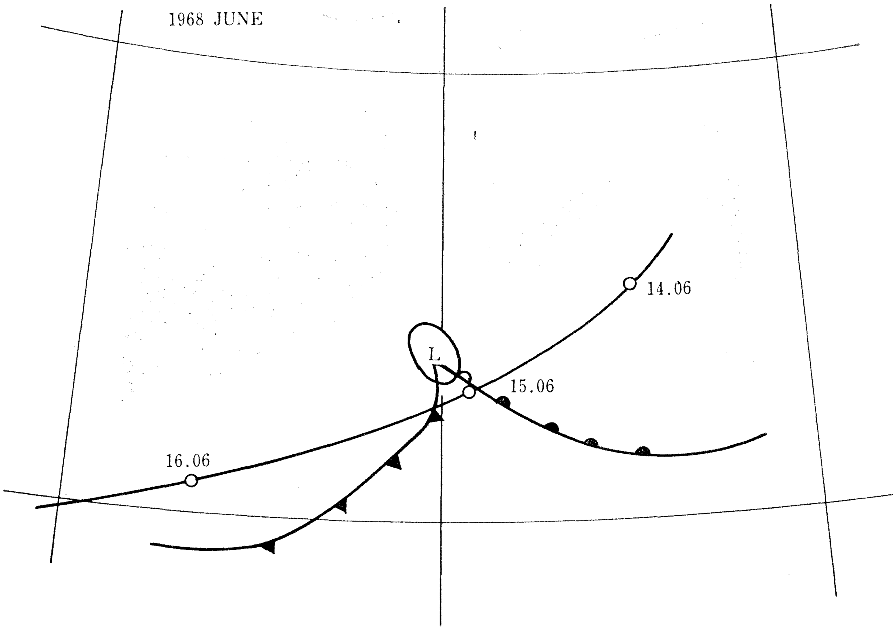


Fig. 7. Schematic presentation of interrelation between frontal system and the observatory ship. Lines of latitude and longitude are in a scale of 10°.



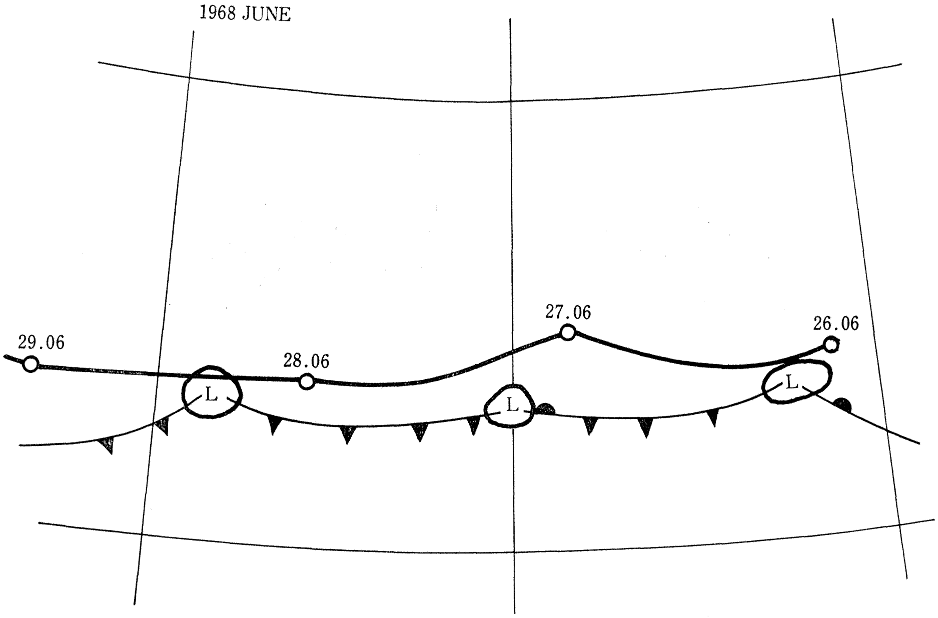


Fig. 8. Schematic presentation of interrelation between frontal system and the observatory point, Chikugo, at sporadic immigrations.

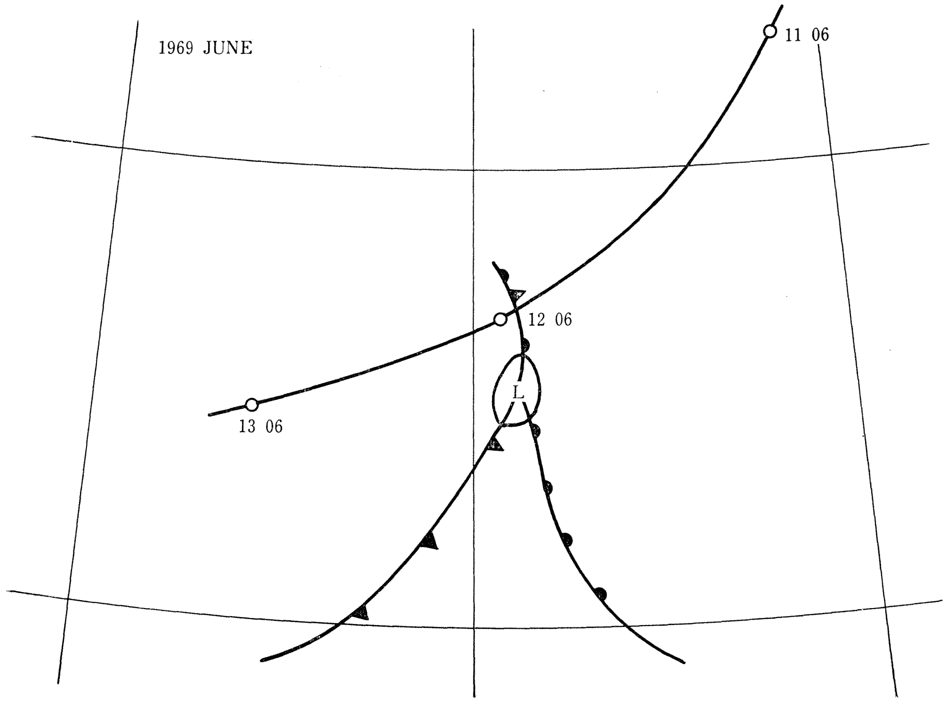


Fig. 9. Schematic presentation of interrelation between frontal system and the observatory point, Chikugo, at sporadic immigrations.

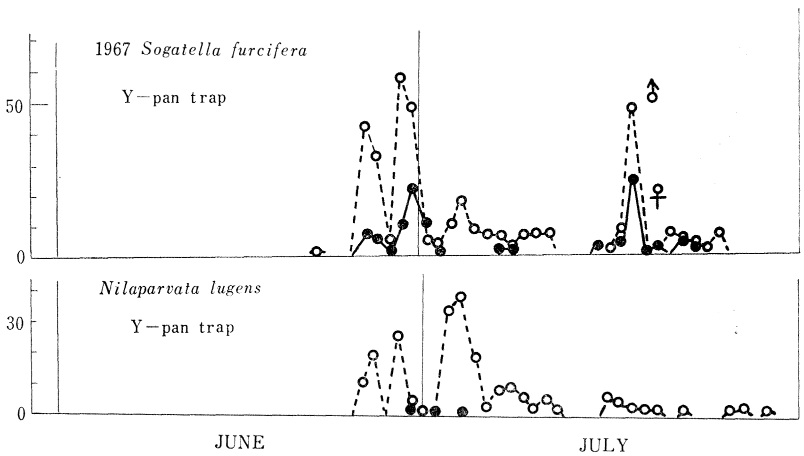


Fig. 10. Catches by a yellow pan water trap in a paddy field in 1967.

In these two cases as shown in Fig. 11, no clear frontal system was formed as the rainy season approached to the final state, but the Pacific high pressure had not yet developed enough to cover the whole Japan. SW wind of 12 to 20 km/hr blew continuously for 2 to 3 days in 1970 and *S. furcifera* of fairly high density and a few *N. lugens* were caught. The immigrants of *N. lugens* of this time were the main source of popu-

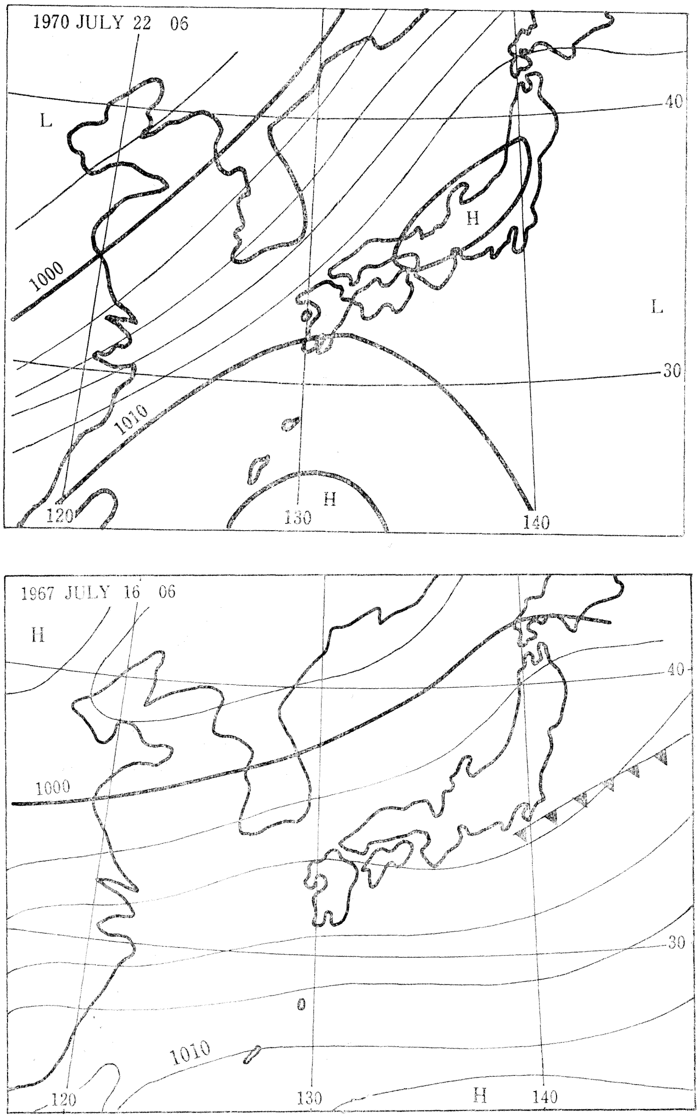


Fig. 11. Synoptic maps on days of long lasting immigration at the final state of the Bai-u season.

lations that developed afterwards in paddy fields. In 1967, SW winds blew for 3 to 4 days at 24 to 30 km/hr. These cases suggest that the frontal system might be not an inevitable factor inducing immigration but an auxiliary one which favours occurrence of continuous SW wind for a considerable duration in a synoptic scale. Huff (1963) analysed the relation between meteorological conditions and influxes of the potato leaf-hopper, *Empoasca fabae*, and found that a persistent southerly flow, at least 36 hrs prior, of maritime tropical air from the Gulf States, rainshowers or thundershowers and the presence of cold front, favour influxes.

Conclusion

As shown above, long distance migration of planthoppers, particularly those of *S. furcifera* and *N. lugens* are undoubtedly the main cause of the appearance of these species in paddy rice fields between June and July in Japan, though overwintering in Japan Mainland cannot be entirely ruled out.

Source of migrations, or the permanent breeding area, are still unknown and further researches are particularly important for a complete understanding of this migration process. Okubo and Kisimoto (1971) studied the behaviour of take off of *N. lugens* which had bred on rice plant in the fields at the end of August to October with a Johnson and Taylor suction trap. *N. lugens* showed one of the typical crepusular bimodal, dawn and dusk, type. Strong winds and low temperatures inhibit the take off. The striking contrast between the conditions favouring the take off and those that occur during mass flights into paddy fields in June to July strongly suggest that the two states occur at localities far apart from each other in time and distance ,i.e., on a synoptic scale. Real flight behaviour during migration, height and other aspects of migration need to be analysed in future.

The author sincerely acknowledges the kind reading of the original manuscript and criticism of Dr. C. G. Johnson, Rothamsted Experimental Station, England.

Discussion

S. N. Banerjee, India: 1) Do you think this migration is from the main land of Asia. Because Dr. Ford in England has shown that aphids migrated from France over the English Channel to England. 2) I find you are using suction trap of Jonson, yellow trap and net trap of yours. Which one you think best for the study of migration?

Answer: 1) So far, it is very difficult to decide the source of the migration. Most parts of tropical and sub-tropical South-East Asia are to be the permanent breeding areas. I was told in the present symposium that in many regions they often suffered from outbreaks of planthoppers. 2) At present, the net trap is the best, because it catches flying insects directly at any conditions. Yellow pan, the next. Johnson trap is useful for analysis of take-off periodicity of planthoppers inhabiting densely there.

K. S. Kung, Republic of China: Do you think that it is possible to set up your trap-net on a model-plane which is controlled in certain distance in your future research work?

Answer: Real densities of planthoppers, so far analysed, were very low even in case of mass-immigration, which necessitate employing the net trap as large as possible. Therefore, possibility to adopt the modelplane depends on the capacity to carry large nets.

T. Hidaka, Japan (Comment): In northern Thailand, transplanting is usually done during July. On those days, population density of *S. frucifera* and *N. lugens* was prominently lower than that in August and September. The peak of the density has been seen from the middle of August to September. This is indicating that the peak of the population density was built up later than immigration season in Japan.

T. Hidaka, Japan: From where do you think the two species come to Thailand?

Answer: I am now inclined to think that immigration season of the two species coincides in many regions in South East Asia. Informations about immigration season and population growth in paddy fields and among wild host plants are very much valuable to full understanding of the problem concerned.

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