Variations in the occurrence patterns of male moths of the common cutworm, *Spodoptera litura* (Lepidoptera: Noctuidae) among Southeastern Asian countries, as detected by sex pheromone trapping

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Abstract

Traps with sex pheromone (litlure) of *Spodoptera litura* were set at nine locations in five countries in Southeastern Asia to compare the daily patterns of male moths caught in traps during the overlapping two years between 1997 and 1999. When the records for observation periods were averaged, the daily number of males from June to November was low in the locations of the year-round occurrence of males, as 0.4 on Sulawesi Island in Indonesia (5°S), 2 on Luzon Island in the Philippines (15°N), 2 in Chiayi, Taiwan (24°N), 4 in Kwangsi, China (25°N), 11 in Fukien, China (27°N), and 20 in Okinawa, Japan (26°N), whereas in locations where essentially no males were caught during winter, significantly more males were caught daily as follows: 108 in Chekiang, China (30°N), 192 in Kagoshima, Japan (31.5°N) and 47 in Saga, Japan (33.5°N). This increasing tendency of males toward northern latitudes suggested the northward migration of this species, and further to Kyushu from China, distributed at the same and/or a lower latitude, if they could migrate overseas. The possible migration of this species to escape natural enemies was discussed.

Key words: Pheromone trap; sex pheromone; *Spodoptera litura*; natural enemy; migration

INTRODUCTION

The common cutworm, *Spodoptera litura*, is distributed in much of Asia, including tropical, subtropical and temperate areas and Oceania (Venette et al., 2003), and the larvae are known to feed on more than 120 plant species, including many crops such as rice, taro, soybean, sweet potato, tomato, tobacco and eggplant (Okamoto and Okada, 1968; Balasubramanian et al., 1984; Sharma, 1994; Pogue, 2003; Venette et al., 2003).

The sex pheromones released by *S. litura* females have been identified (Tamaki et al., 1974), the septa impregnated with the two components of the pheromone have been demonstrated to effectively attract the males (Yushima et al., 1974) and are commercially available as litlure. Since that time, the occurrence patterns of *S. litura* males have been elucidated in broad areas of Japan (Tamaki, 1985) and other countries (Venette et al., 2003) whereas, until now, essentially no comparison of the occurrence pattern of males using the litlure among different countries has been reported.

In Kyushu, the southernmost mainland, very few males are trapped in winter and increase from spring to summer, rather suddenly in typhoon season and lingering during the rainy season (Murata et al., 1998; Murata, 2001). Meteorological analyses suggested immigration of the moths overseas to Kyushu with the aid of wind (Murata, 2001).

Here, we set pheromone traps in different areas of Asia, found higher numbers of males toward the

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north compared with in tropical and subtropical areas, and pointed out the possibility of immigration of this species to Kyushu from China distributed at the same and/or lower latitude, if they could migrate overseas.

MATERIALS AND METHODS

The synthetic sex pheromone, litiure, used in this study was supplied as Pherodin® SL by Takeda Pharmaceutical Company, and was composed of (9Z,11E)-9,11-tetradecadienyl acetate and (9Z, 12E)-9,12-tetradecadienyl acetate at a ratio of 10 : 1. A single trap (dry type, Takeda Pharmaceutical Company) along with a rubber septum impregnated with 1 mg of litiure was set 1.0–1.5 m above the ground shortly before dusk and withdrawn the following morning, and caught males were counted daily. The septum was renewed monthly. The traps were set in the following locations (Fig. 1): Saga University, Saga-shi (Saga: 33.5°N, 130° E), at Kagoshima Agricultural Experiment Station, Kagoshima-shi (Kagoshima: 31.5°N, 130.5°E) and at the University of the Ryukyu, Nishihara (Okinawa: 26°N, 128°E) in Japan, in Hangzhou, Chekiang Province (30°N, 120°E), in Zhenghe, Fukien Province (27°N, 118°E) and in Yongfu, Guilin, Kwangsi Province (25°N, 110°E), China, in Chiayi (24°N, 121°E), Taiwan, in Pangasinan, Luzon Island in the Philippines (15°N, 121°E) and in Makassar, Sulawesi Island in Indonesia (5°S, 120°E). Daily catches were checked for overlapping for nearly two years during 1997 and 1999 in these locations, except for the observatory on Sulawesi Island where the survey was conducted for one year (Figs. 2–4).

RESULTS

Attraction patterns of males to traps in Indonesia, the Philippines and Taiwan

In these locations, the traps were set in 1997 and 1998 (Fig. 2). On Sulawesi Island, Indonesia, zero or one male was mostly caught per day, and only four males at maximum during the survey period of nearly one year: the number slightly increased toward the new year. On Luzon Island, the Philippines, less than two males were caught daily, mostly before December 1997, five males at maximum, but then toward early 1998, more males were caught, often exceeding 10 per day, 45 males at maximum. Again, very few males, less than three, were caught daily from May to August 1998, and then a prominent increase was often recorded, reaching over ten per day to October, after which no checks were conducted. Thus, more males seemed to occur near the end and in the early period of the year.

In Chiayi, Taiwan, males caught per day from May to August were less than five at maximum and tended to increase toward the end of both years, as in the Philippines (Table 1), but a catch of over 20 males per day was recorded only once during the two years.

Attraction patterns of males to traps in China

Pheromone traps were set at three places in China in 1998 and 1999 (Fig. 3). In Kwangsi, males were caught throughout the year, as in Taiwan, but on most days fewer than two from January to February, and several to ten in other months, several peaks of a sudden increase in number being recorded, especially in October and November 1999.

In Fukien, more males were caught than in Kwangsi, but males were rarely caught before May. Marked increases in the number of males caught
per day were observed in May or June, one or two times achieving over 30. Thereafter, 10 to 20 males per day were continuously caught, and more males were trapped in October and November.

In Chekiang, the numbers of males caught were conspicuously higher than those recorded in the aforementioned locations. No males were caught before May, but then the number of males caught markedly increased, sometimes exceeding 100 or 200 per day. From July to October, nearly 200 males were caught every day, with the maximum number per day almost reaching 500.

**Attraction patterns of males to traps in Japan**

Pheromone traps were set at three places in Japan in 1997 and 1998 (Fig. 4). In Okinawa, the occurrence of males was recorded all year around; even in January and February, several males were
caught per day. Sharp increases in males were recorded two or three times in April or May, reaching over 200 in 1997 and 75 in 1998 on one day; thereafter, males caught per day usually decreased to under 50 in both years.

In Kagoshima, the occurrence patterns of males were considerably different from those in Okinawa, many more males being attracted to traps in autumn. Very few males were caught before April, but then increased markedly in April or May. Thereafter, moths were continuously caught and increased in number toward September and October, when daily catches of males exceeded 600 in 1997, and 2000 in 1998.

In Saga, the occurrence patterns of males were also different from those in Okinawa and rather similar to those in Kagoshima, but the numbers of males caught per day were two and five times lower than in Kagoshima. In both years, no males were caught before April and males were first captured in May or July.

**Higher tendency of the number of males caught in traps toward northern Asia**

As shown in Table 1, we found a higher tendency in the number of males caught per day from June to November with a higher northern latitude of the trap. In locations where year-round occurrence of males was recorded, a rather small number of males were caught daily on average during this period as follows, (averaged if two or three years’ records were obtained): 0.4 in Sulawesi (5°S), 2 in Luzon (15°N) and Chiayi (24°N), 4 in Kwangsi (25°N), 11 in Fukien (27°N), and 20 in Okinawa (26.5°N), whereas many more males were caught in more northern areas where *S. litura* might not be able to hibernate, as reflected in the very small number of males caught during winter, 108 in Chekiang (30°N), 192 in Kagoshima (31.5°N), and 47 in Saga (33.5°N).

**DISCUSSION**

As *S. litura* does not enter diapause and its developmental zero is 10°C (Ishida and Miyashita, 1976), the species is thought to be unable to hibernate in temperate zones where the temperature often falls below 5°C in winter. The species is, however, found even in frigid zones, such as areas at 50°N in Russia (Venette et al., 2003). Such a broad distribution of *S. litura* suggests high migratory ability, as suggested by Murata et al. (1998) and Murata (2001). The high ability of *S. litura* was demonstrated by tethered flight (Murata and Tojo, 2004). As only one trap was set at each observation point in the present study, the number of males caught in each trap might not represent the general...
level of moths distributed at the observation point in a limited season. Detailed surveys might therefore be necessary to deduce the occurrence of this species from the present data; however, considering that each location was surrounded by crops in a flat area with a broad view, and also the high migratory activity of *S. litura*, as mentioned above, the level of males caught in a trap recorded over two overlapping years is expected to somewhat reflect the population density and its change according to location, as the result of mingling populations by migratory movement. The following discussion depended on this expectation.

**Possible northward migration of *S. litura***

Coinciding with the non-diapausing characteristics of *S. litura*, essentially no or very few males were caught during January and February where temperature often fall below 5°C, as in Saga (33.5°N) and Kagoshima (31.5°N), Japan, and Chekiang (30°N), China (Figs. 3 and 4; Table 1). In Kagoshima, one or two males were sometimes caught per day during these periods, which might have originated from those hibernating in heated greenhouses during winter. Fukien (27°N) and Kwangsi (25°N) in China also seem not to be annual breeding areas of *S. litura*, because fewer than one male on average was caught daily during January and February (Table 1), when the temperature is over 10°C.

The possible immigration of *S. litura* moths to Japan with the aid of wind in the typhoon and rainy seasons has been suggested (Murata et al., 1998; Murata, 2001). The higher tendency in the number of males caught per day from May to November with the more northern latitude of the trap (Table 1) also seems to support their migration to northern zones. In 1999, sudden increases of males caught in traps occurred in late May in Fukien (27°N), then in June and July in Chekiang (30°N), and a further three or four times from August to November at these locations (Fig. 3). It is reasonable to assume that the populations occurring in these locations after essentially no catches of males for a long period are immigrants from more southern areas, and also that several prominent peaks of

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**Table 1. Comparison of average numbers of males caught in traps per day among different locations during the trapping period**

<table>
<thead>
<tr>
<th>Locations</th>
<th>Year</th>
<th>January to February</th>
<th>March to May</th>
<th>June to August</th>
<th>September to November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Celebes Is., Indonesia</td>
<td>1997</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>1.5</td>
<td>0.2</td>
<td>0.7</td>
<td>0.1</td>
<td>—</td>
</tr>
<tr>
<td>Luzon Is., The Philippines</td>
<td>1997</td>
<td>—</td>
<td>0.2</td>
<td>0.6</td>
<td>1.1</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>10.8</td>
<td>3.9</td>
<td>1.2</td>
<td>4.9</td>
<td>—</td>
</tr>
<tr>
<td>Chiayi, Taiwan</td>
<td>1997</td>
<td>—</td>
<td>2.2</td>
<td>0.8</td>
<td>3.2</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>5.5</td>
<td>2.2</td>
<td>4.3</td>
<td>2.6</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>5.3</td>
<td>2.5</td>
<td>0.6</td>
<td>1.5</td>
<td>4.7</td>
</tr>
<tr>
<td>Kwangsi, China</td>
<td>1998</td>
<td>—</td>
<td>2.1</td>
<td>3.0</td>
<td>3.1</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>0.6</td>
<td>3.0</td>
<td>4.6</td>
<td>5.1</td>
<td>2.7</td>
</tr>
<tr>
<td>Fukien, China</td>
<td>1998</td>
<td>—</td>
<td>2.8</td>
<td>7.5</td>
<td>14.7</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>0.3</td>
<td>3.5</td>
<td>5.9</td>
<td>16.1</td>
<td>4.4</td>
</tr>
<tr>
<td>Chekiang, China</td>
<td>1998</td>
<td>—</td>
<td>—</td>
<td>70.8</td>
<td>149.8</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>0.0</td>
<td>0.3</td>
<td>105.1</td>
<td>104.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Okinawa, Japan</td>
<td>1997</td>
<td>3.4</td>
<td>37.6</td>
<td>22.7</td>
<td>34.1</td>
<td>18.1</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>8.2</td>
<td>15.9</td>
<td>10.0</td>
<td>12.4</td>
<td>11.0</td>
</tr>
<tr>
<td>Kagoshima, Japan</td>
<td>1997</td>
<td>0.2</td>
<td>16.3</td>
<td>34.7</td>
<td>148.1</td>
<td>13.7</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>0.8</td>
<td>24.2</td>
<td>141.8</td>
<td>442.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Saga, Japan</td>
<td>1997</td>
<td>0.0</td>
<td>0.0</td>
<td>15.6</td>
<td>52.6</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>0.0</td>
<td>0.4</td>
<td>13.1</td>
<td>93.0</td>
<td>—</td>
</tr>
</tbody>
</table>

a From data presented in Figs. 2 and 3.

b From data not shown in Figs. 2 and 3.
male capture indicate migration to these locations.

The patterns of males caught in traps were similar between Kagoshima (31.5°N) and Chekiang (30°N), where males tended to increase from June toward October, reaching over 400 per day (Figs. 3 and 4). If moths could migrate overseas under appropriate weather conditions, the region of China at around 30°N would be a possible migration source to Kyushu. In Chekiang, many males were caught in late May in 1998, but essentially none in May in 1999 (Fig. 3). Low levels of male capture during May have been further confirmed in Chekiang in several succeeding years (Sumio Tojo, unpublished) while, in Kagoshima, a considerable numbers of males were captured during April and/or May (Fig. 4). These results suggest that the moths would migrate to Kyushu from more southern parts of China, possibly from annual breeding areas, in spring, supposing their overseas migration.

Low levels of male capture in tropical and subtropical areas

We found that far fewer males were captured in traps with litlure set in tropical and subtropical countries. The lower numbers of *S. litura* in hot zones might be explained by growth retardation at high temperature; however, the development rate of this species increases with higher temperature up to 33°C, i.e., the highest temperature tested (Ishida and Miyashita, 1976), so it is not plausible that the lower occurrence of *S. litura* males at lower latitude was due to growth inhibition at high temperature.

On Sulawesi Island, Indonesia, quite low numbers of males were caught, fewer than one was caught per day on average (Fig. 2, Table 1), although *S. litura* is a serious pest of various crops, including soybean and corn, in Indonesia (Kalshoven, 1981). Also, in the field on Sulawesi Island where the trap was set, soybean plantations were generally damaged by *S. litura* larvae (Putu Oka Ngakan’s observation). This information suggests the presence of populations not responding to litlure.

Polymorphism with respect to female sex pheromone components is known in some moths, such as the Asian corn borer, *O. furnacalis* (Huang et al., 1998) and the rice leaffolder, *Cnaphalocrocis medinalis* (Kawazu et al., 2005). The numbers of males caught in litlure are also expected to be influenced by the numbers of virgin females in the locations; therefore, to render the low catches of males to population not responding to litlure, work is required to clarify population changes, especially of virgin females at the observation site, and to identify the pheromone composition of the dominant population.

Although many environmental factors are considered to be involved in the population density suppression of *S. litura* in annual breeding zones, one candidate of suppressive factors is expected to be the higher density of natural enemies. As it is reasonable to estimate that denser networks exist there between insect hosts and their natural enemies than in non-breeding area, immigration of the moths to a non-breeding area would enable better population growth as a result of escaping from natural enemies if sufficient food resources are available in the new habitat, as has been demonstrated in mobile pests (Kennedy and Margolies, 1985; Hirase, 2006).

An endoparasitoid, *Microplitis manilae* (Hymenoptera: Braconidae) is distributed in tropical and subtropical Asia and Oceania (Austin and Dangerfield, 1993), but recorded in Japan only in Okinawa (26°N) (Ando et al., 2006). *M. manilae* shows a higher growth rate from 15°C toward 35°C, and its females have the capacity to lay more than 500 eggs at 30°C (Ando et al., 2006), which would be highly effective for this species to reproduce during the hot season. In Okinawa, *S. litura* males markedly increased from March or April to June, whereas they subsequently did not increase, but rather decreased (Fig. 4). *S. litura* larvae in Okinawa are predominantly parasitized by *M. manilae* at a high percentage, sometimes reaching over 80% in spring (S. Tojo, unpublished). This suggests that reduced numbers of *S. litura* males in summer and autumn are due to high parasitization by *M. manilae*.

In Kagoshima, however, *S. litura* males were caught in small numbers in spring, but continued to increase toward autumn (Fig. 4). Another Hymenopterous endoparasitoid, *Meteorus pulchricornis*, is predominant in taro fields in Kagoshima, nearly 30% of *S. litura* larvae being parasitized by this species in autumn, but no *M. manilae* exists there (Tomotoshi Kashio, personal communication). As *M. pulchricornis* shows retarded growth over 25°C and lays only 25 eggs at 30°C (Takashino et
ences in the occurrence pattern of Kagoshima and Okinawa cause significant differences in predominant parasitoids between in summer. It is not implausible that such daily average temperature often exceeds 30°C expected in hot summers in Kagoshima, where the high fecundity of this species is not unknown. Recently, the authors would like to express their sincere thanks for recording the daily catches of S. litura males to Dr. Mika Murata, National Institute of Agrobiological Sciences, Tsukuba, Japan, Mr. A. R. Bertuso, National Tobacco Administration, Rosales, Pangasinan, the Philippines, Mr. Fa-Zhu Yang, Fukien Parasite Disease Institute, Fuzhou, China and Dr. Chang-Peng Yang, Kwangsi Agricultural Vocation-Technical College, Kwangsi, China and Dr. Shu-Sheng Liu, Department of Plant Protection, Zhejiang University, Hangzhou, China.

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REFERENCES


Perspective for further study on S. litura migration

This species is regarded to have originated in a hot area, from its non-diapausing trait, and from our results demonstrating that this species existed all year around in tropical and subtropical locations, but essentially not at all in temperate areas in the cold season. Especially from the patterns of males caught in traps in China, the migration of S. litura from these annual breeding zones to temperate zones is expected to occur on a large scale. We suggested here two possibilities to explain the unexpectedly low numbers of males in tropical areas, i.e., the presence of populations not responding to the sex pheromone used, and higher suppression by natural enemies, which would function to induce emigration to other areas, but these possibilities may be connected to male occurrence in other locations.

The major ecological features of S. litura remain unknown. Recently, S. litura strains significantly differing in host ranges were discovered (Tojo et al., 2008), suggesting the presence of populations feeding on plants with a broader host range to those with a narrower host range, if they repeatedly migrate to the north. We are conducting or plan-


