Habitat Selection of Pine Bark Weevils (*Shirahoshizo* spp.) (Coleoptera: Curculionidae) Attracted to Pine Bait Logs

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Behaviour of adult pine bark weevils (*Shirahoshizo* spp.; including three species) in selecting habitat for oviposition was determined by their responses to pine bait logs. Movements of adults were monitored using capture-recapture data. Logs having larger surface area and more thick bark were colonized by more adults. By partial correlation coefficients, the effect of bark thickness was found stronger than that of surface area. The main part of tramping (i.e. intra-plot movements) consisted of mutual interchanges among logs having many immigrants, but there was no tendency for adults to congregate upon any particular log. The constancy of the tramp ratio for a wide range of immigration density indicated that about one half of the immigrants on each log emigrated from the plot without any intra-plot movements. The duration time of staying on a log did not change significantly with log size. Emergence of progeny was restricted to logs having bark more than about 1.5 mm thick.

INTRODUCTION

The most numerous species of bark weevils in Japan are *Shirahoshizo* spp. (including *S. rufescens* ROELOFS, *S. insidiosus* ROELOFS and *S. pini* MORIMOTO (MORIMOTO, 1963)) and *Pissodes* spp. (including *P. nitidus* ROELOFS and *P. obscurus* ROELOFS (ROELOFS, 1874)). Both genera feed on pine tree phloem during their larval period and consequently play an important role in the first step of dead pine tree decomposition. The larval population of pine bark weevils living under the bark suffer much mortality from many factors, and most of these factors show seasonal changes. In addition local variation in mortality occurs along the stems of pine trees, because the bark is remarkably different with increased height on the stem. For example, larval populations of subcortical species living in the upper part of the stem can be affected heavily by woodpecker predation (BERRYMAN, 1976). The main mortality factor may also vary from the resin flow in spring to the disease in autumn (YOSHIKAWA, 1977).

In the lower part of the stem intra-specific competition is much greater than found in the upper part because of the lack of an outer regulatory factor(s) (YOSHIKAWA, 1978).

It was known by many authors (ISHIKUBO, 1952, 1954, 1955, 1957; Shikoku Branch Gov. For.Expt. Stn., 1962) that the community structure of subcortical insects in Japanese red pine tree (*Pinus densiflora* SIEB. et ZUCC.) differs by height with changes in bark

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Fig. 1. Setting places of bait logs (with bait log number).

Fig. 2. Frequency distribution of surface area and bark thickness of the bait logs.

conditions. *Pissodes* spp. do not oviposit in thick bark because their rostra are not long enough to chew through the outer bark and into the phloem layer to make an oviposition site. Therefore the distribution of *Pissodes* spp. is determined mainly by bark thickness. On the other hand, *Shirahoshizo* spp. lay their eggs in the crevasses of the bark just under the outer bark. Consequently they oviposit all over the pine stem except near the top where the bark is too smooth. However the distribution of *Shirahoshizo* spp. is restricted to the lower part of the stem. Dispersion of larvae of these subcortical insects depends upon the amount of feeding resource but usually is not far from the point of hatching. The main cause of spatial distribution of *Shirahoshizo* spp. larvae along the stem seems therefore to be the habitat selection by adults to mate and oviposit their eggs. In this study, habitat selection of adult *Shirahoshizo* spp. was briefly studied by observing (1) responses to bait logs and subsequent restriction of larval distribution under the bark, and (2) the interior movements within the adult population maintained around bait logs for a long time as mentioned by YOSHIKAWA (1981 a).

Fig. 3. Relationship between bark thickness and surface area of the bait logs. ○: plot 1, ●: plot 2 (these symbols are same for other figures in this paper); correlation coefficients for plot 1 and 2 are 0.7871 and 0.8558 respectively.

Fig. 4. System for marking pine bark weevils individually. (a) the pattern; (b), (c) marked individuals.

Fig. 5. Schematic explanation of oviposition behaviour of the pine bark weevils.

METHOD

This study was carried out in a Japanese red pine forest at Takatori Town in Nara Prefecture. A few healthy red pine trees were cut on May 9 and 31, and two groups consisting of fourteen and nineteen bait logs (ca. 100 cm long), respectively, were laid on the forest floor about 20 m apart. Figure 1 shows the setting of the bait logs in the two plots. Bait logs were made from all parts of the stem of the pine trees, thus giving a wide range in bark thickness. The frequency distribution of surface area and bark thickness of each bait log is shown in Fig. 2. Diameter of the stem decreases with height from the ground, and bark thickness shows a similar gradient. Lengths of the bait logs were about the same, but the shapes changed depending upon the portion of the stem from which the log was taken. There was a strong relation between bark thickness and surface area of the bait logs (Fig. 3).

All the bait logs were examined at 1–3 day intervals from May 11 to July 26, 1977. As the bait logs were directly laid on the forest floor, the major species attracted were *Shirahoshizo* spp., a complex of three species as mentioned above. Although there are slight differences in their attraction behaviour (TAKETANI et al., 1968; IWASAKI et al., 1971; FURUTA et al., 1972 a, b, c), these three species were not separated in this study. They are morphologically so similar that the risk of misidentification in the field is great and therefore would have decreased the reliability of the data. Even though *Shirahoshizo* spp. is a complex of three species, they can be treated as a group, because the purpose of this study was to determine the responses of a group of weevils that serve as a decomposer of the major part of pine tree phloem during the larval period.

At each census, all pine weevils on the bait logs were collected by hand and, after marking and recording, they were released again on the same bait log on which they had been caught. As shown in Fig. 4, marking was done by lacquer (red, blue, yellow and white) on the pronotum and elytron (SOUTHWOOD, 1971). Handling time including marking and recording was about one minute per individual. All the bait logs were brought back to the laboratory on September 20, 1977, and emergence holes of *Shirahoshizo* spp. were counted after the termination of emergence. The details of methods were described by YOSHIKAWA (1981 a).

RESULTS

The oviposition behaviour of the pine weevil in relation to pine bait logs was analyzed by the four aspects shown in Fig. 5. Matured adults must first encounter the volatile substance(s) from damaged pine trees. MORIMOTO (1970) and IWASAKI

Fig. 6. Relationships between the number of immigrants and (a) bark thickness and (b) surface area of the bait logs. Correlation coefficients for plot 1 and 2 are 0.8672 and 0.9306 with bark thickness and 0.8461 and 0.7969 with surface area.

et al. (1969) reported that when marked adults of *Shirahoshizo* spp. were released, the recapture rate was remarkably high within a certain distance (ca. 50 m) from the trap bait log, and they concluded that beyond, at least, 50 m from the trap, adults fly at random. However, the effective trap area for a bait log should be affected by the quantity and quality of the log. After arriving in the area immigrants shift their position by walk or flight from log to log to seek a suitable site for mating and oviposition (Attack and Intra-plot movement in Fig. 5). After they attack one or more bait logs, they leave the plot to seek another oviposition site (Emigration in Fig. 5).

In the capture-recapture experiment, the unmarked individuals on each census occasion could be regarded as the new immigrants and the recaptured ones as the settlers respectively. The movements of the settlers could be traced when the settlers were recaptured in successive census occasions. The individuals that were not recaptured until the final census were regarded as emigrants from the last captured or recaptured time.

The mean immigration number per bait log of plot 1 was 38.3 (variance=1,343.2) and the mean of plot 2 was 77.6 (variance=2,721.5). The value of variance/mean was 35.1 for both plots. These figures may suggest that newly attracted adults immigrated contagiously on particular bait logs to the same degree in both plots. Figure 6 shows the relation between the number of immigrants and the bait log sizes such as bark thickness and surface area. All correlation coefficients for these relations were significant at the 2% level and seem to suggest that the immigrants were oriented to bait logs having more thick bark and larger surface area. Unfortunately, as shown in Fig. 3, there was a strong relation between bark thickness and surface area of the bait logs. To determine the effects of bait log sizes in detail, bark thickness or surface area was held constant and the partial correlation coefficients between the immigration number and bait log parameters were calculated. The partial correlation coefficients of plot 1 were 0.6121 and 0.5324 between the immigration number and bark thickness or surface area respectively, and of plot 2 were 0.7955 and 0.0026. These values sug-

Fig. 7. Schematic representation of the intra-plot movements. (a)–(d): plot 1, (e)–(h): plot 2, accumulated number of tramps is (a) more than 5; (b) 3 and 4; (c) 2; (d) 1; (e) more than 8; (f) 6 and 7; (g) 5; (h) 3 and 4 individuals.

Fig. 8. Relationships between the number of tramps (moving to (a)-1, (a)-2, moving away (b)-1, (b)-2) and bait log sizes (bark thickness and surface area).

gest that the effect of bark thickness on immigration was stronger than that of surface area.

The variance/mean ratios of the number of individuals moving to and away from bait logs in plot 1 were 14.72 and 7.62 and in plot 2 were 18.05 and 15.82 respectively. All these values were significant at the 1% level and suggested that the intra-plot movements were unevenly distributed. It can be said that the greater the number of immigrants, the greater the number of individuals moving away from the plot. As mentioned above, *Shirahoshizo* spp. showed an aggregative immigration. It seems reasonable that the distribution of the number of individuals moving away was also contagious.

Figure 7 shows the flow of intra-plot movements by the accumulated number of migrants within the plot (=tramps) for the entire experimental period. On the whole, the manner of adult migration was complicated all over the experimental plots in both cases and did not show one-way aggregation on particular logs having thick bark or large diameter. Most adult movements resulted in mutual interchanges, for example, among bait logs No. 4, 6 and 15 in plot 1 and among bait logs No. 10, 12 and 18 in plot 2 (Fig. 7(a), (e)). These logs were rather large with thick bark. The mean bark thickness and surface area of these bait logs in plot 1 were 4.0 mm, 3,564 cm² (the mean values of all bait logs were 2.35 mm, 2,529 cm²) and in plot 2 were 4.4 mm, 3,921 cm² (all logs were 2.19 mm, 3,082 cm²). Figure 8 shows the changes in number of tramps moving to and away with bark thickness and surface area. The partial correlation coefficients between the number of tramps moving to and bark thickness and surface area of plot 1 were 0.376 and 0.383 respectively, and of plot 2 were 0.510 and -0.074. The coefficients for the density of tramps moving away were

Fig. 9. Relationships between the tramp ratio and the number of immigrants (see text for further explanation).

Fig. 10. Relationships between the average duration of staying and the bait log sizes. Correlation coefficients for plot 1 and 2 are 0.3878 and 0.6272 with bark thickness and 0.5723 and 0.4475 with surface area.

—0.080 and 0.638 for plot 1 and for plot 2 were 0.513 and —0.012 respectively. These coefficients did not show any clear relations between number of tramps and bait log sizes. In Fig. 9, the tramp ratio (the number of tramps moving away/the number of total immigrants) for each bait log shows approximately a constant level, about 0.4, for a wide range of total immigrants.

The length of adult stay on a bait log should be related to habitat selection. The time when an individual stayed on a particular bait log is represented by the period from the first capture until the final recapture. This period of time was 3.74 ± 0.48 (SE) days

Fig. 11. The density of emerged progeny in the relationships between the density of total parent catch and bark thickness of the bait log.

in plot 1 and was 3.58 ± 0.15 days in plot 2. Although the experiment in plot 1 was begun about twenty days earlier than that in plot 2, the average duration time weevils stayed were similar for the two plots, and suggests that the length of time on bait logs does not have seasonal changes. The duration of staying was not significantly related with the bait log sizes shown in Fig. 10 except the case with bark thickness in plot 2 at the 1% level.

Weevil progenies did not emerge from all bait logs. The number of progeny emerging from each log showed an aggregative frequency distribution (variance/mean ratios were 43.1 for plot 1 and 71.6 for plot 2). The relations among the density of emergence, total catch and bark thickness of each bait log are shown in Fig. 11. Most emergence occurred from logs having bark more than 1.5 mm thick.

DISCUSSION

Bait logs cut into one meter long sections were laid randomly on the ground without regard to the differences of log conditions. The distance among logs was about one meter. This separation among logs made a barrier to the tramping adults. Results of this study indicate in part the tree selecting behaviour of adult weevils rather than movements on the stem. The number of immigrants showed an aggregative tendency upon logs having thick bark and large surface area (Fig. 6), but not on logs having thin bark and small surface area. Therefore it seems that immigration is affected by

the logs and not by the site or the surrounding environmental conditions of the logs.

In this experiment, instead of differences in the quality and quantity of volatile substance(s) emitted by bait logs, the shape of bait logs was considered as the factor affecting attraction behaviour. Surface area may serve as an index to the amount of volatile substance(s) from a bait log, and bark thickness through visual and tactual stimulants probably indicates suitability for oviposition. From laboratory experiments, SHEPHERD (1966) showed that the mountain pine beetle (*Dendroctonus ponderosae* HOPKINS) used visual stimuli, and probably selected trees to be attacked on the basis of size. Because of the strong relation between bark thickness and surface area, factor(s) affecting behaviour of weevils were not clearly detected. However partial correlation coefficients strongly suggest that the main factor affecting the immigration phase is the differences in bark thickness rather than the log biomass expressed by surface area. The data suggested that after random flying adults detect volatile substance(s) coming from the bait logs, and the immigration flight then becomes oriented to the bait log plots. Upon reaching the plot, adults may use visual information in selecting logs which to land on.

Mountain pine beetles show a sexual difference in the flight stratum in lodgepole pine stands (SCHMITS et al., 1981). Therefore, differences in both the immigration and tramping behaviour between sexes may be important. Unfortunately adults treated in this study were not sexed.

Although intra-plot movement (tramping) was complicated, the major part appears to consist of mutual interchanges among logs attracting a large number of immigrants (Fig. 7), with tramping unaffected by the shape and quality of individual logs. The tramping adults did not show a tendency to concentrate upon a particular log (Fig. 8). The tramp ratio shown in Fig. 9 indicates that about one half of the immigrants on each log tramped to an other log to search a mating and oviposition site. The other half emigrated from the plot without any intra-plot movement. The other half emigrated from the plot without any intra-plot movement. The analysis of population trend (YOSHIKAWA, 1981 a) using capture-recapture data showed a large population of *Shirahoshizo* spp. was maintained around the plot for a considerably long period with frequent immigration and emigration. The high tramp ratio indicates frequent migration. The main factor determining settlement and departure of adults was not detected in this experiment, but such tramping behaviour appears to be unaffected by size of bait log. If a log had strong ability to attract weevils and keep them, adults should have shown a prolonged stay. On the other hand, if adults had an inclination to avoid unsuitable logs, the number of immigrants should be smaller and the number of emigrants greater than occurred on suitable logs. However, the tramp ratio does not show such trend and indicates that both the attraction of logs and responses of adults do not differ by log quality of itself, not by the quality of neighbouring logs.

The adults of *Shirahoshizo* spp. copulated more frequently on thick bark than thin bark (YOSHIKAWA, 1981 b). Therefore, a longer stay was expected on thick than thin barked logs. However, the average time spent on each type of log (Fig. 10) was approximately the same regardless of bark thickness and surface area. Therefore after landing on the logs, adults spend similar periods of time mating and ovipositing before tramping to another bait log or emigrating to a new oviposition site. There is no tendency to increase the stay on particular bait logs suitable for mating and ovi-

position. Therefore, it seems that attractiveness of a log to adults should decrease with time from the first arrival on the log, and that time spent is determined not by conditions of the bait log but by habits or physical conditions of the weevil itself. However, in some cases, adults do show a rapid departure to avoid logs unsuitable for mating and oviposition.

The number of emerging progeny did not directly relate with total parent catch. Even though a large number of adults were attracted, emergence of progeny was restricted to logs having thick bark (Fig. 11). The survival of mountain pine beetle (*Dendroctonus ponderosae*) per unit surface area was much greater in the larger diameter trees (REID, 1963). COLE and AMMAN (1969) and AMMAN (1977) showed exponential increase of phloem thickness with increased diameter and concluded that the principal reason of this high survival was the thicker phloem. Japanese red pine trees do not show an increase in phloem thickness with increased diameter, but do show an increase in bark thickness with increased diameter as mentioned above. Although egg density and larval mortality may have differed with bark thickness, these were not measured. However, it can be said that a certain thickness of bark is necessary for weevil larvae to develop fully. Large numbers of adults were caught on bait logs regardless of log size. Therefore, the reason why thin barked bait logs attracted as many adults as thick barked logs was not apparent. There was no tendency for emergence to increase as bark thickness increased beyond a certain threshold thickness. We did not detect any changes in adults behaviour below and above this threshold condition.

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REFERENCES

- AMMAN, G. D. (1977) The role of the mountain pine beetle in lodgepole pine ecosystems: Impact on succession. In *The Role of Arthropodes in Forest Ecosystems*. (W. J. WATSON, ed.), Springer-Verlag, New York, pp. 3–18.
- BERRYMAN, A. A. (1976) Theoretical explanation of mountain pine beetle dynamics in lodgepole pine forests. *Envir. Ent.* **5**: 1225–1233.
- COLE, W. E. and G. D. AMMAN (1969) Mountain pine beetle infestations in relation to lodgepole pine diameters. *USDA For. Serv. Res. Note INT-95*: 7.
- FURUTA, K., K. KOBAYASHI, A. YAMANE and N. ENDA (1972 a) An ecological study of mixed species population of *Shirahoshizo* spp. on bait logs of pine tree (I). *J. Jap. For. Soc.* **54**: 6–11 (in Japanese with an English summary).
- FURUTA, K. and H. OHSHIMA (1972 b) An ecological study of mixed species population of *Shirahoshizo* spp. on bait logs of pine tree (II). *J. Jap. For. Soc.* **54**: 41–46 (in Japanese with an English summary).
- FURUTA, K. (1972 c) An ecological study of mixed species population of *Shirahoshizo* spp. on bait logs of pine tree (III). *J. Jap. For. Soc.* **54**: 329–332 (in Japanese with an English summary).
- ISHIKUBO, S. (1952) Studies on the beetles attacking pine trees of southern Kyushu (I). *Bull. Fac. Ed. Univ. Kagoshima* **4**: 83–87 (in Japanese).

- ISHIKUBO, S. (1954) Studies on the beetles attacking pine trees of southern Kyushu (II). *Bull. Fac. Ed. Univ. Kagoshima* **6**: 125–130 (in Japanese).
- ISHIKUBO, S. (1955) Studies on the beetles attacking pine trees of southern Kyushu (III). *Bull. Fac. Ed. Univ. Kagoshima* **7**: 123–128 (in Japanese).
- ISHIKUBO, S. (1957) Studies on the beetles attacking pine trees of southern Kyushu (IV). *Bull. Fac. Ed. Univ. Kagoshima* **9**: 11–15 (in Japanese).
- IWASAKI, A. and K. MORIMOTO (1971) Behaviour of adult *Shirahoshizo* spp. attracted to pine bait log and their oviposition site. *Ann. Rev. Kyushu Branch of Jap. For. Sec. Stn.* **13**: 104 (in Japanese).
- IWASAKI, A., K. MORIMOTO and T. HOTTA (1969) Dispersion of *Shirahoshizo* spp. *Bull. Kyushu Branch of Jap. For. Soc.* **23**: 173–175 (in Japanese).
- MORIMOTO, K. (1962) Taxonomic revision of weevils injurious to forestry in Japan (I). *Bull. Gov. For. Sta.* **135**: 35–46 (in Japanese with an English summary).
- MORIMOTO, K. (1970) Host selection and population size of pine bark weevils. *Shinrin-boeki* **19**: 149–151 (in Japanese).
- REID, R. W. (1963) Biology of the mountain pine beetle, *Dendroctonus monticolae* HOPKINS, in the East Kootenay Region of British Columbia. III. Interaction between the beetle and its host, with emphasis on brood mortality and survival. *Can. Ent.* **95**: 225–238.
- ROELOFS, W. (1874) Curculionidae recueillis au Japon par M. G. LEWIS. *Ann. Soc. Ent. Belgique* **17**: 121–176.
- SCHMITZ, R. F., M. D. MCGREGOR and G. D. AMMAN (1981) Mountain pine beetle response to lodgepole pine stands of different characteristics. In *Dispersal of Forest Insects* (A. A. BERRYMAN, ed.), Proc. 2nd. IUFRO, pp. 234–243.
- SHEPHERD, R. F. (1966) Factors influencing the orientation and rates of activity of *Dendroctonus ponderosae* HOPKINS (Coleoptera: Scolytidae). *Can. Ent.* **98**: 507–518.
- Shikoku Branch Gov. For. Expt. Stn. (1962) Pine borers in Shikoku Island. *Kochi Rinyu* **429**: 2–12; **430**: 8–29; **431**: 2–14; **432**: 2–17; **433**: 1–18 (in Japanese).
- SOUTHWOOD, T. R. E. (1971) *Ecological Method with Particular Reference to the Study of Insect Populations*. Chapman and Hall, London, 391 pp.
- TAKETANI, A. and F. KOBAYASHI (1968) A study of *Shirahoshizo* spp. attacking on pine tree—seasonal changes in population size attracted on bait log. *Trans. 79th Mtg. Jap. For. Soc.* 206–207 (in Japanese).
- YOSHIKAWA, K. (1977) Population study of pine bark weevils (Coleoptera: Curculionidae) in bait logs. *Appl. Ent. Zool.* **12**: 9–17.
- YOSHIKAWA, K. (1978) Spatial distribution of pine bark weevils (Coleoptera: Curculionidae) in bait logs. *Appl. Ent. Zool.* **13**: 63–75.
- YOSHIKAWA, K. (1981 a) An analysis of the trend of the pine bark weevil (*Shirahoshizo* spp.) (Coleoptera: Curculionidae) population attracted to pine-bait logs. *J. Jap. For. Soc.* **63**: 227–234.
- YOSHIKAWA, K. (1981 b) Seasonal changes in numbers and distribution patterns of pine bark weevils (*Shirahoshizo* spp.) (Coleoptera: Curculionidae) attracted to pine bait logs. *Appl. Ent. Zool.* **16**: 367–373.