Population Study of Pine Bark Weevils (Coleoptera: Curculionidae) in Bait Logs

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The population densities of three species of pine bark weevils, *Shirahoshizo* spp. (including *S. rufescens* ROELOFS, *S. insidiosus* ROELOFS and *S. pini* MORIMOTO), *Pissodes nitidus* ROELOFS and *P. obscurus* ROELOFS, living within bait logs (70—80-cm long, 15—20 cm in diameter) of *Pinus densiflora* SIEB. et ZUCC., were estimated in a pine forest.

In all species, the larval density reached maximum at about forty days after the beginning of the attack by adults, thereafter the densities decreased throughout the larval stage. The initial larval density of *Shirahoshizo* spp. was the highest of all but it decreased rapidly after the peak. While the changes in larval density of *P. nitidus* and *P. obscurus* did not show such a great decrease and the pupal density of these species was higher than that of *Shirahoshizo* spp. A large number of larvae disappeared during their growth period, which accounted for 93.69, 80.75 and 52.00 percent of the total mortality of *Shirahoshizo* spp., *P. nitidus* and *P. obscurus* respectively. Parasitism was a severe factor operating on the old larval stage of *Shirahoshizo* spp. and *P. nitidus*, while larvae of *P. obscurus* seldom suffered parasitism.

INTRODUCTION

Five species of pine bark weevil, *Shirahoshizo rufescens* ROELOFS, *S. insidiosus* ROELOFS, *S. pini* MORIMOTO, *Pissodes nitidus* ROELOFS, *P. obscurus* ROELOFS, are common in Japanese red pine forest. The life histories of these species have been studied by some workers (NITTO et al., 1959; SHIKOKU BRANCH GOV. FOR. EXPT. STN, 1962; KATAGIRI, 1964; ODA, 1970). Within any pine tree, *Shirahoshizo* and *Pissodes* have their habitats distributed along the gradient of the bark thickness. *S. rufescens*, *S. insidiosus* and *S. pini* prefer the thick part of the bark near the ground and can oviposit in crevices from early April to late October, while both *P. nitidus* and *P. obscurus* oviposit in cavities excavated by means of the beak into the phloem on the part of thin bark, but the oviposition periods differ between the two species of *Pissodes*. *P. nitidus* attacks trees from February to March and the brood emerges from early- to mid-summer, feeds on shoots during autumn, and overwinters in the litter or duff of the forest floor, whilst the oviposition period of *P. obscurus* is in autumn and it overwinters in the larval and/or the pupal stages to emerge as an adult in the early summer of the next year.

Information about within-tree populations of these pine weevils is restricted to qualitative aspects and little is known about the dynamics of such populations. Studies on the numerical changes in their larval populations are important for the clarification of their ecology and the control of the population. This study is concerned with the changes in larval and pupal density and mortality factors of the populations of *P. nitidus*, *P. obscurus* and *Shirahoshizo* spp. which have the aforementioned phenological

and distributional difference in their habitats. Three species of *Shirahoshizo* were not distinguished each other in this study, because it is difficult to distinguish the larvae of these three species by their morphological characteristics and their habits are also quite similar. In the year preceding this investigation, about 200 male adults of *Shirahoshizo* spp. were caught in the same way as this study at the same site. Only one specimen was *S. pini* and the rest were *S. rufescens*. Although larvae examined in this study included three species, most of them were *S. rufescens*.

MATERIALS AND METHODS

This study was carried out in a Japanese red pine (*Pinus densiflora* SIEB. et Zucc.) forest at Kamigamo Experimental Forest Station of Kyoto University situated about 12 km north of Kyoto City (35°04' N, 135° 45' E and 100-225 metres in altitude). The experimental site was chosen in a Japanese red pine forest mixed with *Chamaecyparis obtusa* STAND., which was located on a gentle slope facing north-east. At this Experimental Station, many pine trees infected by pine bark weevils have been felled during the last few years.

In order to prepare the bait logs for *Shirahoshizo* spp., thirteen Japanese red pine trees being about 15-20 cm in diameter at breast height were felled at the end of March 1974. Sixty-six bait logs (70-cm long, and 2.42 cm in the mean bark thickness) were taken from the lower part of stems having thick bark. The bait logs were laid horizontally in a circle on the site, supported by hardwood logs at each end about 10 cm above the ground on March 30, 1974, so that virtually the whole surface was available for attack by weevils. Samples were taken at about fortnight intervals from May 9 to August 19, 1974.

As to *P. nitidus* and *P. obscurus*, four Japanese red pine trees of 15-20 cm in diameter at breast height were felled at the end of March and the beginning of September 1975 respectively. On each occasion, twenty-five bait logs (80-cm long, and 0.32 cm in the mean bark thickness) were taken from the upper part of stems where the bark was smooth and thin. The bait logs were laid horizontally in a circle on the same site as in the case of *Shirahoshizo* spp., supported about 50 cm above the ground on March 28 and September 15, 1975, respectively. Samples were taken at more or less irregular intervals from May 4 to July 28, 1975, and from October 4, 1975, to June 17, 1976, respectively.

The sample unit was one half of the bait log, 35-40 cm long, for all three investigations. On each sampling occasion, four sample units were taken at random from the bait logs and brought back to the laboratory for analysis. In order to avoid the "end effects" which arise from log dryness and abnormal attacks by insects, only the middle parts, 20 cm in width, of the sample unit were used for analysis.

The following information was recorded : number of oviposition sites, eggs, living and dead larvae, pupae, teneral adults, emergence holes, the causes of death at all stages, and the number of other associated organisms found below the bark. The developmental stages were defined by measurement of the length and width of the head capsule. These counts and measurements were made under a binocular microscope of 40X magnification.

RESULTS

Developmental stages

Fig. 1 (A),(B),(C) show the correlation between the head capsule lengths and the

Fig. 1. Correlation between the length and width of larval head-capsule. (A), *Shirahoshizo* spp.; (B), *P. nitidus*; (C), *P. obscurus*. Size of circle indicates number of individuals. The solid lines represent the boundary between the young and old larvae.

widths for *Shirahoshizo* spp., *P. nitidus* and *P. obscurus*. These figures are comprised of measurements from more than 1500 larvae found in the samples. Judging from the frequency distribution, the number of instars of *Shirahoshizo* spp., *P. nitidus* and *P. obscurus* seems to be six, four and four or five respectively. This method determining the number of instars from the frequency distribution of head length and width was criticized by KISHI (1970c), because the frequency distribution does not always show a clear separation of each instar especially in the case of the field-sampling data. BEJER-PETERSEN et al. (1962) shows that, under the same climatic conditions, larvae of *Hylobius abietis* reaching the last instar later have larger head capsules, and concluded that this may be account-

ed for by the occurrence of extra instars. Therefore it seems that the number of instars separated from the frequency distribution in Fig. 1 (A),(B),(C) does not show the true number of instars, so in this study the larvae are divided into two groups, young and old, and their boundary is drawn in Fig. 1 with a solid line. The stages of prepupa, pupa and teneral adult are treated together as "pupal" stage.

The numerical changes in larval density

Fig. 2 (A),(B),(C) show the population changes in the case of the three species examined in this study together with the changes in the age structure. In all cases of this study, it seems that the oviposition was nearly completed before the larval density reach-

Fig. 2. Seasonal changes in (a) age structure and (b) density. (A), *Shirahoshizo* spp.: (B), *P. nitidus*; (C), *P. obscurus*. The white areas represent percent of young larvae; the hatched areas, old larvae; the stippled areas, pupae; ●, number of total observed individuals/100 cm²; ○, number of living individuals/100 cm². Standard errors are indicated. The dotted line represents the maximum total population density.

ed maximum, since when the larval density reached maximum the larval galleries were elongated enough and no newly hatched larvae were found. The adult pine weevils do not make parental galleries, so the number of eggs laid per unit area can not be accurately estimated. However the larval galleries, for the most part, were still separately constructed when the larval density reached maximum, so the major part of the destructive mortality, namely being eaten completely by predators or by other individuals, could be counted to some extent. Therefore the maximum total density might be used as the initial density of the larval population. The amount of decrease from the maximum density was regarded as the mortality on each sampling occasion. On each sampling occasion, the difference between the dotted line and the lower solid line represents the total mortality, and differences between the two solid lines and between the dotted line and the upper solid line respectively represent the observed mortality and the disappearance which was mainly caused by predation and disturbance by other living organisms.

Adults of *Shirahoshizo* spp. began to fly and oviposit on the bait logs on April 27, 1974. The larval density reached maximum on June 4, 1974. At the maximum, the density of living larvae was 30.01 ± 10.16 individuals per 100 cm^2 , and the total density including both living and dead larvae was 31.36 ± 10.45 individuals per 100 cm^2 . The egg density at this time could not be estimated. The larval density decreased rapidly after the population density reached maximum. By June 16, the next sampling time, about 84 percent of the maximum density had died and the density of living larvae had decreased to 4.88 ± 1.22 individuals per 100 cm^2 . The population changes through the larval stage were characterized by the steep decline of the total density just after the population density reached maximum and by continuous decline of the density of living larvae during the larval stage. Pupal chambers began to be constructed at the beginning of July and were completed during July. The total number of pupal chambers was 0.97 ± 0.17 per 100 cm^2 and this was the lowest density among the three species examined in this study. New adults began to emerge from the end of July 1974.

P. nitidus began to attack on April 8, 1975. The larval density reached maximum on May 19, 1975. The maximum density of living larvae was 10.75 ± 1.33 individuals per 100 cm^2 and the total density was 14.09 ± 2.57 individuals per 100 cm^2 . At that time, 2—3 eggs per 100 cm^2 were still unhatched or had died. The density of both total and living larvae decreased gradually throughout the larval stage. Pupal chambers began to be constructed at the beginning of July. The total number of pupal chambers was 4.80 ± 0.48 per 100 cm^2 . New adults began to emerge from the middle of July 1975.

Oviposition by adults of *P. obscurus* started immediately after the setting of the logs. On November 5, 1975, the larval density reached maximum. The density of living larvae was 5.96 ± 1.08 individuals per 100 cm^2 and the total density was 6.88 ± 0.99 individuals per 100 cm^2 . At that time, 1—2 eggs per 100 cm^2 were still unhatched or had died. The total density did not show a steep decline throughout the larval stage and the density of living larvae decreased gradually during the winter. The changes in the age structure shown in the upper part of Fig. 2(C) indicate that the larvae were slowly growing throughout the winter. In spring of the next year, they began to construct the pupal chambers and finally 2.52 ± 0.61 pupal chambers per 100 cm^2 were made. New adults began to emerge from June 1976.

In all cases of this study the oviposition continued for about a month and the larval density reached maximum about forty days after the beginning of the attack.

Mortality factors

Fig. 3(A),(B),(C) show the changes in the number of observed dead bodies caused by each mortality factor. The mortality factors were classified into resinosis, parasitism, disease, cannibalism or predation and unknown. The dead numbers from each cause in Fig. 3(A),(B),(C) must be more or less underestimated, because the number of dead individuals completely eaten by other organisms was not estimated.

The resistance of trees to attack by bark beetles is characterized by the resin flow (BERRYMAN, 1969; BERRYMAN and ASHRAF, 1970). In this study, resinosis was the main mortality factor for *P. nitidus* during the early larval stage and accounted for 35-40 percent of the total number of death until the larval density reached maximum. Especially on May 19, 90 percent of the observed dead bodies were due to this factor. However this mortality was negligible in the cases of *P. obscurus* and *Shirahoshizo* spp. The difference in the intensity of this mortality factor between the cases of *P. nitidus* and the other two species may be due to the condition of the host trees. Namely the bait logs for *P. nitidus* were taken from the upper part of pine trees in the growing season, while those for *Shirahoshizo* spp. and *P. obscurus* were taken respectively from the lower part of stems in the growing season and from the upper part of stems in the dormant season.

Fig. 3. Seasonal changes in the observed mortality caused by each mortality factor. (A), *Shirahoshizo* spp.; (B), *P. nitidus*; (C), *P. obscurus*.

In this study, two species, *Spathius radzayanus* RATZBURG and *Rhopalicus tuta* WALKER, parasitizing the larval stage and two species, *Dolichomitus* sp. and *Caliptus satai* WATANABE, parasitizing the pupal stage were found, but they have not been dealt with separately. Throughout the pupal and old larval stages, parasitism was the major mortality factor for all three species except for the old larval stage of *P. obscurus* and accounted for 25.28, 23.31 and 20.65 percent of the pupal density of *Shirahoshizo* spp., *P. nitidus* and *P. obscurus* respectively. The intensity of parasitism obtained in this study for *Shirahoshizo* spp. was almost in accordance with the results obtained by KISHI (1970a) who showed that 22.4 percent of the pupae of *Shirahoshizo* spp. were parasited by *Dolichomitus* sp. Throughout the old larval stage, there was a difference in the mortality pattern between the cases of *Shirahoshizo* spp. and *P. nitidus*, namely the mortality of *Shirahoshizo* spp. continued to increase throughout the developmental period, while that of *P. nitidus* ceased to increase on the 20th June, when the pupal chambers began to be constructed.

The larval population of *P. obscurus* were hardly attacked by parasites until the next spring because of the lack of synchronization between the life history of host and parasites. ISHIKUBO (1959) reported that the parasitic activity of *Rhopalicus tuta* is presumed to last from early April to mid October in the southern part of Kyusyu. It seems that the activity of these parasites in this study area ceased before October. Contrary to the cases of *Shirahoshizo* spp. and *P. nitidus*, the major part of the old larval death of *P. obscurus* was caused by disease. The death due to disease seemed to be closely related to the habitat conditions such as the humidity under the bark.

The observed values of mortality due to cannibalism and predation shown in Fig. 3 (A),(B),(C) were relatively small, but the number of disappearance shown in Fig. 2 (A),(B),(C) as the difference between the dotted line and the upper solid line should be included in these mortality factors, and so the greatest number of individuals were killed by these factors in the cases of *Shirahoshizo* spp. and *P. nitidus* at the larval stage. *Temnochila japonica* REITTER is an important predator of these pine weevils (KISHI, 1970b). Only in the case of *Shirahoshizo* spp., a small number of *T. japonica* was observed through the period when the log became to have large spaces which were constructed by larvae of weevil. In the other two cases, neither *T. japonica* nor any other predators were found. Although the cannibalism could not be distinguished from predation, these evidences suggested that the number of mortality caused by cannibalism might be larger than predation.

DISCUSSION

The results indicate that a relatively large number of larvae disappeared during their growth period, which accounted for 93.69, 80.75 and 52.00 percent of the total mortality of *Shirahoshizo* spp., *P. nitidus* and *P. obscurus* respectively. Most of the disappearance seemed to be due to predation and intraspecific competition. The ability of larvae to exploit the available food is important for intraspecific competition during the larval stage under the bark. BEAVER (1974) noted that larvae developing from later-hatching eggs in a log are subject to higher intensities of competition and are at a competitive disadvantage relative to earlier-hatching larvae. Even in the early period of the development of each population in this study, there was a considerable difference in body sizes among larvae because of the prolonged oviposition period. Further, in

the case of *Shirahoshizo* spp., having the highest initial density in this study, most of the total disappearance occurred in the relatively short period immediately after the peak, while the populations of the other two species having lower initial density did not show such a steep decrease in numbers. These facts suggest that the intraspecific competition is an important component of the mortality during the larval stage of these weevils.

Through the old larval and pupal stages, parasitism by Hymenoptera contributed to the effect on reproduction. The parasitism had a minor effect on the population of *P. obscurus* which overwinters in the larval stage, but the other species suffer intensive parasitism during the larval period (Fig. 3 (A),(B)). The effect of parasitism on the weevil populations seems to depend upon the activity of Hymenopteran insects during the old larval stage of the weevils. The lack of synchronization of life cycles between *P. obscurus* and Hymenopteran parasites may account for the low degree of parasitism on that population.

The three species of weevils are almost similar in their body size but the spatial demand for the construction of pupal chambers and the distribution of them under the bark differed among the species (KOBAYASHI, 1973; YOSHIKAWA, unpublished). *Shirahoshizo* spp. require a larger area than the two species of *Pissodes* for the construction of pupal chambers and avoid constructing in aggregates, so that the distribution of their pupal chambers becomes uniform under the bark. It seems that the population density of the pupal stage is partly related to the distribution characteristic of the species.

The natural populations of pine weevils living under the bark suffered from different factors, such as intensive predation and unfavorable weather conditions (TAYLOR, 1929; STEVENSON, 1967; HARMAN and KULMAN, 1968) compared with the semi-natural within-bait-log populations in this study. But the intraspecific competition for food and space has also been considered as an important regulation factor for several scolytids (ATKINS and McMULLEN, 1960; BERRYMAN, 1973; COLE, 1973 and 1974; BEAVER, 1974;). In this study, there was a possibility that the larval abundance was determined finally by intraspecific competition for the limited food and space in the same way as with many insects that live in their food medium as larvae.

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