Laboratory and Field Studies on Behaviouristic Response of the Minute Pine Bark Beetle, *Cryphalus fulvus* NIJIMA (Coleoptera : Scolytidae) to the Female Pheromone¹

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Basic studies on the minute pine bark beetle, *Cryphalus fulvus* NIJIMA, a species attacking the Japanese red-pine, *Pinus derstflora* SIEB. et ZUCC., were conducted under both laboratory and field conditions, using the bait traps.

Traps with the virgin female-infested logs are strongly attractive to newly emerged beetles of both sexes. After emergence, the females disperse flight and attack hosts as pioneers. Mass attack flight then occurs in response to the species-specific pheromone produced by the invasion of pioneers. The maximum response to the trap is achieved between the third and fifth day after the introduction of females into the log. The response flight is influenced by temperature and wind. With an increase in wind speeds, the dispersal flight is directed toward the inside of forest stands. Diurnal patterns in response to the trap and of emergence of the beetles are similar in general form, having a single peak in the late afternoon when the environmental factors are favorable.

The female produces a population aggregation pheromone that both attracts and arrests the adult beetles.

INTRODUCTION

The attraction phenomenon of many scolytid species in a number of genera has been described during the past 10 years. The minute pine bark beetle, *Cryphalus fulvus* NIJIMA, is one of the most destructive species of the Japanese red-pine, *Pinus derstflora* SIEB. et ZUCC. It passes through three or more generations per year. The young adult or full-grown larva overwinters under the bark, and the adult emerges in the late spring in Kyoto. The virgin female is responsible for the initial attack, as in *Dendroctonus* (RUDINSKY, 1963) and *Trypodendron* (CHAPMAN, 1966), and after emergence selects a suitable site on the bark surface, and tunnels through outer bark into the primary phloem tissue. When a virgin female begins excavating the egg gallery, the male alights and finds the entry hole made by the female.

Much is known of the biology and habits of this species but very little on behaviour during attack on the host plant. This paper will deal with investigations conducted under laboratory and field conditions to ascertain the behavioural respon-

¹ Ecological studies on the minute pine bark beetle (Part 1).

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siveness to and production of the pheromone and to provide basic information for possible behavioural control.

MATERIALS AND METHODS

Infested logs of the Japanese red-pine containing large numbers of callow adults of the minute pine bark beetle were taken from the Experimental Forest of Kyoto Prefectural University, Ooe, Kyoto, and placed in cages in the laboratory. As beetles emerged they were collected in a water-pan placed on the bottom of cage. The male was distinguished from the female by the presence of a transverse carina on the posterior frons. The bait logs were obtained from the same pine forest about 10 days before the experiments started and held at room temperature.

In 1970, preliminary experiments were conducted in the laboratory and outdoors. Virgin females were retained in small sections of log measuring 5 cm in length and covered with paraffin-film at both cut-ends to prevent drying-out. These will hereafter be termed log "bolts". Three kinds of decoys were prepared: bolt containing 30 virgin females, bolt with 30 newly emerged males and bolt only. The bolts were placed in a glass vessel (9×6.5 cm) which was covered with wire screen (0.5 mm mesh) to prevent invasion by attracted beetles. This vessel was set on the centre of a larger plastic vessel (25×12 cm) filled with water to a depth of 2 cm. Three of these traps were arranged equidistantly from the centre of infested logs placed in the laboratory (240 cm^2) away and were also placed at random near the boundary of pine forest. The number of beetles attracted to each trap was counted daily for a week.

In 1971, the funnel-shaped trap, shown in Fig. 1, was used in the field. The metallic tube below the funnel is detachable and filled with water to catch attracted beetles. The tube also contains a small drainage hole covered with wire mesh to remove excess water after rain. A log-bolt (32×5.2 cm) containing 150 virgin females and a control bolt were covered with nylon cloth to prevent both the escape of the virgin females and invasion by attracted beetles and suspended in the centre of trap. Three plastic baffles were placed around the bait bolts to assist in the capture of the beetles. One trap in the forest and three traps out of the forest were placed randomly at a height of about 1.5 m above groundlevel. The species and numbers of insects attracted to these traps were investigated at certain time (11:00—12:00 AM) each day during the period 30 July to 12 Aug. and 18 to 28 Aug. 1971 and 1 to 28 July 1972.

The diurnal activity of beetles attracted to the above-mentioned traps was studied every two hours from 4:00 AM to 20:00 PM. The diurnal emergence pattern was examined by two-hourly counts of the number of beetles in water-pans arranged around the infested logs outdoors.

Observations on the change in attractiveness with time after the introduction of females into logs on alternate days for 9 days using 30 newly emerged females per bolt were made. Bolts were also infested with 30 females on days ranging from 1 to 11, and were then all examined on the same day in the laboratory to ascertain changes in attractiveness.

Other laboratory experiments were performed to determine male behaviour during entry into the hole made by the female during the initial attack on the host-tree. Benzene extracts were obtained by drawing air through a plastic cylinder containing logs infested by 250 females for 10 days with 3 l of benzene and concentrated to 500 ml.

Fig. 1. Funnel-shaped bait-trap.

One ml of the extract and a similar quantity of benzene as a control were placed on the centre of filter-papers (30 cm dia.). The time of arrestment within the central circle of 9 cm in diameter was measured. Also, the frequency with which 4 circlets (5.5 mm dia.) drawn on the filter-paper were crossed during the walking period was noted. In a further experiment, the number of beetles entering into 24 holes (0.8 mm dia.) in a filter-paper placed on a glass vessel (9 × 6.5 cm) with or without a 10 female-infested bolt were counted at intervals. This experiment was carried out with 10 newly emerged adults.

RESULTS

Attractiveness of the female-infested bolt

In the first laboratory experiment, a mean number of 292 beetles were attracted to each female-infested bolt during a week (Table 1). The difference in the number of attracted beetles between the bolts containing females and males was significant at the 5% level (*t*-test). A similar result was noted in a field experiment using the same traps, i.e., 29 beetles were attracted to the female-infested bolt, 1 to the male-infested one and none to a control bolt. It was, therefore, ascertained that the logs already infested by the virgin females are strongly attractive to the newly emerged beetles.

Table 1. MEAN TOTAL NUMBERS OF THE MINUTE PINE BARK BEETLES ATTRACTED TO THE DIFFERENT TRAP-UNITS

Sex of captures	Trap		
	Bolt + 30 ♀ ♀	Bolt + 30 ♂ ♂	Bolt only
Male	129	65	62
Female	163	73	52
Total (%)	292 (53.68)	138 (25.37)	114 (20.96)

Table 2. SPECIES AND TOTAL NUMBERS OF INSECTS CAUGHT IN TRAPS PLUS BOLTS CONTAINING 150 FEMALES

Species name	No. caught
COLEOPTERA	
Erotylidae	
<i>Aulacochilus japonicus</i> CROTCH	1
<i>Megalodacne bellula</i> LEWIS	2
Buprestidae	
<i>Buprestis haemorrhoidalis japonensis</i> E. SAUNDERS	5
Elateridae	
<i>Stenagostus umbratilis</i> LEWIS	1
Tenebrionidae	
<i>Ceropria induta</i> WIEDEMANN	1
<i>Uloma bonzica</i> MARSEUL	5
<i>Tetraphyllus lunuliger</i> MARSEUL	14
<i>Strongylium marseuli</i> LEWIS	1
<i>Elixota curva</i> MARSEUL	1
Melandryidae	
<i>Serropalpus niponicus</i> LEWIS	12
Cerambycidae	
<i>Prionus insularis</i> MOTSCHULSKY	8
<i>Spondylis buprestoides</i> L.	3
<i>Megasemum quadricostulatus</i> KRAATZ	4
Curculionidae	
<i>Pissodes nitidus</i> ROELOFS	1
<i>Hylobius abietis haroldi</i> FAUST	2
<i>Shirahoshizo insidiosus</i> ROELOFS	14
Genera and species unidentified	28
Scolytidae	
<i>Cryphalus fulvus</i> NIJIMA	3,775
Scarabaeidae	
<i>Protaetia orientalis submarmorea</i> BURMEISTER	1
Cleridae	
Genera and species unidentified	19
HYMENOPTERA	
Braconidae	
<i>Ecphylus hattorii</i> KONO et WATANABE	2

Fig. 2. Number of the minute pine bark beetles attracted to a funnel-trap with a female-infested bolt during two periods 30 July to 12 August and 18 to 28 August, 1971.

Fig. 3. Percentage of the minute pine bark beetles responding to bolts artificially infested with 30 females on different days.

Fig. 4. Percentage of the minute pine bark beetles responding to the funnel-trap in and out of a pine stand, and the mean daily wind velocity outside of a stand.

In another funnel-traps containing female-infested bolts, 23 species of insects belonging to 11 families and 2 orders were attracted (Table 2). Three species of the pine-borers were attracted—*Cryphalus fulvus*, *Shirahoshizo insidiosus* and *Hylobius abietis*. The number of the minute pine bark beetles attracted daily during two periods is shown in Fig. 2. In the first period, a great number of male and female beetles were attracted to the trap for the first three days, but after this the numbers decreased gradually except for an unusual peak on 7 August. During the second period they were much less attracted in the first three days. The reason for this different response may be temperature. The mean temperature during the second period was 26.1°C (about 3°C lower than that of the first), with a record of about 22°C for the first three days.

Response pattern in relation to age of females

The highest response of the beetles was elicited by logs that had been infested for 3—5 days (about 40% of total number of beetles responded), after which there was a sharp decrease (Fig. 3). Similar results were obtained in the field with logs that had been infested for 3 days.

Effect of wind on response

The relation between the percentage of beetles captured in each one funnel-trap within and out of a pine stand and mean wind velocity during the experiment period is shown in Fig. 4. The wind speed increased day by day after 1 August, because of

Fig. 5. Relation between percentage of beetles responding to a trap in a stand and wind velocity outside of a stand.

an approaching typhoon. A distinct difference is seen in percentage response during 1 to 6 August when higher wind speeds prevailed. When the wind velocity is about 2 m/sec, the proportion of beetles responding in a stand is only about 30% of total. The regression equation for percentage response and wind velocity was $Y = 31.25 + 19.299(X - 2.392)$, where Y is the percentage of beetles responding and X the mean wind velocity (Fig. 5). The correlation coefficient was 0.703***. The wind velocity, therefore, has a strong influence on the response pattern of the minute pine bark beetle. The beetles possibly cease flying or lose control of flight direction with higher wind speeds outside the forest and might prefer to fly to the region of least wind activity.

Diurnal patterns in response to traps and of emergence from host-logs

The diurnal activity of the minute pine bark beetle responding to the funnel-trap containing bolts infested by 150 virgin females was observed in summer under field conditions. The beetles responded in low numbers from early morning to middle afternoon, but catches rose sharply at 17:00 PM (Fig. 6). There was little response after sunset. There were no differences between the sexes in these response patterns.

The diurnal pattern of emergence of beetles from infested pine logs was similar to the diurnal flight pattern except for a gradual rise after 13:00 PM (Fig. 7). The both sexes again showed a similar emergence pattern.

The time required to arrive at the attractive source after emergence from the host seems to be influenced by distance and climatic conditions. This time may be equivalent to one to two hours, because beetles were still responding actively to trap at 19:00 PM, that is one to two hours after the last emergence.

Sex ratio

It is evident that the females produce the attractants, but both sexes respond to it. The sex ratio of the minute pine bark beetles captured in the funnel-trap in the 1971 and 1972 field experiments fluctuated irregularly day by day (Fig. 8), but averaged 0.45 and 0.48 respectively throughout the period; the sex ratio in a laboratory population was 0.50.

Fig. 6. Diurnal activities of the minute pine bark beetles responding to the funnel-traps in summer, 1971.

Fig. 7. Diurnal emergence activities of the minute pine bark beetles from the infested pine logs.

Fig. 8. Sex ratios of the minute pine bark beetles responding to the funnel-traps in summer, 1971 and 1972.

Table 3. ARRESTMENT TIME OF THE MINUTE PINE BARK BEETLES TO BENZENE EXTRACT AND BENZENE ONLY

Attractant source ^a	Sex	> 3 min	3-2 min	2-1 min	1 min>
Benzene extract	♂	66 (44.59%)	15 (10.14)	19 (12.84)	48 (32.43)
	♀	24 (28.92%)	8 (9.64)	10 (12.05)	41 (49.40)
Benzene only	♂	2 (2.63%)	0	0	74 (97.37)
	♀	0	0	2 (2.86)	68 (97.14)

^a 1 ml on centre of a filter-paper (30 cm dia.).

Table 4. ARRESTMENT TIME AND CROSSING RATE OVER CIRCLETS OF MALE BEETLES

Attractant source ^a		> 3 min	3-2 min	2-1 min	1 min>
Benzene extract	No. of beetles	32	14	13	54
	Crossing rate	50.00	57.14	83.33	18.52
Benzene only	No. of beetles	0	2	2	93
	Crossing rate	—	—	—	15.05

^a 1 ml on centre of a filter-paper (30 cm dia.).

Response behaviour to female pheromone

Experiments were conducted to investigate concerning the time of arrestment at a female pheromone source and invasion behaviour at artificial holes similar in size to the entry holes made by the female on the pine logs.

The time of arrestment within a central circle drawn on the filter-paper impregnated with benzene extract was clearly longer than that on the control (Table 3). About 45% of the males was arrested for more than 3 minutes.

Fig. 9. Accumulated numbers of the minute pine bark beetles entering artificial holes. —●—, —○—: bolts+10 females; --●--, --○--: without female.

Fig. 10. Numbers of beetles progressively entering the holes. A and C: bolts+10 females; B and D: without female.

On the other hand, only about half of the females were arrested for less than 1 minute on paper with extract. Although sensory stimuli are presumably important in the walking behaviour of beetles on logs, this result suggests that the beetles are arrested by the pheromone within a certain limits for a particular time.

Table 4 shows the rate of crossing through 'circletes' among male beetles when they are arrested on filter-papers. It is calculated that 40.6% of the total number of male beetles arrested on the benzene extract crossed over the circlets, i.e., 1.2 circlet per individual. But in the control paper, the crossing rate was less than half of the former—0.2 circlet per individual. The longer arrestment of male beetles within certain limits may facilitate the location of entry holes.

More males than females entered the artificial holes (Fig. 9). When the data are plotted the individual numbers of beetles entering the holes at intervals of several minute, follow hyperbolic trends in both sexes when exposed to pheromone activity but show no distinct fluctuation in the control (Fig. 10). The differences in numbers of beetles entering the holes within 3 minutes between A and B, C and D, and A and C were highly significant ($P < 0.001$, t -test), but not significant between B and D. These were no significant difference between any of the treatments after 10 minutes. The results indicate that the female pheromone induces an increase in the frequency of male entries.

DISCUSSION

The results show that in the host colonization pattern of the minute pine bark beetle in the Japanese red-pine, the females pioneer the initial attack, as is also the case in *Dendroctonus pseudotsugae* HOPKINS (RUDINSKY, 1963), *D. obesus* MANNERHEIM (DYER and TAYLOR, 1968), *D. frontalis* ZIMM. (VITÉ et al., 1964) and *Trypodendron lineatum* OLIVIER (CHAPMAN, 1966). The female beetles emerge from the infested logs three days earlier than the males (unpublished data). This means that the females are able to locate suitable host material and can begin to produce pheromone before the emergence of males. It is said that the weakened standing trees with less resin are preferably selected by the females during their host-finding flight. In the present study, primary attraction by host substances could not be distinctly recognized. It is possible that the bolts used in the traps were too short. It is, however, known that host substances such as α -pinene, 3-carene, etc. are essential in guiding the beetles to trees suitable for breeding scattered throughout a stand (YASUNAGA et al., 1962; RUDINSKY, 1966; RUDINSKY and ZETHNER-MØLLER, 1967; FRANCA and GRAHAM, 1967; RENWICK and VITÉ, 1970; PITMAN, 1971).

Interspecific attraction has been noted in bark beetles (VITÉ et al., 1964; RUDINSKY and DATERMAN, 1964; WOOD, 1970). No other scolytids were, however, attracted to traps, containing bolts artificially infested with virgin females of the minute pine bark beetle. Mass attraction of both sexes, following the invasion by pioneer females, suggests that the pheromone is species-specific, like the female attractants of *Trypodendron lineatum* (RUDINSKY and DATERMAN, 1964). On the other hand, it is interesting the traps with females attracted two species of the Cleridae predatory on the pine-boring beetles and also a braconid parasite of the minute pine bark beetle, *Ecphyllus hattorii*. Similar results have been obtained with predators, belonging to the Cleridae and Ostomatidae, following aggregation of *Dendroctonus* and *Ips* beetles,

in response to pheromones (frontalin or brevicomin) released by their prey (VITÉ and WILLIAMSON, 1970; RICE, 1970; PITMAN and VITÉ, 1971; RUDINSKY et al., 1971). RICE (1969) observed a pteromalid parasite, *Tomicobia tibialis* ASH., responding to the male pheromone of *Ips confusus*.

The response of the flying population of the minute pine bark beetles to the trap was extremely high between the third and fifth day after the introduction of virgin females into the sample. A similar situation was observed in *Ips confusus* (WOOD and BUSHING, 1963), while peak activity in *Ips grandicollis* EICHHOFF occurred between the second and fourth day (HERTEL et al., 1969). The duration of attraction was not established as the flight response to old females decreased sharply, but it is known to last eighteen days in *Ips confusus* (GARA, 1963; VITE et al., 1963; WOOD and BUSHING, 1963; BORDEN, 1967) and up to six weeks in *Dendroctonus pseudotsugae* (RUDINSKY, 1963; WILKINSON, 1964).

Both diurnal patterns in response to the trap and of emergence of the minute pine bark beetles exhibited a single peak in the late afternoon in summer. An evening period of the greatest scolytid activity has been reported by many others (GARA and VITÉ, 1962; RUDINSKY, 1963; VITÉ et al., 1964; RUDINSKY and DATERMAN, 1964; MORGAN 1967; CAMERON and BORDEN, 1967; MCCAMBRIDGE, 1967; HERTEL et al., 1969; PITMAN and VITÉ, 1969; SCHÖNHERR, 1971); the time and pattern of flight peak are, however, influenced by both temperature and light intensity in most cases.

The effect of wind on flight of the minute pine bark beetle is obvious. In *Ips confusus* and *Trypodendron lineatum*, the beetles cannot fly when the wind velocity is more than 3 or 4 m. p. h. unless they are close to the ground where the velocity is decreased by the ground cover (GARA, 1963; RUDINSKY and DATERMAN, 1964; CHAPMAN, 1966). A larger beetle, *Dendroctonus pseudotsugae*, has the ability to control flight at wind velocities up to 5 m.p.h. (RUDINSKY, 1963). In the present study, a distinct change in flight dispersion occurred from the outside to the inside of forest when the wind velocity exceeded 3 m/sec; the beetles could presumably orientate more readily to the higher level of pheromones in the stand. An unexpected peak occurred on 7 August, 1971, when numbers attracted were about forty times greater than catches before or after that data. This may have resulted from beetles accumulating in the stand because of high wind velocities outside during the period between 1 and 6 August. In the calmer conditions within the stand accumulated beetles would be available to respond to the traps.

Male beetles were somewhat more attracted to the trap than females. A lower female proportion might result from the fact that females are flying as the initial attackers over a wide range in the forest and are also less responsive to the pheromone than the males as examined in the laboratory. However, the fact that both sexes respond indicates that the material produced by the females is an aggregation pheromone. Therefore, the mass attack will be determined by the number of females and suitable breeding sites will be maintained until the death of the host-trees.

The bio-assay studies involved the arrestment, turning and invasion reactions on the filter-paper, in or underneath which the test materials were placed. Most of the beetles walk in almost straight lines on filter-paper without the female pheromone. But, beetles placed on filter-paper contained pheromone extracts exhibit characteristic behaviour, such as a definite increase in rapid turning reactions and intermittent arrestment of walking. The female pheromone of the minute pine bark beetle arrests

beetles of both sexes, although the male response is greater than that of female, as also noted in other scolytids (JANTZ and RUDINSKY, 1965; BORDEN et al., 1968). The quick turning reaction during walking increases the frequency with which beetles encounter the entrance holes. A considerable number of beetles also entered the artificial holes without the female pheromone suggesting that other sensory stimuli, especially vision and contact, might be essential factors in invasion behaviour.

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