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ABSTRACT: The Formosan red-bellied tree squirrel (Callosciurus erythraeus.) is a pest animal that causes serious damage to many conifer plantations in Taiwan. Poisoning has been the major means to control the damage. The feasibility of forestry control through habitat manipulation has been evaluated during the past 5 years. The objective of this study was to investigate the effects of forest-tending operations on the activity and damage by squirrels. Forest-tending conducted included weeding and thinning. Test sites were at three Japanese cedar (Cryptomeria japonica) plantations located in Chitou. The results of this study revealed that squirrel activity in the treated plots was greatly reduced. It was found that new damage done by the squirrels in treated areas was also reduced. This was particularly significant during an abnormal weather period when there was a continual rainstorm lasting for about 3 months. The treatments of weeding and thinning showed more significant effects on the reduction of squirrel activity than the reduction in the occurrence of new damages.

INTRODUCTION

Debarking damage caused by the Formosan red-bellied tree squirrel (Callosciurus erythraeus) has become a serious economic problem in many conifer plantations in Taiwan. It is believed that the squirrel debarking is a result of food shortage in the conifer plantations. The principal measures of controlling squirrel damage has emphasized reducing squirrel populations in the stands. Chemical poisoning has been effective, but it has also killed some nontarget animals that inhabit the forest. In addition, it is a labor-intensive operation which is difficult to apply over a wide area of forest plantations on steep mountains. In contrast, silvicultural treatments or tending cares are usually conducted throughout the entire period of stand rotation. Silvicultural treatments, as referred in this report, include weeding and thinning operations which are commonly practiced in Taiwan forestry for improving the tree growth in young plantations.

"Habitat manipulation" by cultural treatment has been well documented (Marsh 1984). It has recently become a promising approach to control wild rats in Taiwan. This approach has been extensively used in many parts of the world. Sapling to pole-stage Japanese cedar (Cryptomeria japonica) plantations were selected to evaluate the effectiveness of such "habitat manipulation" in Taiwan. This evaluation was aimed to find out how habitat manipulation would affect the activities of squirrels and level of damage in the test plantation.

METHODS OF STUDY

Three experiments were conducted at Chitou Experimental Forest, National Taiwan University, located in the central part of Taiwan. Experimental sites were established in June 1980 and ended in February 1986. The size of treated or control plots was 0.25 ha. There were three to four replications in each treatment. The stand density of test plantations was 2,000 to 2,500 trees/ha. The ages of test plantations at the time of study were 8 years for weeding, 18 for light thinning, and the heavy thinning plots had 20-year-old trees.

The mark-recapture method was employed for the squirrel activity observation. The live-traps (25cm x 15cm x 11cm) were placed 20 meters apart in each test plot. The trap was installed on the trunk of each tree at 1.5 to 2.0 meters above the ground. Banana was placed as bait in the traps. Number of captured squirrels and number of times captured were recorded. Each live-trap was observed monthly for 5 days. These observations were continued for 5 years and analyzed using Lincoln Index method for population estimation. Activity differences among squirrels were detected with a Chi-square test of independence assuming multinomial sampling.

Squirrel damage in each plot, i.e., the amount of debarking of the trees, was estimated by recording the weight of bark pieces dropped to the forest floor when debarking was taking place. Weather records were compiled from the statistics taken by the Chitou Forest Working Station.

RESULTS AND ANALYSIS

Squirrel Activity

During the 5-year test period, 156 squirrels were caught. Among the 156 captured squirrels, 93 of them were recaptured. The total number of captures was 463. The recapture made up 60% of total captures.

The number of squirrel captures recorded in the weeded and thinned plots was much lower than that for the untreated control plots (Fig. 1). The results clearly showed that squirrels were less active in plots with weeding and thinning treatments. Results of statistical analyses indicated that cultural

influences on squirrel activity were highly significant in the heavily thinned plots (X^2=53.98>$X^2$0.01=20.09) and were less significant in weeded (X^2=23.85>$X^2$0.01=16.81) and lightly thinned plots (X^2=10.57>$X^2$0.05=9.49). The 5-year data (Figs. 1 and 2) on live-trapping of squirrels showed that, silviculturally, treated plots had a much less number of captures, especially in the heavily thinned plots, than untreated plots.

The population density of squirrels, as estimated by the Lincoln Index method, indicated that a higher squirrel density was found in the thinned, old plantations, while a lower squirrel density was observed in the weeded young plantations. This means that the heavily thinned test plantations had a higher population density of squirrels than the lightly thinned test plantations. The total number of squirrel captures in the weeded, lightly thinned, and heavily thinned plots was 41, 23, and 16, respectively. The number of squirrel captures recorded in the control plots established for each type of those treatments was 77, 25, and 247, respectively. It is interesting to note that the smallest number of squirrel captures was found in the heavily thinned plots, but the number of squirrel captures recorded in its control plots was the highest among all the control plots.

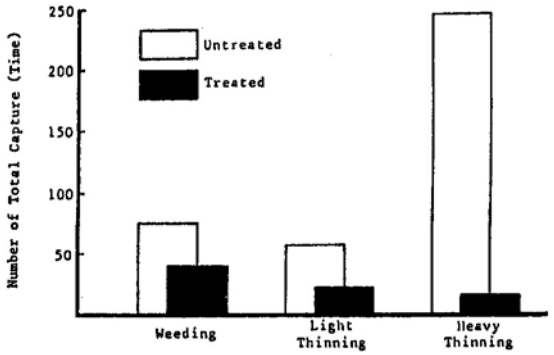

Figure 1. Number of squirrels captured in the weeded, thinned and untreated plots (September 1981-February 1986).

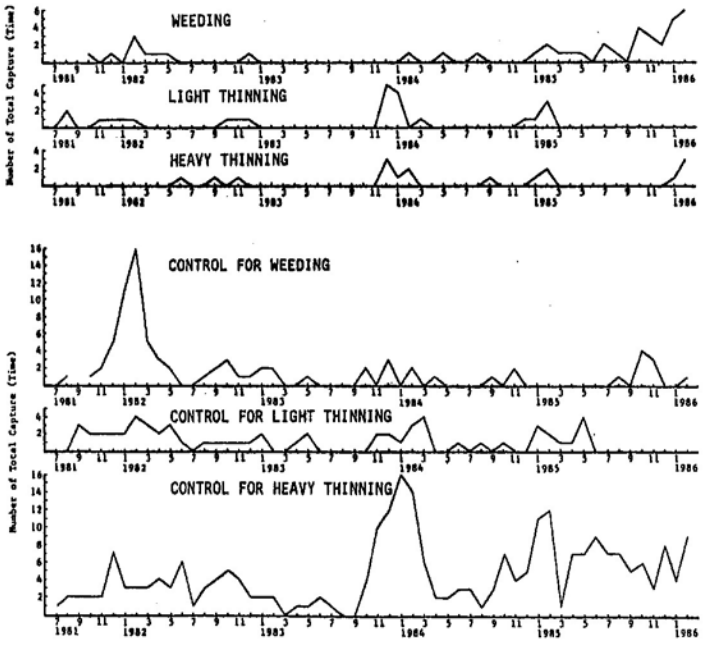

Figure 2. Monthly variation in the number of squirrel captures for silviculturally treated (upper half) and control (lower half) plots.

Figure 2 revealed that the squirrel captures were highly concentrated during the period of winter to spring. Normally, a short supply of food was also observed in the forest during the period of winter to spring. This was especially true for the silviculturally treated plots. The year of 1983 showed the lowest captures. It was due to the occurrence of prolonged rainfall in the spring. It also indicated that there was a tendency of increased captures of squirrels in the weeded areas. This would reflect that the influence of weeding on the squirrel activity in the forest stand is decreasing. The total number of squirrel captures in the weeded plots began to increase from the summer of 1985. This may be due to the formation of dense canopy which made the site more favorable for squirrels. However, all thinned plots still showed a strong preventive effect on the activity of squirrels. This means that thinnings conducted 5 years ago are still effective on the control of squirrel activity.

Squirrel Debarking

The amount of squirrel damage to forest trees was evaluated by the total weight of bark pieces peeled by squirrels in the test plots. Results (Fig. 3) showed that the debarking happened more often in the untreated control plots. The amount of squirrel debarking, in terms of bark weight, for the control plots was 1 to 2 times higher than those for the lightly and heavily thinned plots. The difference in debarking damage between treated and untreated plots was highly significant in the year of 1983 when heavy rainfall was concentrated during the period of January to March (Fig. 4). For the period of January to March of 1983 the total rainfall was 960.5 mm, which was about eight times higher than the average rainfall recorded from the same period of 1982 and 1984. Results from the comparison between thinned and unthinned plots suggested that the thinned plots had less squirrel-debarking problem ($p>0.01$); however, such findings were not shown in the weeded plots.

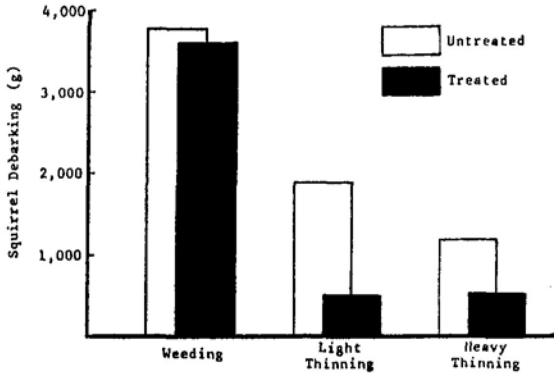

Figure 3. Amount of squirrel debarking in the weeded, thinned and untreated plots (August 1982-February 1986).

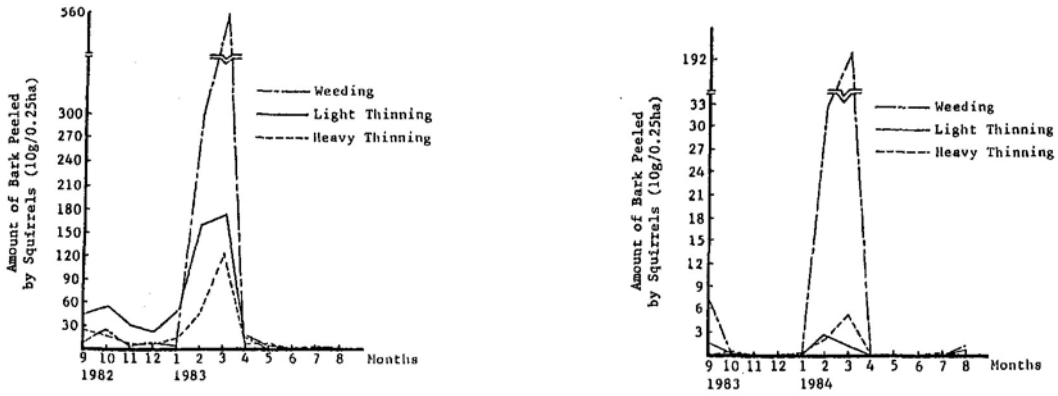

Figure 4. Monthly variation in the amount of bark peeled by squirrels in the untreated control plots: during the year with abnormal rainfall (right) and below--during the year with normal rainfall (left).

As shown in Figure 4, the highest amount of bark peeled by the squirrels appeared during the period of a prolonged rainstorm (March 1983). It was three times more than that collected during the year with normal rainfall (March 1984). The measurements for those two periods were 5,600 and 1,920 g/0.25 ha.

DISCUSSION

This investigation clearly demonstrated that the population density of squirrels did vary greatly with different conditions around the test sites. Heavily thinned plots adjacent to the natural hardwood forest showed a high density of squirrels. Weeded and lightly thinned plots near conifer plantations

or bamboo stands had low squirrel density. This may be due to the variation in carrying capacity of the squirrel habitat. Rusch and Reeder (1978) suggest that the squirrel density is related to the amount of available food in the forest. Due to the results of intensive management and tending care practiced in Taiwan, the bamboo plantations generally have little undergrowth and may not have enough food to maintain a great number of squirrels.

The squirrel debarking problem mostly occurred during the period between late winter and early spring. This investigation also revealed some interesting phenomena. Firstly, a high squirrel damage was found in the weeded plots where the squirrel population density was very low. Secondly, a high squirrel population density was found in the heavily thinned plots where the squirrel damage was quite limited. It is believed that the amount of squirrel debarking was highly related to the age of stand. The younger stands usually show high squirrel damage even when they have fewer squirrels. Irving and Beer (1963) and Keith (1965) indicated that the level of squirrel damage reflects the activity of squirrels inhabiting that area, and has no direct correlation with the squirrel density. Many reports (Pike 1934, Cook 1954, Lutz 1956) explained that the squirrel debarking reflects a strong habit of preference over the conditions of debarked trees. Data compiled by Kuo (1984) in Chitou area showed that heavy squirrel damage often occurred in the 13 to 14-year-old conifer plantations.

The incentive of squirrel debarking on trees is quite complicated (Taylor 1966, Davidson and Adams 1973, Kuo et al. 1982). This study found that squirrel debarking became severe when a heavy rainstorm occurred from January to March of 1983. This might be due to the stress on survival of squirrels. It might be also due to a short supply of other available food resulting from the continual rainfall. It was also found that there was very little squirrel activity during this bad weather period as a very low capture rate was recorded for that season (Fig. 2). Gunter and Eleuterius (1971) reported that in Mississippi, USA, during August 1969 the amount of squirrel debarking on trees increased sharply because of a hurricane. It was also observed that the amount of tooth marks imprinted on the bark pieces was quite small which reflected that eating of the cambium layer was not responsible for the serious debarking during the bad weather period.

It is generally feasible to control rodent damages by manipulating environmental conditions (Borrecco 1976). Patton (1977) reported that the evaluation of a habitat requirement for the Abert's squirrel needed to be based on the food supply, cover and diversity of the trees. Tinga and Garreett (1966) found that these rodents could cause serious damage to young pines grown through dense undergrowth. It has been suggested that cleaning the undergrowth plants on the forest floor by weeding or removing of climbers can surely make habitats unfavorable to pest animals. Therefore it has often been considered as a silyicultural means to control pest animals. Because this approach is economically feasible and ecologically sound, it has been highly recommended by many resource conservationists. Howard (1985) also indicated that the most cost-effective form of biological control of tree squirrels is to remove their principal food plants. However, habitat manipulation cannot be always effective for controlling every type of pest animal (Ahlgren 1966, Gashwiler 1970, Fala 1975, Borrecco et al. 1979).

For Japanese cedar, the young trees are more susceptible to squirrel debarking than the old trees (Wang and Kuo 1980). Results of this study agree with the previous finding. Based on the number of squirrels recorded present, silvicultural treatments can definitely reduce the activity of squirrels. However, it was less significant for the reduction of squirrel damage. Squirrel damage can be greatly reduced at the silviculturally treated areas during a prolonged rainy period. Thinning is more effective than weeding, especially heavy thinning. With Japanese cedar squirrel damage is more common in the 10 to 15-year-old stands. For an improved approach, a heavy thinning operation should be performed within 20 years after the stand was established.

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