Monitoring the masson pine moth, *Dendrolimus punctatus* (Walker) (Lepidoptera: Lasiocampidae) with synthetic sex pheromone-baited traps in Qianshan County, China

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Abstract
The masson pine moth, *Dendrolimus punctatus* (Walker) (Lepidoptera: Lasiocampidae) was monitored at 102 trapping locations distributed in Qianshan County, China, with a synthetic sex pheromone during the 1998–2000 field seasons. Traps baited with a 25:10:28 three-component blend of Z₅,E₇-12:Ac; Z₅,E₇-12:Pr, and Z₅,E₇-12:OH (>97% pure) were used to attract male moths. The mean numbers of adult male *D. punctatus* captured in pheromone-baited traps during the overwintering generation flight periods in 1999 and 2000 increased sharply by 6.25 and 112.43, respectively, compared with those of male *D. punctatus* in 1998. The mean numbers of male *D. punctatus* captured during the first generation flight periods in 1999 and 2000 increased by 0.2256 and 5.92, respectively, compared with those in 1998. Traps placed at lower than 5.5 m in a masson pine forest canopy caught significantly more males of *D. punctatus* than did those placed higher in the forest canopy during the overwintering generation of 1998 and the first generation of 1999 flight periods. No significant differences were found among catches in traps placed on different slopes. A theoretical simulation method was used to estimate the suitable number of trapping locations needed in this study for acceptable precision. We estimated that 33–72 trapping locations are needed to monitor with statistical significance the dynamics of *D. punctatus* in Qianshan County during different field seasons.

Key words: *Dendrolimus punctatus* (Walker); sex pheromone; monitoring

INTRODUCTION

The masson pine moth, *Dendrolimus punctatus* (Walker) is endemic to southeast Asia and has been the most serious and economically damaging insect pest in south China forests in recent years. Although masson pine, *Pinus massoniana*, is the main host plant of *D. punctatus*, its caterpillars have been also reported to feed on *P. thunbergii*, *P. ellottii* and *P. taeda*, mainly in China, but also to some extent in Vietnam (Cai, 1995; Hou, 1997). *D. punctatus* in China completes one to five generations per year, depending upon latitude (Chen, 1990). Pure masson pine forest is popular in much of south China. In Qianshan County, Anhui Province, the overwintering generation emerges as adults in late June. The first generation moth flight peaks in early to mid-August. Damage can be so extensive that the forest appears to be burned and has been called “a forest fire without smoke” (Hou, 1979). Moth population density changes easily from low to high in a few generations. Low-density populations are difficult to detect in the field, rendering timely and effective control difficult. With heightening awareness of the potential negative effects of pesticides, the necessity for environmentally sound insect pest management, including timely and effective application of insecticides when required, is clear. An effective and inexpensive trap baited with a synthetic lure is needed for an economical and manageable monitoring system for the masson pine moth.

Black-light traps are typically used to monitor adult populations of *D. punctatus* (Wang and Zhou, 1994). However, the lack of species specificity and the need for a power source usually limit their use. The successful use of the pheromone trap as a better tool for monitoring low density field populations has been shown in several insect species such as *Diorystria resinella* (Grant et al., 1993),

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Lymantria mathura (Odell et al., 1992), Spodoptera frugiperda (Mitchell and McLaughlin, 1982), and Heliothis virescens (Hartstack and Witz, 1981), which are also difficult to monitor in the early or overwintering populations with light traps (Hwang, 1987). Live virgin females of D. punctatus have been used to detect the occurrence of males in the field (Chen et al., 1980; Jian, 1984), but could not be used for a large-scale pest-monitoring program as proposed by Jackson et al. (1998). Sex pheromones are highly species specific, non-toxic compounds that have potential in masson pine caterpillar control (Chen et al., 1980; Cardé and Minks, 1995; Liang et al., 1998).

The identification and synthesis of the sex pheromone for D. punctatus, a mixture of (Z,E)-5,7-dodecadienol (Z5,E7-12:OH), (Z,E)-5,7-dodecadienyl acetate (Z5,E7-12:Ac), and (Z,E)-5,7-dodecadienyl propionate (Z5,E7-12:Pr) (Chen et al., 1980; Zhu, 1986), has provided an opportunity for developing pheromone-based management programs for this insect (Chen et al., 1980; Zhao et al., 1993). The objective of this study is to evaluate the potential of sex pheromone for monitoring masson pine moth populations in forests.

MATERIALS AND METHODS

Traps and synthetic pheromones. Two-layer plastic cymbiform sticky traps (42 cm × 22 cm) were used (Xi’an Insect Traps Factory, Xi’an, China). This kind of trap is waterproof and can release pheromone in all directions. Grey rubber septum dispensers (American West Company) impregnated with sex pheromone, containing a 25:10:28 blend of Z5,E7-12:Ac, Z5,E7-12:Pr, and Z5,E7-12:OH (>97% pure) (Chemtech B.V, Amsterdam, The Netherlands and Institute of Sex Pheromone, Jingtian, Jiangsu; Jing and Liu, 1996; Zhao et al., 1998; Zhang et al., 2001) were used as lures. The rubber septum dispenser was placed about 1–2 cm above the base of the second layer in the center of each trap. The residual amounts of pheromone components and their isomers have been shown to be four times greater in synthetic rubber baits as in natural rubber baits. In addition, the release of sex pheromones from this type of rubber septum dispenser is nearly constant and can continue for at least 40 days in the field (Zhao et al., 1998). This permits traps to be deployed for a relatively long time under field conditions, with improved trap efficacy.

Study area. Qianshan County (E116°15’–116°30’, N30°27’–31°04’) lies in the foothills of the Dabieshan Mountain between the Huaihe River and the Yangtze River. The climate in the region is subtropical. The average annual temperature is 16.3°C and the average annual rainfall is 1,307.1 mm. Pure masson pine forest covers 72,000 ha in Qianshan County.

Trap placement. Field trapping experiments were conducted in 102 locations throughout Qianshan County during the 1998–2000 field seasons except for 50 locations in 1998. The distance between neighboring trapping locations is about 1 km (Fig. 1). Most traps were set in areas which have experienced masson pine caterpillar outbreaks before 1998. Some traps were set in areas in which masson pine caterpillar outbreaks were occasionally observed and others in areas where outbreaks have not been observed. In 1998, ten traps were set in each of the towns of Hangpu, Domo, Pailo, Tianzhushan and Gujin. In 1999 and 2000, ten traps were again set in each of these towns and varying numbers of traps were also set in the towns of Qinlo (3 trapping locations), Linto (16), Yujin (17), Dubu (5), Yuntan (2), Sanmiao (7), Hangbai (1) and Suiho (1). Traps were set in the upper part of pine trees and left for about one month, the period of adult male moth activity for the overwintering and the first generation. Fifty-one traps were set in shorter trees (less than 15 years old) and the

![Fig. 1. Distribution of 102 trapping locations in Qianshan County, Anhui Province, China. Triangular spot denotes trapping location. Straight broken line indicates dividing line between different areas. Light black line indicates road.](image-url)
others were placed in taller trees (more than 15 years old) so that the effect of height or age of the pine on trapping efficiency could be evaluated. The traps were set and collected on the same date during each field season.

Field investigation. Pheromone traps were deployed throughout the moth flight period, i.e., from 10–30 August 1999. Tree samples were taken to determine the population densities of second-generation third instars of the same year. Twenty masson pine trees were chosen randomly around each of the trapping locations at a range of 100–200 m. The percentage of trees damaged by the larvae of the masson pine caterpillar among these trees was calculated as a second index of relative larvae density. In addition, the direction of slope was recorded.

Statistical analysis. Total trap catch for each year and the location from this experiment were analyzed by analysis of variance (ANOVA) using the SAS GLM procedure (SAS System for Windows, version 6.12, SAS Institute, 1989, 1993). A theoretical simulation method was used to estimate the suitable number of trapping locations needed in this study. One simulation procedure was as follows: step 1, average male catches per trap was calculated according to the initial 102 trapping locations; step 2, three trapping locations (one trap per location) were removed at random from the 102 trapping sites and the mean number of moths per trap was calculated from the remained traps; step 3, the next three trapping sites were removed randomly and the mean catches calculated; i.e. every three trapping sites were removed at each step randomly and mean catches were calculated for the remaining traps. This process was repeated until the last three trapping locations could be removed. The above simulation was conducted two hundred and twenty times for four trapping seasons (from the 1998 overwintering generation to the 2000 first generation) (Figs. 3–6). The mean catches and standard deviation at each step for two hundred and twenty simulations were recorded. The fitting models were constructed for the standard deviations in order that the characters of the mean catches and standard deviation could be studied (Figs. 7–10, Table 4).

RESULTS

Fluctuation of masson pine moth population

*D. punctatus* was observed at low population density in 1998. Only five males from the overwintering generation and eight males from the first generation were captured in 50 trapping locations over the period of May–June and August–September in 1998 (Table 1). The average number of catches per trap was 0.1 and 0.16, respectively, for the two generations. During this period few larvae of *D. punctatus* were found in the field. The mean numbers of adult male *D. punctatus* captured in pheromone-baited traps during the overwintering generation flight periods in 1999 and 2000 increased abruptly by 6.255 and 112.43, respectively, compared with those in 1998 (Table 1). The mean numbers of male *D. punctatus* captured during the first generation flight periods in 1999 and 2000 also increased by 0.2256 and 5.924, respectively, compared with those of male *D. punctatus* in 1998 (Table 1).

<table>
<thead>
<tr>
<th>Year and generation</th>
<th>Total number</th>
<th>Males captured/trap</th>
<th>Increase</th>
<th>Number of traps</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SEM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overwintering</td>
<td>5</td>
<td>0.1000</td>
<td>0.0714</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>First</td>
<td>8</td>
<td>0.1600</td>
<td>0.0775</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Overwintering</td>
<td>74</td>
<td>0.7255</td>
<td>0.1442</td>
<td>6.255</td>
<td>102</td>
</tr>
<tr>
<td>First</td>
<td>20</td>
<td>0.1961</td>
<td>0.0592</td>
<td>0.2256</td>
<td>102</td>
</tr>
<tr>
<td>Overwintering</td>
<td>1,157</td>
<td>11.3431</td>
<td>0.7074</td>
<td>112.431</td>
<td>102</td>
</tr>
<tr>
<td>First</td>
<td>113</td>
<td>1.1078</td>
<td>0.2023</td>
<td>5.924</td>
<td>102</td>
</tr>
</tbody>
</table>

*Compared to 1997 overwintering generation.*  
*Compared to 1998 first generation.*
**Relationship between trap catches and field investigation**

It was found that traps in six trapping towns out of ten towns captured the adult male moths of the first generation in 1999 (Fig. 2a). The occurrence of the second generation of masson pine caterpillar in 1999 was found through field investigation at the above six trapping towns (Fig. 2b). Figure 2 demonstrates that the mean catch per trap at Pailo was the highest among the above six trapping towns, and the percentage of trees damaged by the second generation caterpillar was the highest, as well. Traps in the remaining four trapping towns (Sanmiao, Yuntan, Qinlo and Gujin) captured no male moths of the first generation in 1999, but an occurrence of the second generation caterpillars was found. This indicates that the traps baited with sex pheromone lures could monitor the presence of the masson pine caterpillar to some extent.

**Effects of masson pine height and slope direction on catches**

The traps placed lower than 5.5 m high in the masson pine forest canopy caught significantly more *D. punctatus* males (*F*=4.91, *p*=0.0289 for 1998; *F*=7.48, *p*=0.0074 for 1999) than did those placed higher in the masson pine forest canopy during the overwintering generation of 1998 and the first generation of the 1999 flight periods (Table 2). The mean capture of *D. punctatus* per trap was not significantly different between heights lower than and higher than 5.5 m for the overwintering generation of 1999 and the first generation of 2000 flight periods. No significant differences due to slope direction were observed through the 1998–2000 flight periods (*F*≥1.73, *p*=0.1502, Table 3).

**Influence of number of trapping locations on mean catches by theoretical simulation**

The mean catches per trap fluctuated with reduced numbers of trapping locations (Figs. 3–6). The greater the mean catches per trap fluctuated, the fewer the number of trapping locations. The standard deviations (or variance) of the means fluctuated with the number of trapping locations (Figs. 7–10). The fitting models functions for standard deviation are as following: \( y_{std} = 3.0 \times 10^{-7}x^5 - 2.0 \times 10^{-5}x^4 + 0.0005x^3 - 0.0047x^2 + 0.0246x \), \( x = \text{step} \).

**Table 2.** Catches of male *Dendrolimus punctatus* in traps baited with synthetic sex pheromone in masson pine of different heights

<table>
<thead>
<tr>
<th>Year and generation</th>
<th>Males captured/trap mean±SEM</th>
<th>( F )</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shorter masson pine (≤5.5 m)</td>
<td>Taller masson pine (≥5.5 m)</td>
<td></td>
</tr>
<tr>
<td>1998 Overwintering</td>
<td>1.0392±0.2566</td>
<td>0.4118±0.1194</td>
<td>4.91*</td>
</tr>
<tr>
<td>1999 First</td>
<td>0.3529±0.1078</td>
<td>0.0392±0.0392</td>
<td>7.48**</td>
</tr>
<tr>
<td>1999 Overwintering</td>
<td>12.3922±1.1875</td>
<td>10.2941±0.7532</td>
<td>2.23</td>
</tr>
<tr>
<td>2000 First</td>
<td>1.3922±0.3510</td>
<td>0.8235±0.1974</td>
<td>1.99</td>
</tr>
</tbody>
</table>

***: Significant and highly significant difference between lower and higher masson pine at \( p<0.05 \) or \( p<0.01 \) (SAS6.12-GLM Procedure).
Table 3. Catches of male *Dendrolimus punctatus* in traps placed on slopes at different directions. Means within the same row followed by the same letters are not significantly different.

<table>
<thead>
<tr>
<th>Generation</th>
<th>Males captured/trap placed over east slope</th>
<th>Males captured/trap placed over south slope</th>
<th>Males captured/trap placed over west slope</th>
<th>Males captured/trap placed over north slope</th>
<th>Males captured/trap placed over flat</th>
<th>Total number of traps</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997 Overwintering</td>
<td>0.00 ± 0.00 a 9</td>
<td>0.00 ± 0.00 a 15</td>
<td>0.00 ± 0.00 a 5</td>
<td>0.00 ± 0.00 a 7</td>
<td>0.35 ± 0.24 a 14</td>
<td>50</td>
<td>1.29</td>
<td>0.28</td>
</tr>
<tr>
<td>1998 First</td>
<td>0.00 ± 0.00 a 9</td>
<td>0.07 ± 0.07 a 15</td>
<td>0.00 ± 0.00 a 5</td>
<td>0.42 ± 0.42 a 7</td>
<td>0.28 ± 0.16 a 14</td>
<td>50</td>
<td>1.01</td>
<td>0.41</td>
</tr>
<tr>
<td>1998 Overwintering</td>
<td>1.00 ± 0.45 a 25</td>
<td>0.52 ± 0.22 a 23</td>
<td>0.87 ± 0.25 a 24</td>
<td>0.90 ± 0.39 a 11</td>
<td>0.31 ± 0.13 a 19</td>
<td>102</td>
<td>0.81</td>
<td>0.52</td>
</tr>
<tr>
<td>1999 First</td>
<td>0.28 ± 0.13 a 25</td>
<td>0.08 ± 0.08 a 23</td>
<td>0.00 ± 0.00 a 24</td>
<td>0.27 ± 0.27 a 11</td>
<td>0.42 ± 0.17 a 19</td>
<td>102</td>
<td>1.73</td>
<td>0.15</td>
</tr>
<tr>
<td>1999 Overwintering</td>
<td>1.76 ± 1.59 a 25</td>
<td>1.25 ± 1.77 a 23</td>
<td>1.18 ± 1.06 a 24</td>
<td>1.02 ± 1.37 a 11</td>
<td>0.91 ± 1.76 e 19</td>
<td>102</td>
<td>0.65</td>
<td>0.63</td>
</tr>
<tr>
<td>2000 First</td>
<td>1.52 ± 0.47 a 25</td>
<td>0.87 ± 0.27 a 23</td>
<td>0.58 ± 0.22 a 24</td>
<td>0.72 ± 0.55 a 11</td>
<td>1.73 ± 0.69 a 19</td>
<td>102</td>
<td>1.29</td>
<td>0.28</td>
</tr>
</tbody>
</table>

**DISCUSSION**

Our results confirmed that sex pheromone traps are effective for monitoring populations of *D. punctatus*, which would be statistically valid for the above four trapping seasons (Table 4, Figs. 7–10). In all, 102–3×(4–1) = 69, 33, 54, 72 traps were effective, as well as the male pheromone responsivity, flight ability, and trap capture rate for *D. punctatus* (Park et al., 1993). Similar results were obtained for other insect species such as *Chilo suppressalis*, where biological factors, such as sex pheromone density, were correlated with the field trapping effectiveness (Park et al., 1993). Our results confirmed that sex pheromone traps are effective for monitoring populations of *D. punctatus* in different field seasons in Qianshan County (Figs. 7–10).

The above fitting models function equal zero, i.e., the number of remaining trapping locations and 11 would be the possible algebraic solutions, respectively. In an actual sense, 11 would be the possible algebraic solutions between 1 and 40 of the above four equations.

The data of the above fitting models function equal zero, i.e., the number of remaining trapping locations and 11 would be the possible algebraic solutions, respectively. In an actual sense, 11 would be the possible algebraic solutions between 1 and 40 of the above four equations.
Table 4. Fitting models of standard deviation vs. step for masson pine moth of different trapping seasons times 220 simulations

<table>
<thead>
<tr>
<th>Generation</th>
<th>Fitting models</th>
<th>Times of simulation</th>
<th>$R^2$</th>
<th>$x=(\text{between } (0,40))$, when $y=0$</th>
<th>$n=\text{int}[x]$</th>
<th>Remaining number of locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998 Overwintering</td>
<td>$y_{ad}=3.0 \times 10^{-7} x^4 - 2.0 \times 10^{-5} x^4 + 0.0005 x^3 - 0.0047 x^2 + 0.0246 x$, $x=\text{step}$</td>
<td>220</td>
<td>0.9957</td>
<td>12.60</td>
<td>12</td>
<td>69</td>
</tr>
<tr>
<td>1999 First</td>
<td>$y_{ad}=1.0 \times 10^{-7} x^4 - 9.0 \times 10^{-6} x^4 + 0.0002 x^3 - 0.0024 x^2 + 0.0121 x$, $x=\text{step}$</td>
<td>220</td>
<td>0.9941</td>
<td>24.90</td>
<td>24</td>
<td>33</td>
</tr>
<tr>
<td>1999 Overwintering</td>
<td>$y_{ad}=1.0 \times 10^{-6} x^3 - 0.0001 x^4 + 0.0026 x^3 - 0.0275 x^2 + 0.1413 x$, $x=\text{step}$</td>
<td>220</td>
<td>0.9921</td>
<td>17.00</td>
<td>17</td>
<td>54</td>
</tr>
<tr>
<td>2000 First</td>
<td>$y_{ad}=3.0 \times 10^{-7} x^4 - 2.0 \times 10^{-5} x^4 + 0.0006 x^3 - 0.0064 x^2 + 0.0363 x$, $x=\text{step}$</td>
<td>220</td>
<td>0.9955</td>
<td>11.50</td>
<td>11</td>
<td>72</td>
</tr>
</tbody>
</table>

Fig. 3. Fluctuation of mean catches of 1998 overwintering generation (/trap) with reduction of trap locations times 220 simulations. $X$ axis denotes the number of steps in each simulation. Line indicates the average catches of 1998 overwintering generation per trap.

Fig. 4. Fluctuation of mean catches of 1999 first generation (/trap) with reduction of trap locations times 220 simulations. $X$ axis denotes the number of steps in each simulation. Line indicates the average catches of 1999 first generation per trap.
Our results show that the catches in traps baited with sex pheromone can reflect the population dynamics of *D. punctatus* in the field to some degree (Fig. 2). These findings are consistent with those of Sanders and Lyous (2001) in monitoring spruce budworm, *Choristoneura fumiferana*, with sex pheromone and those of Shirai and Nakamura (1995), Jactel et al. (1996) and Lyytikäinen-Saarenmaa et al. (1999) for other species. However, in our study, traps at four trapping towns (Sanmiao, Yuntan, Qinlo and Gujin) captured no male moths of the first generation in 1999, but second generation caterpillars were found. The possible cause may be the limited trapping range of the trap or migration of the masson pine moth between the different towns. Although monitoring with sex pheromone-baited traps over a longer time period may provide more detailed information on the dynamics of *D. punctatus* in the field, our results suggest that the fluctuation of catches of adult male *D. punctatus* can detect trends of changes in population size to some extent.

Fig. 5. Fluctuation of mean catches of 1999 overwintering generation (/trap) with reduction of trap locations times 220 simulations. X axis denotes the number of steps in each simulation. Line indicates the average catches of 1999 overwintering generation per trap.

Fig. 6. Fluctuation of mean catches of 2000 first generation (/trap) with reduction of trap locations times 220 simulations. X axis denotes the number of step in each simulation. Line indicates the average catches of 2000 first generation per trap.
When the numbers of moths captured in traps set at heights lower than 5.5 m in a masson pine forest are compared with traps set higher in the pine forest canopy, we find that the lower traps caught significantly more male *D. punctatus* during the 1999 flight period when the population was at a low density level (Table 4). These results are compatible with those obtained by Chen (1990), who found that adult females of *D. punctatus* tend to lay eggs on shorter, younger masson pine in preference to taller, older trees. Further research should be conducted to determine whether young pine trees attract male and female *D. punctatus* equally.

An initial step in the development of any pheromone-based monitoring technique is to examine how trap deployment affects monitoring of flight phenology, and how proximity affects intertrap competition (Harris et al., 1997). Estimates of required trap numbers are shown in Figs. 3–10 and Table 4. Collectively, statistically 33–72 trapping locations should be sufficient to monitor fluctuations in *D. punctatus* in Qianshan County, with statistical significance whether at high or low-density population levels (Table 4). However, it is difficult to determine the spatial pattern of the trapping locations before getting the spatial information of all 102 trapping locations and more trapping data. These data provide some insights into the effective area of trap capture although they are only valid for the trapping system described in this study. Any changes to the pheromone trapping system would require a new analysis of the spatial pattern results, with data collected for specific trap types.

Population spatial pattern is another crucial factor that affects the practical trapping range of pheromone traps (Du, 1986). If population spatial pattern remains relatively stable over different flight periods, theoretically, a higher population density should require fewer traps. In this study, however, 54 traps were needed for a high-density population and 33 traps for a low-density population (Table 4). Further research is necessary to determine the relationship between the effective trapping range of traps baited with sex pheromone and the population spatial pattern of *D. punctatus*. Weather factors such as daily average air tempera-
ture, rain, wind velocity and humidity, and so on, may alter the effective area of traps (Jonsson and Anderbrant, 1993).

We conclude that the pheromone is very effective in rapid and simple monitoring of *D. punctatus*. It also shows promise as a tool to better understand the biology and ecology of *D. punctatus* and may have additional uses in management programs. In combination with other tactics such as, mating disruption (Agnello et al., 1996; Mazomenos et al., 1999; Ostrand et al., 1999), mass trapping (Suckling and Brockerhoff, 1999) sex pheromone could become a powerful tool in integrated management of *D. punctatus*.

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