Early Summer Outbreaks of the Oriental Armyworm,
Mythimna separata WALKER, in the Tohoku District
and Possible Causative Factors
(Lepidoptera: Noctuidae)

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During the last six years serious outbreaks of the oriental armyworm, *Mythimna separata* WALKER, occurred in the early summer of 1971 and again in 1972. The outbreak areas were located mainly in the western parts of the district. This pattern of distribution suggested that the outbreak might be caused by migrating moths carried by the strong southwesterly winds which blew through the district. Some of the local outbreaks could be explained by the topographic effect on the migration. The dates of the moth invasions were inferred from the mean air temperature and the direction and strength of the wind. Meteorological data showed that the inferred dates of moth invasion in the latter half of May coincided with the rapid movement of a depression from eastern China to the northwestern coast of the Tohoku district.

INTRODUCTION

In the Tohoku district of northern Japan, there are two main periods during which outbreaks of the oriental armyworm, *Mythimna separata* WALKER, have occurred in the past. These are from mid June to early July and from mid August to early September (KOYAMA, 1970). Also, a third period during November has been recorded but only infrequently (KOYAMA and WATANABE, 1962). As there is no evidence for a high winter survival in the Tohoku district, the outbreaks, at least in early summer, may be caused mainly by immigration of adults from warmer regions. In China, the northward migration of the armyworm moth in spring has been substantiated by means of a marking and recapture method (LI et al., 1964), and the early outbreaks which are seen in the north are considered to be caused by immigration of the moth from the south (LIN and CHANG, 1964; CHEN et al., 1965; LIE et al., 1965).

In the past it was often stressed that the observed flight direction of migrating insects was not necessarily correlated with the current wind road (FISHER, 1938; WILLIAMS, 1957, 1958), but recent studies revealed that the long-distance displacement of many migratory insects is under the control of the wind (JOHNSON, 1969). Furthermore, the migratory routes were estimated by back-tracking the current winds in some notable examples of noctuid moths (HURST, 1965; MIKKOLA and SALMENSUU, 1965; MIKKOLA, 1967; FRENCH, 1968; BROWN et al., 1969). In this paper, a possible source of the oriental armyworm moth causing the early summer outbreak in the Tohoku district is inferred by analyzing the relation between the distribution of outbreak areas and

wind conditions during the suspected periods of moth invasion.

MATERIALS AND METHODS

Detailed records of the annual survey on the oriental armyworm outbreaks during the last six years were provided by the Agricultural Experiment Stations in the Tohoku district. The annual records include the localities of outbreaks and the approximate date of cessation of infestation. From the approximate date of pupation in the field, the first oviposition periods were roughly inferred based on the heat-unit accumulation in the main outbreak areas. For this purpose, the developmental thresholds and the thermal constants for the egg and larva given by LIN and CHENG (1958) were used. Since the flight duration of this species as tested on a mill has been seen to be remarkably prolonged on the third and fourth days of emergence and rapidly declines on the fifth day with the ovarian maturation (HWANG and HOW 1966), the long-range migration could be made only within a few days just before oviposition. Thus, the approximate date of moth immigration can be inferred from the estimated date of oviposition. For this estimation, the temperature records of several meteorological stations situated in the Ôu Mountain range were excluded, because the outbreak sites were distributed on the plains or the hill sides below an altitude of 300 m. The wind records in the main outbreak areas of Akita and Aomori Prefectures were examined in detecting a possible relation between the moth invasion and the wind, because a great majority of outbreak sites were located in these prefectures. The restricted local flow of the moth swarms were inferred from local wind roads on the suspected day of moth invasion. The direction and speed of wind were recorded daily at 9 a.m.

RESULTS AND DISCUSSION

General distribution of outbreaks and the period of moth invasion

Annual records of outbreaks of the oriental armyworm which have occurred in early summer are summarized in Table 1. This table suggests that serious moth invasions occurred in 1971 and 1972 and resulted in great losses of pasture grass mainly in Akita and Aomori Prefectures. As will be shown in detail later in Fig. 3, the following points can be seen in the distribution of outbreaks in 1971 and 1972:

- 1) The outbreak sites were scattered in a wide area stretching about 300 km

Table 1. EARLY SUMMER OUTBREAKS OF THE ORIENTAL ARMYWORM IN THE TOHOKU DISTRICT DURING THE LAST SIX YEARS^a

Year	Prefecture				Injured plants		Total
	Aomori	Akita	Yamagata	Others	Grasses	Others	
1968	0	0	0	0	0	0	0
1969	0	1	0	0	1	0	1
1970	0	0	0	0	0	0	0
1971	27	62	1	0	88	2	90
1972	9	5	2	0	16	0	16
1973	0	0	0	0	0	0	0

^a Figures indicate the number of localities where outbreak of the armyworm occurred.

from south to north, but many were located in the western parts including Aomori, Akita and northern Yamagata Prefectures, particularly on the coastal plains along the Japan Sea and on the inland plains which open towards the west. This may suggest that the moth invasion was by way of the western coast.

2) Except for Aomori Prefecture which is northernmost part of the district, no outbreak occurred to the east of the Ôu Mountain chain running from south to north along the centre line through the district. This suggests that the Ôu Mountains might be effective as a meteorological barrier to moth migration at this time of the season (WILLIAMS et al., 1956).

3) In Aomori Prefecture, the outbreak occurred mainly to the west of the line running southwest to northeast through Mt. Hakkoda, a prominent northern peak of the Ôu Mountains, and Cape Shiriya, the northeastern extremity of the district. In the region north of Mt. Hakkoda, the Ôu Mountains are much lower and would therefore not constitute a barrier to moth migration, and consequently the outbreak sites might be distributed along the main wind direction. Thus, the moth swarms responsible for the outbreaks were considered to be carried by a strong wind from the southwest. Several outbreaks in 1971 in the Nanbu plain southeast of Mt. Hakkoda could not be explained in this manner, and these will be referred to later in relation to the local topography.

It is also noticed that the local heavy infestation in each year was terminated within a certain short period as indicated in the next paragraph. This may suggest that the moth invasion took place in a particular short period. Thus, a possible explanation for these facts is that the moth swarms were carried by a strong southwesterly wind temporarily established across a wide area of the district.

According to the field records, the infestation was terminated in all localities between 15th and 20th of July in 1971 and between 10th and 20th of July in 1972, with very few exceptions. As the field population usually reached its pupation peak several days before the complete disappearance of larvae, the approximate time of pupation was estimated at about 10th July for both years. The air temperature for 10-day periods in the main outbreak areas of Akita and Aomori Prefectures are shown in Table 2. From these records the first oviposition period was inferred to be May 25—28 in 1971 and May 15—17 in 1972 on the assumption that the developmental thresholds were 13.1 and 7.7°C, and the thermal constants were 45 and 402 day-degrees for the egg and the larva, respectively. This suggests that the moths immigrated in mid or late May and also that the immigration was somewhat later in 1971 than in 1972.

In order to detect possible dates of the moth invasion characterized by the strong

Table 2. AIR TEMPERATURES IN THE MAIN OUTBREAK AREAS

Period	95% fiducial limit of air temperature (°C) ^a	
	1971	1972
May 11—20	14.6—15.2	14.0—14.4
May 21—31	16.0—16.6	13.8—14.1
June 1—10	15.0—15.8	18.3—18.9
June 11—20	16.5—16.9	17.5—17.9
June 21—30	18.6—19.4	17.9—18.2
July 1—10	22.1—22.8	21.6—22.0

^a Based on the mean temperatures at 59 and 56 stations in 1971 and 1972, respectively.

Fig. 1. Wind conditions recorded daily at 9 a.m. during mid and late May in 1971 and 1972 expressed as percentage of meteorological stations which recorded the southerly, southwesterly and westerly winds and the wind speed exceeding 5 m per sec. Solid and broken lines were obtained from daily wind records of 31 and 27 stations in the main outbreak areas of Akita and Aomori Prefectures, respectively; arrows indicate the suspected periods of moth invasion.

southwesterly wind, the wind records of mid and late May in the main outbreak areas were examined. As the observed direction of wind was possibly influenced by the local topography and somewhat differs from the main wind direction, the southerly and westerly winds as well as the southwesterly ones should be taken into account. Fig. 1 illustrates the number of stations which recorded the southerly, southwesterly and westerly winds and wind speeds exceeding 5 m per sec. From Fig. 1 it appears likely that the moths invaded between the 25th and 26th of May in 1971 and the 17th and 18th of May in 1972, because the strong wind from the right direction prevailed over both Akita and Aomori Prefectures during these periods. Although similar wind conditions were observed on the 31st May, 1972, this date was too late for the evocation of outbreaks in this year (see Table 2). The frequency distribution of wind

Fig. 2. Frequency distribution in percentage of wind directions recorded at 9 a.m. during the suspected periods of moth invasion at 58 meteorological stations in Akita and Aomori Prefectures.

directions during the suspected periods of moth invasion clearly demonstrates a marked dominance of the southwesterly wind (Fig. 2). In both years the strong southwesterly wind followed soon after the passage of an atmospheric depression northwards along the northwestern coast of the Tohoku district. In 1972, however, a high wind speed was recorded more frequently in Akita Prefecture on the 17th, and then in Aomori Prefecture on the 18th of May (see Fig. 1) due to a localized and slower passage of the depression.

In general, the process of moth migration can be divided into 'ascending', 'transmigrating' and 'descending' phases. With regard to an invasion into a locality, the latter two may be important. In the cases under consideration in the present discussion, the 'transmigration' phase could be explained by the wind analysis shown above, but the larval outbreak can not be evoked unless the final 'descending' phase is achieved. In this connection, LIN (1963) reported that the landing of the migrating oriental armyworm moth was observed most frequently in the cyclonic centre, the cold front area, and the thunder-storm. In 1971 and 1972, the cyclonic centres under discussion passed close by the outbreak area. Furthermore, the depression in 1971 was followed by a prominent cold front, which moved eastwards through the Tohoku district at dawn of 25th May. These facts suggest that the weather conditions at this time were favorable for the moth landing. According to the weather maps of 1972, no frontal system developed in association with the described depression. During the estimated invasion period, however, the air temperature in the Tohoku district was very low, the minimum temperature at sea level being estimated at about 10°C on 17th and about 5°C on 18th May. Under this condition, the moths would have inevitably flown at a low level. A similar case was reported for *Spodoptera exigua* HÜBNER (HURST, 1965; FRENCH, 1968). It seems possible that in 1972 the moth landing was favoured by this cold weather.

Local distribution of outbreaks

If a strong wind of particular direction caused the mass immigration of the moth as supposed above, local outbreaks might be expected to occur along the pathway of the local wind prevailing during the time of invasion. Fig. 3 shows the distribution of outbreaks and the migrating routes of moth swarms inferred from the local wind directions. In 1971 (Fig. 3a), a remarkable concentration of outbreaks was found in

Fig. 3. Distribution maps of the oriental armyworm outbreak in early summer of 1971 and 1972. Cross-hatched, more than 800 m above sea level; hatched, from 300 to 800 m above sea level.

the lowlands along the Yoneshiro River, especially in the Takanosu basin. Also, there were several outbreaks in the Nanbu province of Aomori Prefecture northeast to the Raiman pass, around which the Ôu Mountains are of low elevation (about 600 m above sea level).

The above-mentioned facts might be explained in the following manner. When the southwesterly wind blew down into the lowlands along the Yoneshiro River across the southern hills, some crowds of moths carried by the wind were landed, but others were blown further to the east along the river course, and a few of them crossed over the Ôu Mountain chain through the Raiman pass. The local topography probably caused similar turn-off of the moth swarms in the vicinity of Yokote, but in this case invasion to the eastern plain was prevented by the higher elevation of the mountains (more than 800 m above sea level). If so, the upper limit of moth flight in this time would lie between 600 and 800 m above sea level. Although the meteorological records in the Shonai province of Yamagata Prefecture shows that a strong southwesterly wind covered this area on the 25th and 26th of May in 1971, there was only one outbreak site in that year. This might be attributable to the fact that the cyclonic

centre approached the coast farther to the north.

The local distribution of outbreaks in 1972 (Fig. 3b) was somewhat different from that in 1971 since there were fewer outbreaks and an absence of outbreaks to the east of the Ôu Mountains in the Nanbu province of Aomori Prefecture and in the inland area of Akita Prefecture. Although the causes of these differences are unknown, it is noted that in 1972 the depression concerned was of smaller scale and the field temperature in and just after the possible immigration period was much lower (see Table 2). It might be possible that these conditions had some influence on the number of moth immigrants carried by the wind or on the survival of their progenies particularly in the cooler inland areas. Another characteristic feature in 1972 was the occurrence of a few outbreaks in the Shinjo basin, Yamagata Prefecture, where no strong wind was recorded during the critical period of moth invasion. These outbreaks can also be explained by the topographic effect: a few crowds of the moth may have travelled on the southwesterly wind across the Shonai plain to the narrow valley along the Mogami River, and they then reached the Shinjo basin by flying through the valley, even though there was no strong wind in the basin.

Possible source of immigrants

Although the evidence must be considered only circumstantial, it seems likely that the moth invasions dealt with in this study were associated with the passage of depressions through the Japan Sea. Approximate routes of the depressions are given in Fig. 4. From the figure the following interesting points arise: it is certain that

Fig. 4. Approximate routes of the depressions speculated to carry swarms of the oriental armyworm in May of 1971 and 1972. Solid and broken curves, routes of the depressions in 1971 and 1972, respectively; circles, positions of cyclonic centre at 9 a. m. with dates at the starting points; T, Tohoku district (the main outbreak area being shaded); J, Japan Sea; Y, Yellow Sea; C, Chilli Gulf; cross-hatched space, a possible source of the moth immigrants; wide arrow, a customary course of northward migration of the moth in late spring.

(1) the depressions were followed by the strong southwesterly wind around the cyclonic centre on their southeastern flank, which blew in from the Japan Sea to the outbreak area (shaded part in Fig. 4); (2) the depressions came from the Chili Gulf-Yellow Sea region known to be a customary passage for the northward migration of the oriental armyworm moth (HSIA, et al., 1963; LI et al., 1964; LIN and CHANG, 1964); and (3) the highest seasonal peak of the moth abundance lies between mid May and early June in coastal China from 32°N to 36°N as cross-hatched in Fig. 4 (LI et al., 1964; LIN and CHANG, 1964; CHEN et al. 1965). If a depression causes a continuous wind in parallel with its trajectory on the full course of its rapid movement, the moths caught by the wind could conceivably travel from the Chili Gulf-Yellow Sea region to the outbreak area of the Tohoku district within one or two days. Hence, there may be a high possibility that the moth swarms caused outbreaks in 1971 and 1972 were caught by a strong wind in the Chili Gulf-Yellow Sea region during their northward migration from the southern coast of the Yellow Sea. Even if this was proven to be true, the passage of depressions through a similar trajectory in the late spring would not necessarily cause a large-scale invasion of the armyworm moth into the Tohoku district. In China, there has been considerable annual fluctuation of the armyworm abundance (CHEN et al., 1965), which may affect the size of the population immigrating into the Tohoku district. There is also an indication that the immigration route supposed here might not be the only one. For example, KOYAMA (1970) recorded an extensive outbreak of the oriental armyworm in the early summer covering nearly the whole area of the Tohoku district in 1960. The source and route of the immigrant moths in this case is still open to question.

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