Sudden Outbreaks of the Armyworm, *Pseudaletia separata* WALKER and Its Monitoring Systems in Japan

By KAZUO HIRAI

Agroenvironment Division, Tohoku National Agricultural Experiment Station
(Shimokuriyagawa, Morioka, 020-01 Japan)

The oriental armyworm, *Pseudaletia separata* WALKER is a serious pest of grain crops and pastures in Asia and Australasia[13]. In Japan, this armyworm outbreaks once every few years, mainly on the Japan Sea side of the country, from Kyushu through Honshu to Hokkaido.

This insect overwinters in warmer west Japan at low larval densities. Invasion of the adults takes place annually in association with the movement of low air pressure from east China through the Sea of Japan to northeast. Simultaneous outbreaks occur over a very wide area. This is circumstantial evidence that the sudden outbreak is brought about by mass invasion of adults from warmer areas[3,9,12]. On the other hand, migrating adults of *P. separata* were caught over the Pacific[1]. In this paper the actual situation of sudden outbreaks and forecasting techniques of a mass invasion are described based on recent researches.

Overwintering area

In Japan this species normally overwinters as larvae in areas warmer than 2°C, in monthly mean air temperature for January[8]. No overwintering stages were found in Shiga, Shimane and Fukui (surveyed at the end of April, 1986), and in northern Japan, suggesting that it is difficult for the insects to overwinter in such areas with the long period of continuous snow cover. Overwintered larvae were found in Chiba, Hiroshima, Yamaguchi, and Kyushu Island[8,11,15].

Sudden outbreaks for the past 30 years

This species annually flies on warm southwest winds from the warmer areas to the Japan Sea side of the country. Fig. 1 shows an index of *P. separata* larval abundance by the area (ha) of *P. separata* assumed to be brought about by early summer adult immigration into northern Japan from 1958 to 1987. Eight outbreaks of over 200 ha have been recorded for 30 years. These outbreaks occurred simultaneously from south to north, on the Japan Sea side, with larvae reaching densities of over 100 larvae/m^2. Wide area outbreaks occurred in the year of 1960, 1971, and 1987. Up to now, the source of migrants of the early summer generation in northern Japan has been presumed to be the Chugoku district and westward[9]. In the case of the 1987 outbreak, it is presumed that populations originating from the Kyushu district formed a part of the migrants to northern Japan, judging from adult occurrence during April in Kagoshima (Fig. 2), the outbreak in the Goto Islands, and the movement of low air pressure.

In the sudden outbreak in 1987, the first outbreak occurred in a wheat field at the end of May in the Goto Islands in the Kyushu district. Subsequent outbreaks occurred from the end of June to the beginning of July, from Yamaguchi through Honshu to Hokkaido, on the Japan Sea side. It is assumed from the distribution of outbreak areas that some adults

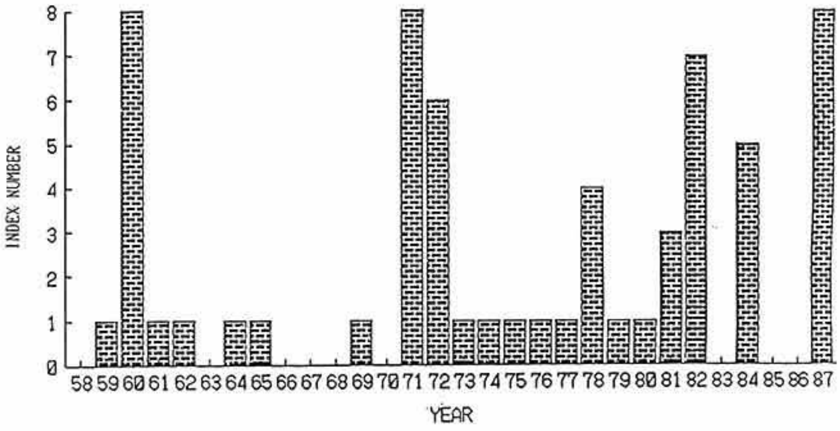

Fig. 1. Index number of larval abundance area (ha) of *P. separata* occurred from late June to early July in northern Japan, from 1958 to 1987
Index 1: less than 200 ha, 3: >200 ha, 4: >1,000 ha, 5: >5,000 ha, 6: >10,000 ha, 7: >15,000 ha, 8: >20,000 ha.
Cited from Oku (1983) and prefectural abundance data.

flew over mountains of about 1,000 m in height, invaded 100 km inlands from the coastal area of the Japan Sea side and reached the Pacific coastal areas of Tohoku. About 200 thousand ha of crop fields such as pasture and corn were damaged in northern Japan.

The third generations occurred over a wider area from the end of August to the beginning of September. Rice, corn and pasture were severely injured. A small number of larvae (0.7 larvae/m^2) and adults were found in pasture in and after October, but showing no damage.

For monitoring adult invasion, molasses traps and synthetic sex pheromone traps were set at Kagoshima (dryland crop), Shiga (wheat), Akita (pasture), Morioka (pasture) and Oono (pasture) from April to October, 1987. Sudden appearances of adults were recorded in and after June 7 by molasses traps in Akita, Morioka, and Oono (Fig. 2). The synthetic pheromone trap attracted few adults during that period, which is considered to be partly because of low air temperature with strong wind, and scarcity of nectar sources that are indispensable to adult for sexual maturity[5], and mass invasion of adults in northern Japan.

From June 7 to 19 in 1987, the number of the adults trapped by a molasses trap set at pasture in Akita was 250 times as many as that trapped in the preceding year. Low air pressure weather systems originating from east China began moving onto Japan from mid April 1987 onwards. On every movement, a few adults were trapped by a sex pheromone trap or a molasses trap. Among the movements, the low air pressure system moving from China to Japan between 21:00 of June 5 and 9:00 of June 8 must have carried lots of adults which may have emerged in west Japan and east China (Fig. 3). When the air temperature at a height of 1,000 m rose to 18°C from 19:00 to 21:00 of June 6 and 7, lots of adults must have passed over mountains of about 1,000 m in height, and were blown in the warm south west wind in the warm sector between the cold and the warm front. Parts of those groups of adults were caught with molasses traps in Morioka (Fig. 2).

Flight habits of the armyworm

The adult eclosion showed its peak 2 hr after sunset in fields, and most newly emerged adults are unable to fly until sunset of the next day because of the teneral period[5]. Field

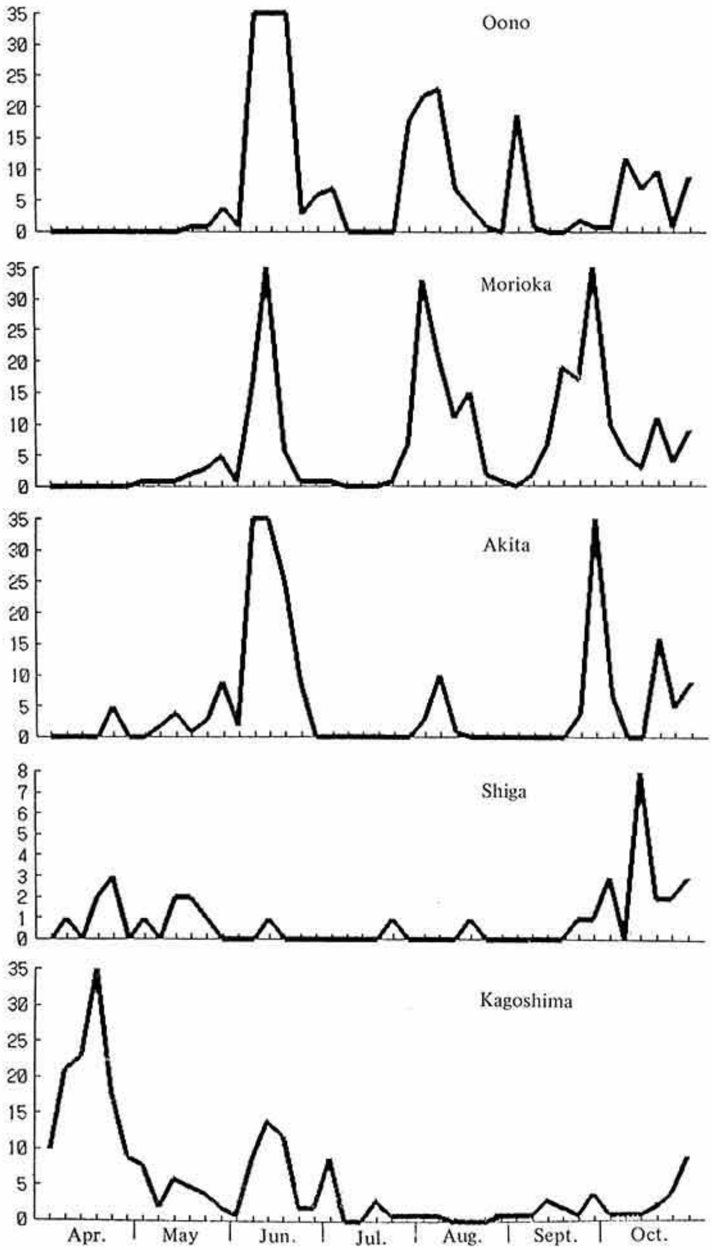

Fig. 2. Numbers of adult *P. separata* caught with a livecapture trap (molasses) set at Kagoshima (ca. 31°N, 131°E), Shiga (35°N, 136°E), Akita (40°N, 140°E), Morioka (40°N, 141°E), and Oono (42°N, 141°E), from April to October, 1987

The number of adults 'over 35' in June is omitted in the figure.

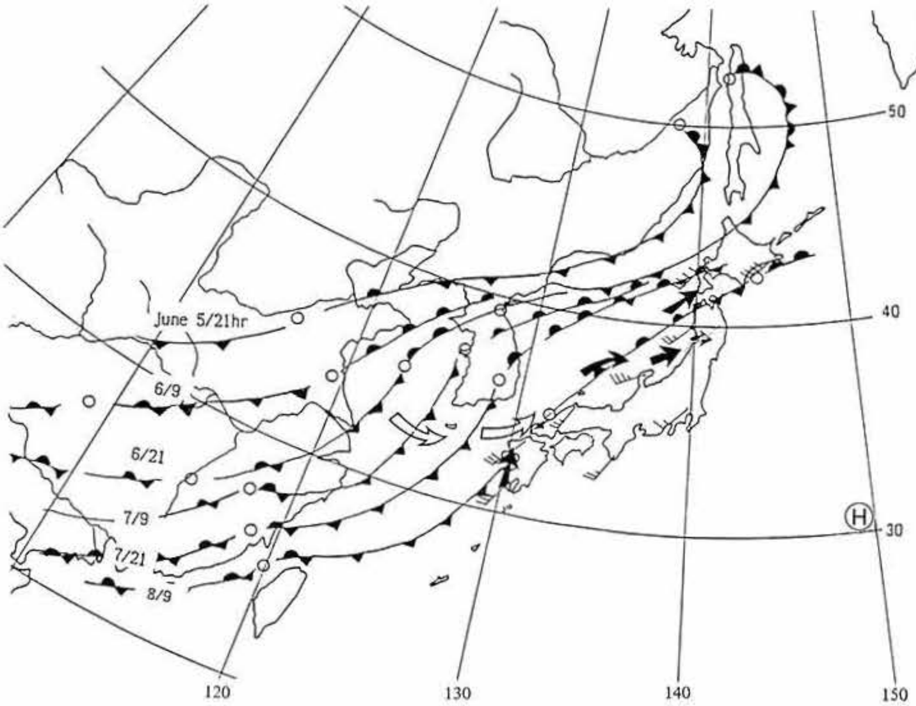

Fig. 3. Movement of low air pressure in association with mass adult immigration of *P. seperata*, 21 : 00 of June 5 to 9 : 00 of June 8, 1987
Arrows indicate a presumed route of migratory adults.
Ⓗ stands for a high atmospheric pressure.

observation confirmed that the adults have a habit of ascending flight around sunset on and after day 1 after eclosion. In the presence of wind, the adults fly downwind[4]. During migration, the adult probably flies at night and descends at break of dawn during overland flight. This is presumed from experiments on flight activity using flight balance[2], and by field observation of take-off and of flight for feeding in the evening. However, during "overwater" flight such as over the sea or river, the adult would continue to fly in the daytime till reaching land, which is presumed by the observation that the immigrant adult did not land on paddy fields filled with water after rice planting[9]. Strong wind, high mountains, low temperature, and host plants[9,10] could also affect landing. After landing, the adults fly to nectar sources such as acacia or bush clover planted around pasture. Both sexes then become sexually mature and mate, and enter the reproductive cycles[5].

Forecasting techniques of early summer adult immigration

1) Forecast of mass immigration

The cause of sudden outbreaks of the armyworm is not yet clarified. It is hard to forecast outbreaks of pests like the armyworm. To forecast the mass immigration is very important in this species. It is required for the forecast to have an accurate grasp of overwintering densities in warmer areas every year. Actually, this is not easy to ascertain within the country or outside of the country. An attempt was made to look for correlations between meteorological factors and armyworm overwintering success in the hope that this can be used to forecast the mass immigration year.

A meteorological phenomenon called "teleconnection" was employed. This is a phenomenon whereby weather factors in two remote stations (east China and west Japan in this case) fluctuate simultaneously or in parallel. Analysis seeking common changes in monthly mean air temperature and in precipitation in the winter season (January and February) in the overwintering area (west Japan) in years of mass immigration to northern Japan (Fig. 1) was made. Outbreaks occurred in years in which the overwintering area was warm and dry. For example, Fig. 4 shows that the dry-wet index (monthly precipitation divided by monthly mean air temperature) of the outbreak year is smaller, in January and February, than that of the 30-year average. An exceptional case was observed when there was an outbreak in the preceding year. The very high air temperature of the winter makes the armyworm outbreak even in a year of heavy winter rain like 1972.

According to the teleconnection, when the winter in west Japan is warm and dry, east China on the same latitude is presumed to have a similar weather condition, which would be good for larval overwintering. The reason for this is not clear, but it is possible that heavy rain under cold temperature during the larval period may increase the larval death due to the coldness and the incidence of larval disease[9]. Fig. 5 shows outbreak ranges of mean air temperature and precipitation for January and February in six stations. For example, in Miyazaki an outbreak (over 200 ha of occurrence area) occurred in the year with mean air temperatures between 4.7 and 6.2°C. Wide area outbreaks (over 20,000 ha) occurred between 6.3 and 8°C for January. In February, outbreaks occurred between 6.0 and 7.9°C and wide area outbreaks between 8 and 9.4°C. In the case of precipitation, outbreaks occurred between 11 to 22 mm and 34 to 52 mm for January and wide area outbreaks between 23 and 33 mm. In February wide area outbreaks occurred between 28 and 93 mm and outbreaks between 94 and 142 mm. It is possible to read from other stations as well that outbreaks occurred in warm and dry weather conditions.

In the case of actually forecasting the adult immigration year, weather analysis of six stations (Fig. 5) should be made in March every year. It will be possible to consider that more adults would immigrate into wide areas in the year when mean air temperature and precipitation of most station fall within the outbreak range, and when the dry-wet index

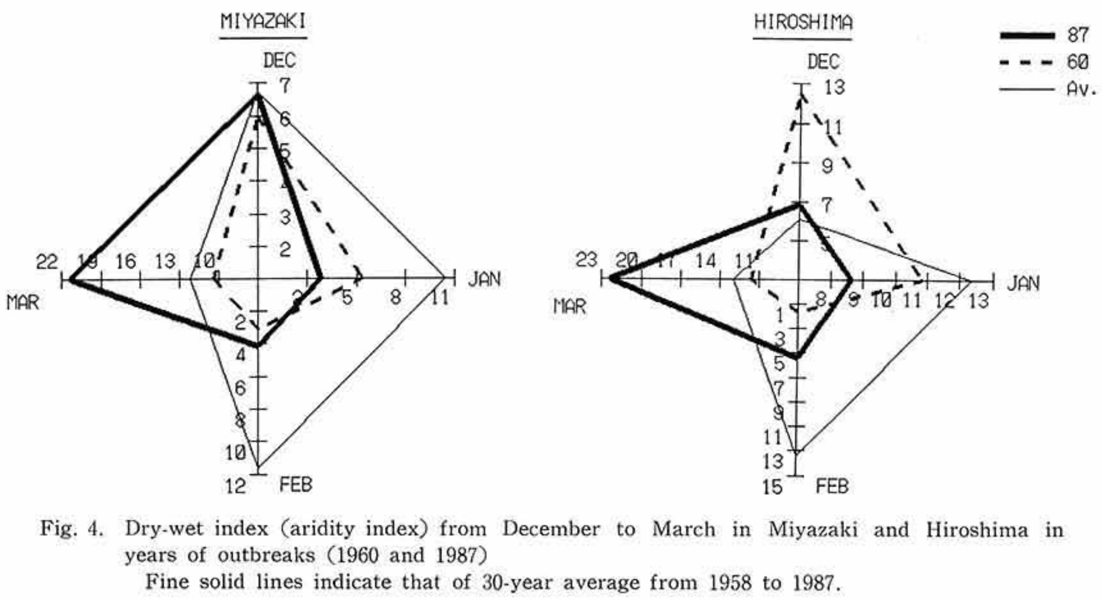

Fig. 4. Dry-wet index (aridity index) from December to March in Miyazaki and Hiroshima in years of outbreaks (1960 and 1987)
Fine solid lines indicate that of 30-year average from 1958 to 1987.

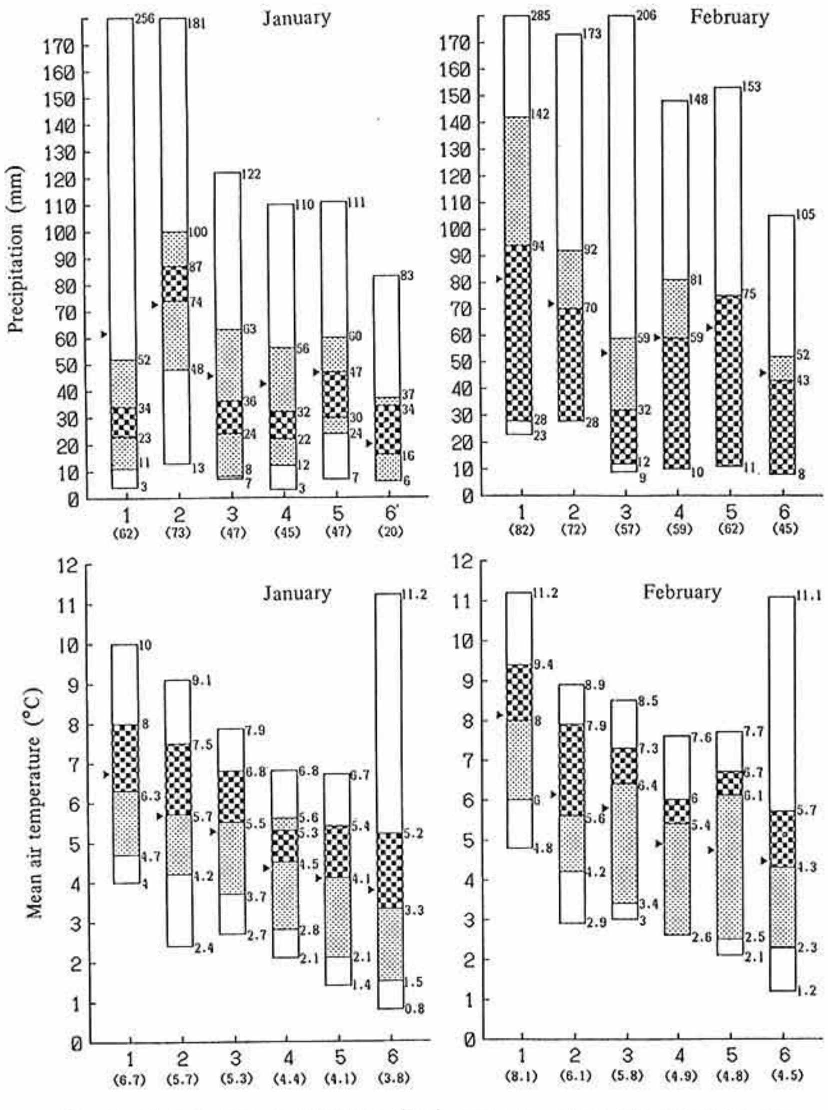

Fig. 5. Ranges of precipitation (top) and of mean air temperature (bottom) for January and February from 1958 to 1987 in 6 stations in west Japan
Wide area outbreaks occurred in the range shown by the checkered portion.
Outbreaks occurred in that of the dotted portion.
Averages (▶) for each station are shown in parentheses below the abscissae.
Station 1: Miyazaki, 2: Shimonoseki, 3: Tokushima, 4: Tsu, 5: Hiroshima, 6: Okayama.

in January and February is smaller than that of the 30-year average. Adult monitoring should be carried out according to the flow chart as shown in Fig. 6 in the forecasted adult immigration year.

2) Observation on occurrence and route of low air pressure

In a forecasted immigration year, careful attention should be paid to occurrence and movement of low air pressure from east China

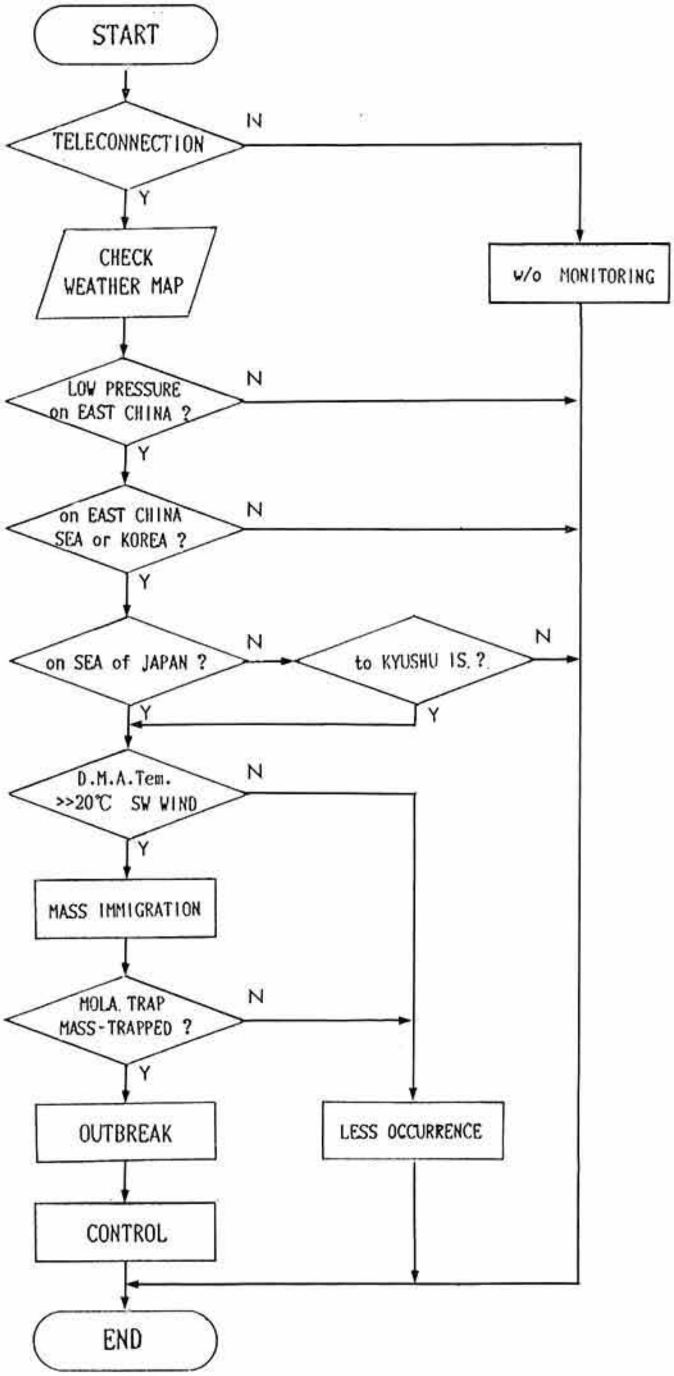

Fig. 6. Forecasting chart of the early summer outbreak by immigrant *P. separata* in Japan

to Japan from mid April to June, by looking at daily weather maps. Especially, mass adult immigration should occur when daily mean air temperature (D.M.A. Tem. in Fig. 6) rises to about 20°C with prevailing southwest warm wind in the respective monitoring station.

3) *Trapping methods for adults*

A molasses trap, a blacklight trap (3,700 Å)[6] and a synthetic pheromone trap[14] are available for attracting adults. Molasses baits are 1.9-litter mixtures of SAKE lees 13, water 32, black sugar 5, vinegar 1 in weight ratio.

In trapping tests carried out in a net house in our Experiment Station during June to July in 1985, each of attractive sources was placed in a live-capture trap shown in Fig. 7. Most adults were trapped in the molasses trap and the blacklight trap on and after day 1 following eclosion. A smaller number of adults were attracted by the synthetic sex pheromone. Most flight to the synthetic pheromone occurred at day 4 following eclosion[7].

Field trapping tests during June 6 to 19 in 1987 in Morioka (Fig. 7), during which mass adult immigration was observed, showed a molasses trap attracted the highest number of adults among the three traps, 127±20 (SD) per molasses trap, 92±67 per blacklight and 3.7±3.8 per synthetic pheromone trap. More adults were caught in a trap which was set at the upwind side of a house, without direct exposure to strong wind.

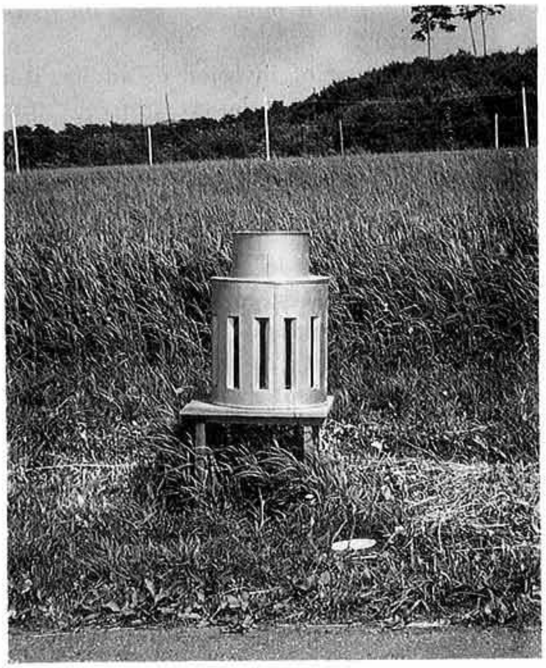

Plate 1. A live-capture lure trap
Adults are attracted through slits around the cylinder. Attracted adults go up and are trapped in the upper cylindrical portion, the lid of which is equipped with transparent plastic. A trap is placed on a 60 cm high rack in a field.

Table 1. Relationship between the number of *P. separata* adults caught with a live-capture lure trap (molasses) and their offspring larval density in the trap-set pasture in northern Japan

Starting date**	Number of adults trapped in indicated period				Date	Larval density	Station	Area (ha)
	1	2	5	10 (days)		M±SD/m²(n)		
'87 6. 8	♀86 ♂96	♀114 ♂115	♀150 ♂137	♀164 ♂151	July 3	359±11 (5)	Noshiro	20
'87 6. 8	♀94 ♂48	♀127 ♂ 54	♀204 ♂107	♀268 ♂214	July 3	181±65 (5)	Takanosu[a]	10
'87 6. 8	♀16 ♂ 1	♀ 17 ♂ 3	♀ 25 ♂ 13	♀ 30 ♂ 21	July 3	49±14 (5)	Takanosu[b]	2
'87 6. 14	♀29 ♂ 5	♀ 44 ♂ 17	♀ 76 ♂ 38	♀ 85 ♂ 51	July 8	128±15 (5)	Morioka[a]	2
'87 6. 11	♀16 ♂30	♀ 21 ♂ 36	♀ 35 ♂ 62	♀ 38 ♂ 65	July 8	ca. 80 (3)	Morioka[b]	1
'87 6. 12	♀98 ♂185	♀149 ♂253	♀225 ♂343	♀273 ♂476	July 10	ca. 130	Oono	1
'84 6. 15	♀♂32	♀♂71	♀♂101	♀♂155	July 10	ca. 77	Ooma	25*
'86 5. 26	♀ 4 ♂ 9	♀ 4 ♂ 10	♀ 7 ♂ 12	♀ 13 ♂ 15	July 8	11± 5(10)	Noshiro	20
'86 6. 10	♀ 2 ♂ 0	♀ 2 ♂ 0	♀ 2 ♂ 0	♀ 4 ♂ 0	July 8	2± 2(10)	Takanosu[a]	10
'86 5. 21	♀ 1 ♂ 0	♀ 1 ♂ 0	♀ 1 ♂ 0	♀ 1 ♂ 1	July 1	1± 1(10)	Morioka[b]	1
'85 5. 31	♀ 2 ♂ 4	♀ 5 ♂ 6	♀ 6 ♂ 7	♀ 6 ♂ 8	June 14	0.2±0.4(10)	Futatsui	15
'85 5. 17	♀ 4 ♂ 2	♀ 4 ♂ 2	♀ 6 ♂ 3	♀ 9 ♂ 3	June 14	0.01 (10)	Noshiro	10

*A molasses tray was set for trapping.
**Adult survey was carried out from the starting date for 10 days.
a), b) show different fields in the same station.

4) Setting of a molasses trap on grass pasture

For monitoring of invasion of adults, it is preferable to set a molasses trap on grass pasture over 1 ha in area, which is open to west or south without exposure to strong wind. When lots of adults are caught with a molasses trap, there is the possibility of mass adult immigration over wide areas. Table 1 shows the relationship between number of moths caught with a molasses trap and their offspring larval density in the trap-set pasture. According to the results, when over 16 female adults were caught per trap per night, larval outbreaks occurred ca. one month later.

When confirming the number of adults trapped, earlier finding of larval occurrence should be made in pasture or other crops. Outbreak in earlier summer always leads to the occurrence toward the end of August in rice, corn, and pasture in wider areas. This will result in an outbreak unless control at younger larval stages is carried out during the beginning of August.

The author thanks Drs. J. Koyama and M. G. Hill for their critical reading of the manuscript.

References

1) Asahina, S. & Turuoka, Y.: Records of the insects visited a weathership located at the Ocean weather station "Tango" on the Pacific, III. *Kontyu*, **37**, 290–304 (1969) [In Japanese with English summary].
2) Hill, M. G. & Hirai, K.: Adult responses to larval rearing density in *Mythimna separata* and *Mythimna pallens* (Lepidoptera: Noctuidae). *Appl. Entomol. Zool.*, **21**, 191–202 (1986).
3) Hirai, K.: Outbreaks of the armyworms *Pseudaletia separata* WALKER, in and around west Japan in early summer of 1981, with the analyses of weather maps involved in the moth's displacement. *Kinki Chugoku Agr. Res.*, **64**, 66–68 (1982) [In Japanese].
4) Hirai, K.: Long-distance migration and outbreak in *Pseudaletia separata* WALKER II. similarity and difference between *Mythimna pallens*. *Abstr. Ann. Meet. of Entomol. Soc. of Jpn. at Tsukuba Univ.*, **B104** (1984) [In Japanese].
5) Hirai, K.: Migration of *Pseudaletia separata* WALKER (Lepidoptera: Noctuidae); Considerations of factors affecting time of taking-off and flight period. *Appl. Entomol. Zool.*, **19**, 422–429 (1984).
6) Hirai, K.: Light and molasses attraction of some noctuid moths. *Tohoku Kontyu* (Tohoku Entomol. Soc.), **24**, 3–5 (1986) [In Japanese].
7) Hirai, K.: Live-capture trap for insects. *Agriculture of this month*, **31**(7), 92–96 (1987) [In Japanese].
8) Hirai, K. & Santa, H.: Comparative physio-ecological studies on the armyworms, *Pseudaletia separata* WALKER and *Leucania loreyi* DUPONCHEL (Lepidoptera: Noctuidae). *Bull. Chugoku Nat. Agr. Exp. Sta.*, E **21**, 55–101 (1983) [In Japanese with English summary].
9) Hirai, K. et al.: Outbreaks of the armyworm, *Pseudaletia separata* WALKER (Lepidoptera: Noctuidae) in northern Japan in the mid-July of 1984, with analysis of weather maps involved in the moths' displacement. *Chugoku Nat. Agr. Exp. Sta.*, E **21**, 55–101 (1983) [In Japanese with English summary].
10) Koyama, J.: The relation between the outbreak of armyworm (*Leucania separata* WALKER) and the richly nitrogenous manured cultivation of rice plant. *Jpn. J. Appl. Entomol Zool.*, **10**, 123–128 (1966) [In Japanese with English summary].
11) Nagano, M.: Forecast at outbreak period of the armyworm, *Leucania separata* WALKER in grassland. *Bull. Nagasaki Agr. Exp. Sta.*, **2**, 38–45 (1974) [In Japanese].
12) Oku, T.: Annual and geographical distribution of crop infestation in northern Japan by the oriental armyworm in special relation to the migration phenomena. *Misc. Publ. Tohoku Nat. Agr. Exp. Sta.*, **3**, 1–49 (1983) [In Japanese with English summary].
13) Sharma, H. C. & Davies, J. C.: The oriental armyworm, *Mythimna separata* (WLK.) distribution, biology and control; a literature review. *Centre for Overseas Pest Research, ODA Misc. Rep.*, **59**, 1–24 (1983).
14) Takahashi, S. et al.: Pheromone components of *Leucania separata* WALKER and *Leucania loreyi* DUPONCHEL. *Jpn. J. Appl. Entomol. Zool.*, **23**, 78–81 (1979) [In Japanese].
15) Tanaka, A.: Ecology of the armyworm, *Mythimna* (*Leucania*) *separata* (WALKER). *Plant Protection*, **30**, 431–437 (1976) [In Japanese].

(Received for publication, January 25, 1988)