PROJECT REPORT 1999-13

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ISBN 1-55261-027-6

Effects of Commercial Thinning on Bark Beetle Diversity and Abundance

SFM Network Project: Effects of Commercial Thinning of Mature Lodgepole Pine Stands on Wood-inhabiting Insect Biodiversity.

by

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May 1999

EXECUTIVE SUMMARY

Scolytid bark beetles typically attack freshly dead trees, including harvested ones, and sometimes switch to live trees when population sizes become large. It is therefore important to consider bark beetles when developing forest management plans. Beetles are likely sensitive to changes in the forest environment, and may therefore be affected by low impact harvesting practices such as commercial thinning. We investigated the effects of thinning mature lodgepole pine stands on bark beetle diversity and abundance near Whitecourt, Alberta.

Pheromone trapping suggests that thinning had no effect on bark beetle diversity, but did significantly increase their abundance relative to unthinned stands. The number of individuals of the two dominant bark beetle species (*Trypodendron lineatum* Olivier and *Ips pini* Say) captured in thinned and unthinned stands was positively correlated with wind speed. Only coarse woody debris in thinned stands was found to contain breeding bark beetles. Beetles only used coarse woody debris that was dead less than two years, and debris significantly larger than that readily available (10.7 $\pm$ 0.5 cm diameter versus 8.2 $\pm$ 0.2 cm, respectively). It therefore appears that finding a suitable host, which may be affected by both wind and coarse woody debris availability, determines patterns of abundance.

Thinning also enhanced dispersal success of pine engraver bark beetles. The temperature threshold for flight was met more often in thinned stands than in unthinned stands. Furthermore, thinning reduced dispersal costs as measured by distance dispersed and fat content. This may result in greater reproductive success in thinned stands, and, in turn, larger populations.

Thinning may also enhance reproductive success of pine engraver bark beetles as a result of increased tree vigour in the residual stand. Pine engraver reproductive success was significantly greater in trees that had been growing vigorously at the time of death: females laid more eggs and a higher proportion of their eggs developed resulting in more offspring produced per female than in less vigorous hosts. Consequently, trees that fall in thinned stands are superior hosts when compared to trees that fall in unthinned stands, and may lead to larger populations in thinned stands.

Both short- and long-term effects of thinning on beetle populations may be mitigated. Reducing the amount and size of coarse woody debris due to thinning will be important in limiting the number of hosts available to beetles. This would include timely removal of harvested boles. Since vigour of the remaining trees may be important, thinned stands should be regularly monitored for natural tree fall. Removing fewer trees during thinning should make stands less desirable to bark beetles due to lower

temperatures, lower wind, and increased dispersal costs. Consequently, reproductive success of bark beetles can be limited by leaving more standing trees after thinning.

INTRODUCTION

Bark beetles (Scolytidae) are important to forest ecosystem function and forest managers. Many of these beetles attack coarse woody debris and therefore aid in its decomposition and nutrient cycling within the forest (Harmon et al. 1986; Freedman et al. 1996). However, they may also attack and degrade harvested trees (Bright Jr. 1976). If their population levels are high, they may even attack living trees (Bright Jr. 1976). Their presence in a stand is ultimately determined by their ability to fly there, the availability of suitable hosts, and their reproductive success upon finding hosts. These aspects of beetle biology are likely sensitive to changes in the forest environment. This study investigates the effects of changes in the forest structure and microclimate associated with commercial thinning, a low impact alternative to clear-cutting, on beetle diversity and abundance.

During thinning, trees are selectively removed from a stand, resulting in an evenly spaced stand. The number of trees removed depends on harvesting objectives. Trees that are removed are topped and de-limbed on site, resulting in a large input of coarse woody debris. Furthermore, reduced tree density and crown closure make thinned stands warmer and windier than their unthinned counterparts (Bartos and Amman 1989; Schmid et al. 1991, 1992a, b; Bartos and Booth 1994).

Since most bark beetles fly in the mid-bole region (Forsse and Solbreck 1985; Safranyik et al. 1992), flight may be easier in thinned stands because there is less clutter for beetles to maneuver around en route to a host. Furthermore, large amounts of coarse woody debris in thinned stands mean a smaller distance for beetles to fly to find a host. Beetles are attracted to host volatiles (kairomones) emitted by trees as they senesce or are wounded as would be the case with commercial thinning (Hynum and Berryman 1980). There would be a very large kairomone plume emanating from thinned stands, thereby potentially attracting beetles from a large area. Moreover, increased wind speeds in thinned stands tend to focus plumes of kairomone and pheromone (volatiles produced by beetles that attract conspecifics; Fares et al. 1980) relative to calm conditions, making it easier for beetles to locate the source (Salom and McLean 1991). Finally, higher temperatures also make thinned stands better for flight since the temperature thresholds necessary for flight may be achieved more often in thinned stands than in unthinned stands. In sum, thinning may enhance conditions for bark beetles due to less vertical clutter, more coarse woody debris, higher winds, and higher temperatures.

Once in a thinned stand, beetles have a large number of hosts to choose from. The stand itself would, in turn, have the potential to accommodate large numbers of beetles. This would result in a large and very attractive pheromone plume that increases the attraction of beetles beyond that of host cues alone. However, long-term coarse woody debris dynamics in thinned stands are unknown. Input of coarse woody debris may remain high following thinning as the remaining trees are more exposed to wind (Quine et al. 1995), thereby perpetuating large populations of beetles. Conversely, input of fresh coarse woody debris may quickly return to pre-harvest values, forcing beetles to go to other stands in search of hosts.

Thinning is likely to increase reproductive success in several ways. Higher energy reserves (measured as fat) following flight in thinned stands may be used for acquiring mates and producing offspring. Fatter beetles generally emit larger pheromone plumes to attract mates (Gries et al. 1990), and will be able invest more in egg production. Also, changes in host tree vigour as a result of thinning may affect bark beetle reproductive success.

The main goal of this study was to investigate the effects of commercial thinning of mature lodgepole pine stands (*Pinus contorta* var. *latifolia* Engelm.) on scolytid bark beetle diversity and abundance. Given the many changes in forest structure and microclimate associated with commercial thinning, the second goal of this study was to determine which aspects of forest structure and microclimate best explain diversity and abundance of these beetles. The effects of thinning on flight and reproductive success are also considered.

SUMMARY OF RESULTS

This study was conducted in four commercially thinned lodgepole pine stands and their unthinned counterparts (internal and external controls) near Whitecourt, Alberta, Canada (54°N 115°W). Sampling was done in the summers of 1996, 1997, and 1998. Three of the stands had been thinned in the winter prior to sampling in 1996, while the fourth was thinned in the winter prior to sampling in 1997.

Effects of Commercial Thinning on Forest Structure and Microclimate

During thinning, approximately two-thirds of the trees were removed from the stand, and the harvesting equipment made 4 m wide trails at 20 m intervals throughout the stand. Average tree densities ($\pm$ SE) were 841 $\pm$ 73 trees$\cdot$ha^{-1} in thinned stands, 2703 $\pm$ 289 trees$\cdot$ha^{-1} in internal controls, and 2346 $\pm$ 371 trees$\cdot$ha^{-1} in external controls. The crowns and limbs of trees that were removed were left in the stand. The amount of fresh coarse woody debris in thinned stands was therefore an order of magnitude greater in thinned stands than in their unthinned counterparts in the first year after thinning (Figure 1). Input of fresh coarse woody debris was equal in thinned stands and their unthinned counterparts in the second and third year after thinning (Figure 1).

Temperature and wind were monitored at the centre of each stand weekly. To remove daily and seasonal variation in temperature and wind speed, the data were averaged at each site for each week, and the difference of each stand from the mean (residuals) was used to compare thinned and unthinned stands. Thinned stands were warmer than unthinned stands in the first three years after thinning (Figure 2a). Thinned stands were also windier than unthinned stands over this time (Figure 2b).

Patterns of Beetle Diversity and Abundance

Beetle activity was determined using pheromone baited funnel traps and by excavating coarse woody debris originating at the time of thinning or later. In both cases,diversity was quantified using Shannon's H diversity index, which considers both species richness and evenness.

Twenty-one species were captured in pheromone traps. The diversity of beetles captured in pheromone traps did not differ in thinned and unthinned stands, or differ over time (Figure 4). Two species dominated pheromone trap catches: over ninety percent of individuals captured were either striped ambrosia beetles (*Trypodendron lineatum* Olivier) or pine engravers (*Ips pini* Say). Consequently, abundance analyses focused on these species. Striped ambrosia beetles were more abundant in thinned stands than in unthinned stands, a difference that persisted over time (Figure 5). The abundance of striped ambrosia beetles was positively affected by wind speed (Figure 6). Pine engraver abundance was also greater in thinned stands over time (ANOVA, $F_{1,24} = 623.69$, $p < 0.0001$). Pine engraver abundance was positively associated with the current amount of fresh coarse woody debris (ANOVA, $F_{1,26} = 11.59$, $p < 0.01$), the amount of coarse woody debris available the previous year (ANOVA, $F_{1,26} = 7.73$, $p = 0.01$), and wind speed (ANOVA, $F_{1,26} = 8.86$, $p < 0.01$).

Six species were found during coarse woody debris excavations, and were only found in thinned stands despite similar search effort in unthinned stands. These beetles attacked debris less than 2 years old, and that was larger than average (Figure 7). For coarse woody debris excavations, the abundance ($\#\cdot ha^{-1}$) of striped ambrosia beetles was due to the amount of fresh coarse woody debris (ANOVA, $F_{1,26} = 6042.89$, $p = 0.001$). Pine engraver abundance was also due to the amount of fresh coarse woody debris (ANOVA, $F_{1,26} = 7.99$, $p < 0.01$).

Beetle populations responded positively to the increase in commercial thinning as seen in both the coarse woody debris excavations and pheromone trap catches. The coarse woody debris excavations suggest that this response was due to the large, one-time input of fresh coarse woody debris in thinned stands. This response persisted in the pheromone trap catches, suggesting that some other change in the forest environment associated with commercial thinning helped determine the abundance of beetles. For pheromone trap catches, wind appeared to be important in determining the abundance of beetles. Since coarse woody debris and wind seem to work together were positively associated with beetle abundance, it is likely that finding a host is determining beetle activity in a stand.

Beetle Flight

To determine whether dispersal during host-seeking is more successful in thinned stands, marked pine engravers were released in thinned and unthinned stands (see Hindmarch and Reid, submitted). They were recaptured in pheromone traps placed at 50 m intervals up to 200 m away from the release point in four cardinal directions. Beetles were only recaptured on the first day of trials with temperatures above 19° C (Figure 8). The temperature threshold of 19° C was met more often in thinned stands than in unthinned stands due to significant temperature differences between these two types of stands (Figure 9). Thus, beetles in thinned stands should be able to search for hosts more often than those in unthinned stands.

Thinning did not effect the percentage of beetles recaptured in thinned and unthinned stands on the first day of each trial (ANOVA $F_{1,9} = 0.90$, $p > 0.3$). There was also no difference in the percentage of beetles recaptured in thinned and unthinned stands over the duration of each trial (ANOVA $F_{1,9} = 0.015$, $p > 0.9$). However, beetles were recaptured further from the release point in thinned stands than in unthinned stands (Figure 10). Furthermore, fat content of beetles recaptured in thinned stands was slightly higher than those recaptured in unthinned stands on the first day of each trial (Figure 11), and over the duration of each trial (Figure 12). These results suggest that thinning reduced dispersal costs relative to unthinned stands. Consequently, thinning may have a significant effect on the reproductive success of beetles because beetle will have more energy available for reproduction.

Beetle Reproduction

Reproductive success of pine engravers was examined as a function of tree vigour using freshly felled jack pine (*Pinus banksiana* Lamb.) from a 77 year old stand (Reid and Robb 1999). The number of eggs laid, egg gallery length, proportion of eggs that successfully developed, and number of emerged offspring per female were higher on trees that had been growing most vigorously before death.

MANAGEMENT APPLICATIONS

Commercial thinning had a significant effect on bark beetles. Although diversity did not change after thinning, the number of beetles in thinned stands was higher than in unthinned stands. Furthermore, beetles in thinned stands chose the biggest logs possible for breeding, and had higher reproductive success in the most vigorous hosts. Beetles could also fly on more days and do so more easily in thinned stands than in unthinned stands.

Both short- and long-term effects of thinning may be further reduced by controlling the amount of coarse woody debris. The amount of coarse woody debris affected the number of pine engravers captured in pheromone traps. It did not, however, affect the number of striped ambrosia beetle captured. This is not surprising given that striped ambrosia beetles are wood-borers, and are able to use older debris (Bright Jr. 1976). Perhaps the effects of thinning on striped ambrosia beetle activity will therefore be prolonged. Nonetheless, these two species attacked the largest coarse woody debris in the stand. Controlling the amount and size of coarse woody debris would further reduced the chance of large population sizes that could subsequently force a switch in attack strategies in beetles, going from coarse woody debris to live trees or into log decks.

Long-term effects of thinning on beetle activity may also be mitigated by reducing the number of trees removed during thinning. Tree density will remain relatively constant after thinning. Consequently, wind speeds will remain higher in thinned stands than in unthinned stands (Bartos and Amman 1989; Schmid et al. 1991, 1992b; this study). Since both pine engravers and striped ambrosia beetles were drawn to stands with relatively high wind speeds, their increased activity in thinned stands relative to unthinned stands is likely to persist. They may do well in thinned stands because it is much easier to find suitable hosts (Seybert and Gara 1970; Billings et al. 1976; Fares et al. 1980; Hynum and Berryman 1980), even though coarse woody debris input levels are the same as in unthinned stands. Furthermore, reduced flight costs in thinned stands relative to unthinned stands, as well as a larger window of flight opportunity due to higher temperatures, may result in greater reproductive success in thinned stands. This would, in turn, have an effect on overall beetle activity in a stand.

If thinning increases tree vigour (Mitchell et al. 1983), then coarse woody debris input also needs to be monitored long-term. Beetles make better use of coarse woody debris from vigorous trees, resulting in high reproductive success. Combined with easier flight and host finding in thinned stands, this could allow pine engraver activity to remain higher than in unthinned stands. It may be necessary to quickly remove fallen trees before they are attacked. This would be especially true after large fall-down events due to wind storms or heavy snow fall in which the amount of coarse woody debris is particularly high and therefore capable of attracting a large number of beetles to a stand.

CONCLUSIONS

Commercial thinning changes some attributes of the forest environment that increased the abundance, but not the diversity, of bark beetles. Increased coarse woody debris and wind speeds make thinned stands more desirable to beetles than unthinned stands. The greater abundance of beetles in thinned stands may also be due to enhanced dispersal ability in terms of the amount of time available for flight and reduced dispersal costs. Increased reproductive success of beetles in vigorous hosts may also be important given that the trees remaining after thinning are expected to become more vigorous. The increased population sizes of beetles due to thinning may be reduced by minimizing the amount and size of coarse woody debris remaining after thinning, monitoring coarse woody debris input after thinning, and removing fewer trees.

ACKNOWLEDGMENTS

This project was funded by a Network of Centres of Excellence - Sustainable Forest Management grant to MLR and an Industrial Research Assistance Program grant to TDH, MLR, and Richard Krygier (Millar Western Industries Ltd., Whitecourt, Alberta). Special thanks to Richard Krygier and the staff at Millar Western Industries Ltd. for their help on this project. We appreciate Brett Purdy's assistance with the IRAP application. Ed Johnson (University of Calgary) provided additional equipment. We also appreciate the hard work and dedication of James Burns, Sandra Lucas, Michael Murray, and Campbell Pearce who helped in the field.

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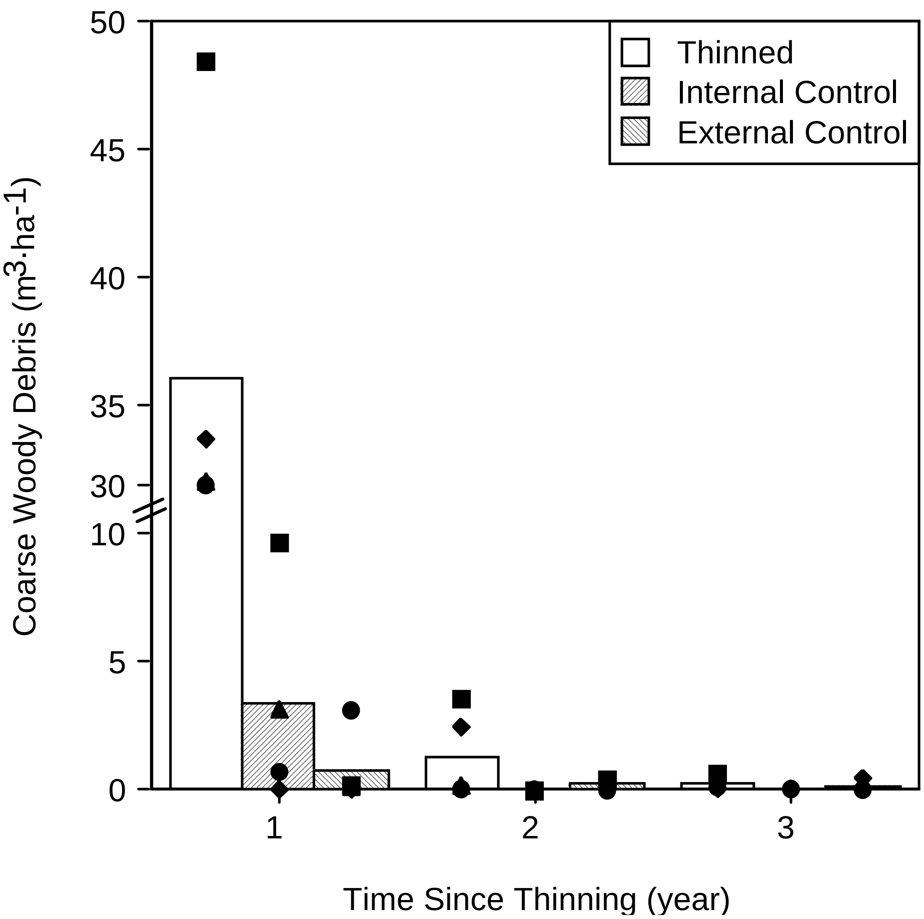

Figure 1. There was a large input of coarse woody debris associated with commercial thinning (Kruskal-Wallis test, $p < 0.05$). Input returned to normal in the second and third years after thinning (Kruskal-Wallis tests, $p > 0.05$). Bars indicate means for all sites. Symbols indicate means for individual sites. Note break in scale on y-axis.

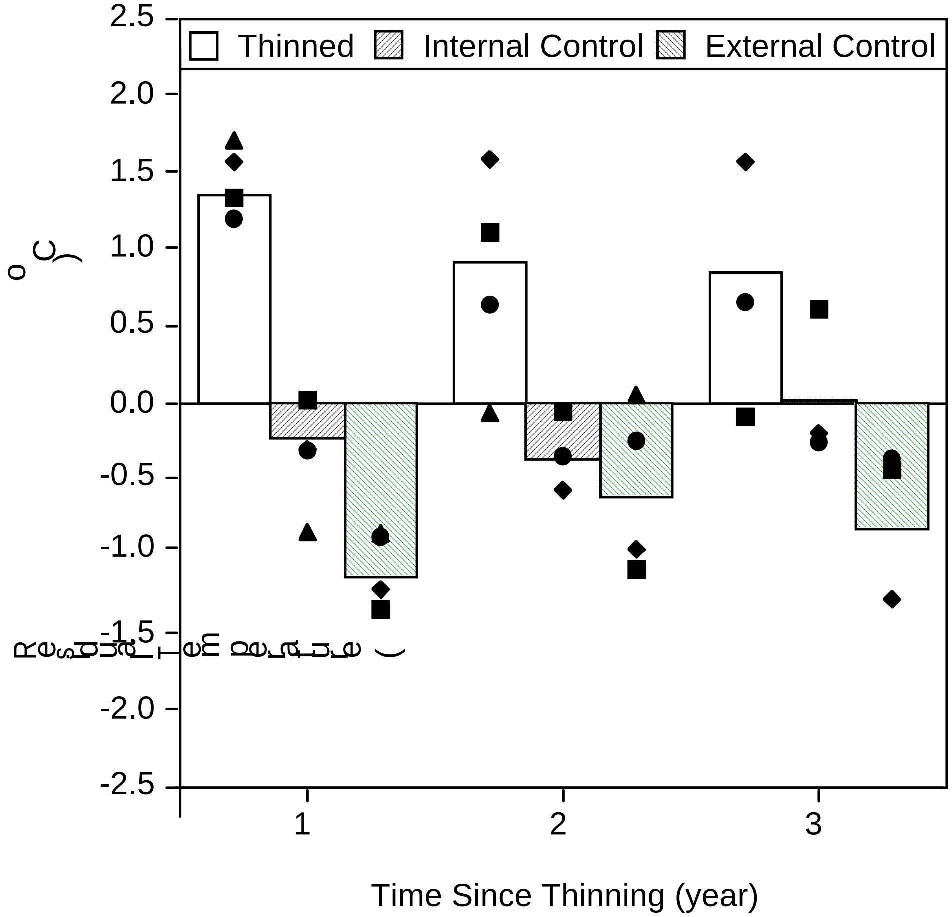

Figure 2. Thinned stands were significantly warmer than unthinned stands (Kruskal-Wallis test, $p < 0.05$) once corrected for seasonal variation (residuals). Bars indicate means for all sites. Symbols indicate means for individual sites.

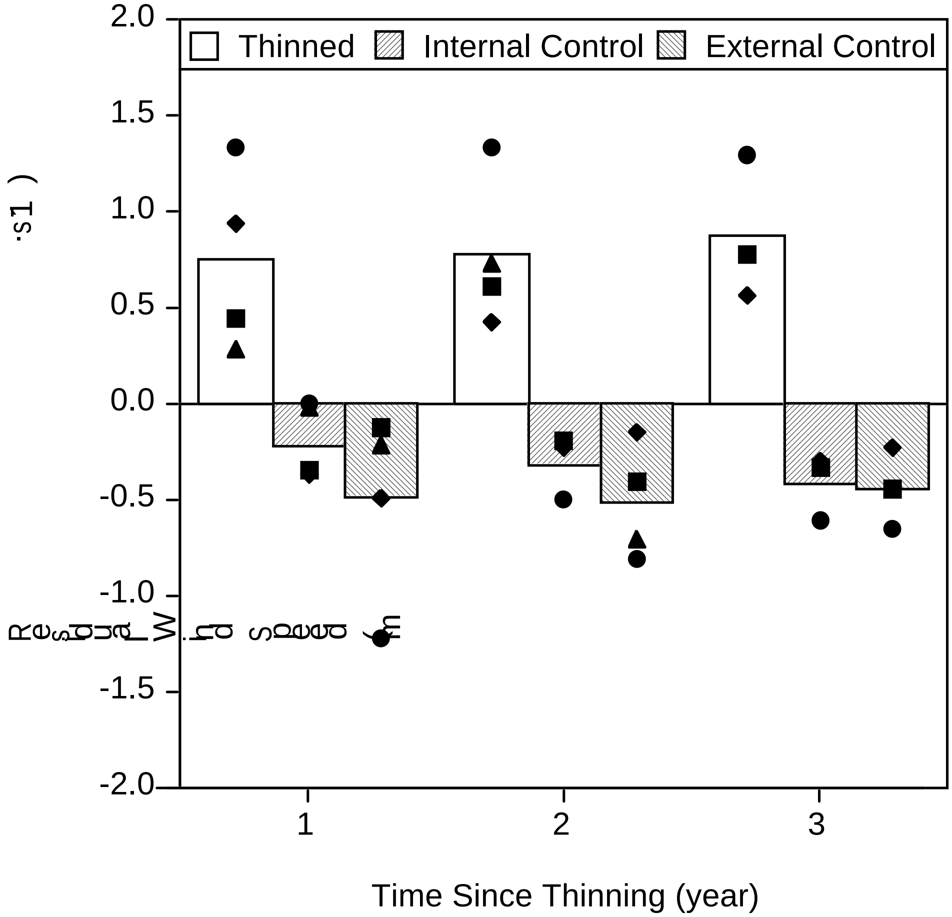

Figure 3. Thinned stands were significantly windier than unthinned stands (Kruskal-Wallis test, $p < 0.05$) once corrected for daily variation (residuals). Bars indicate means for all sites. Symbols indicate means for individual sites.

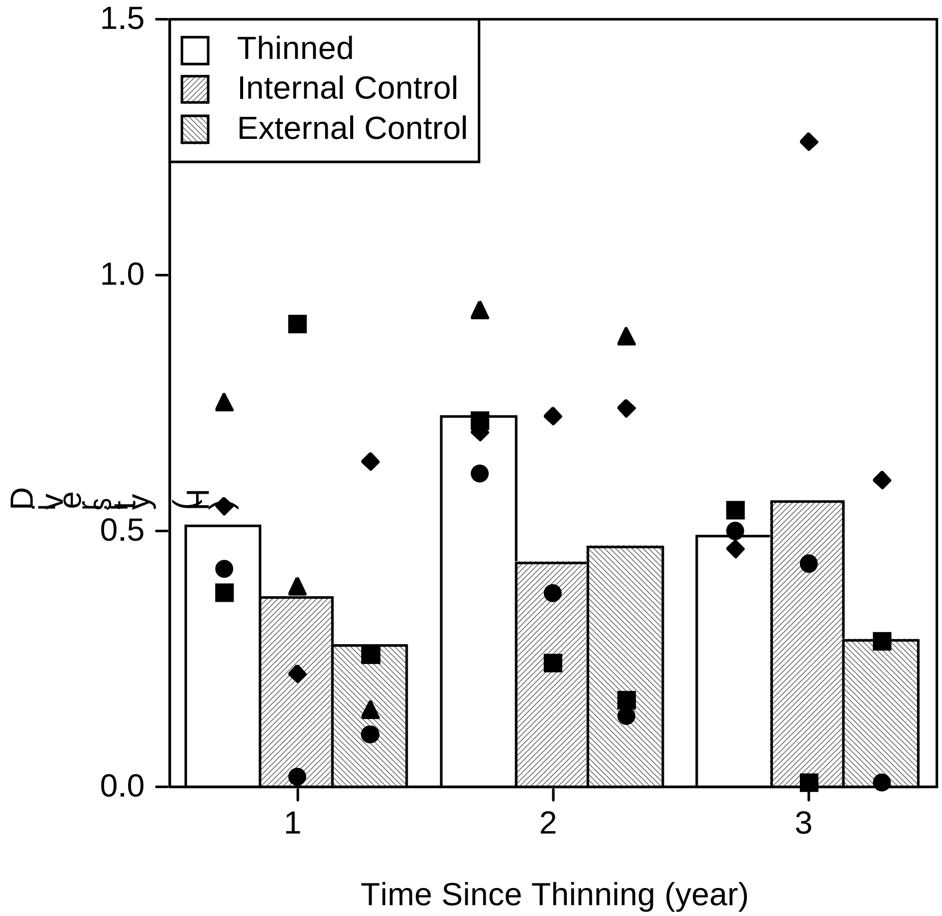

Figure 4. Diversity of beetles captured in pheromone traps did not differ in thinned and unthinned stands (ANOVA, $F_{2,24} = 2.25$, $p > 0.1$) or change over time (ANOVA, $F_{2,24} = 1.39$, $p > 0.2$). Bars indicate means for all sites. Symbols indicate means for individual sites.

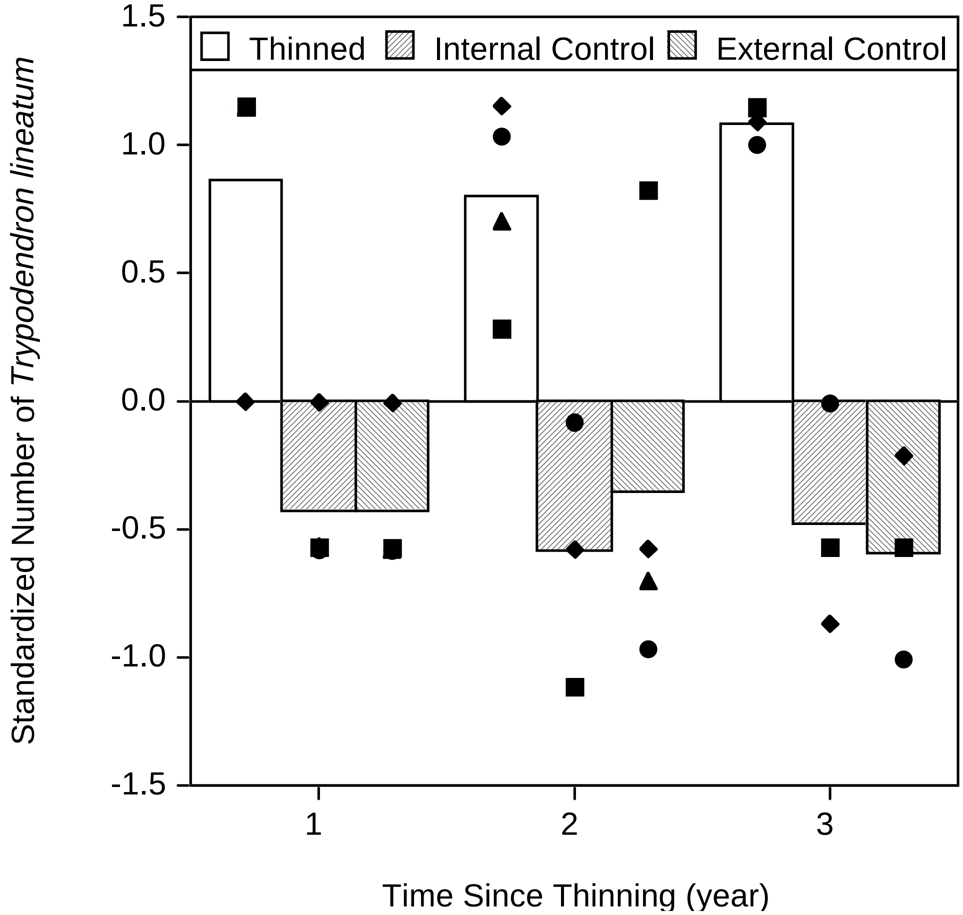

Figure 5. Striped ambrosia beetles were more abundant in thinned stands than in unthinned stands (ANOVA, $F_{2,24} = 30.46$, $p < 0.0001$). This difference persisted over time (ANOVA, $F_{2,24} = 0.036$, $p > 0.9$). Bars indicate means for all sites. Symbols indicate means for individual sites.

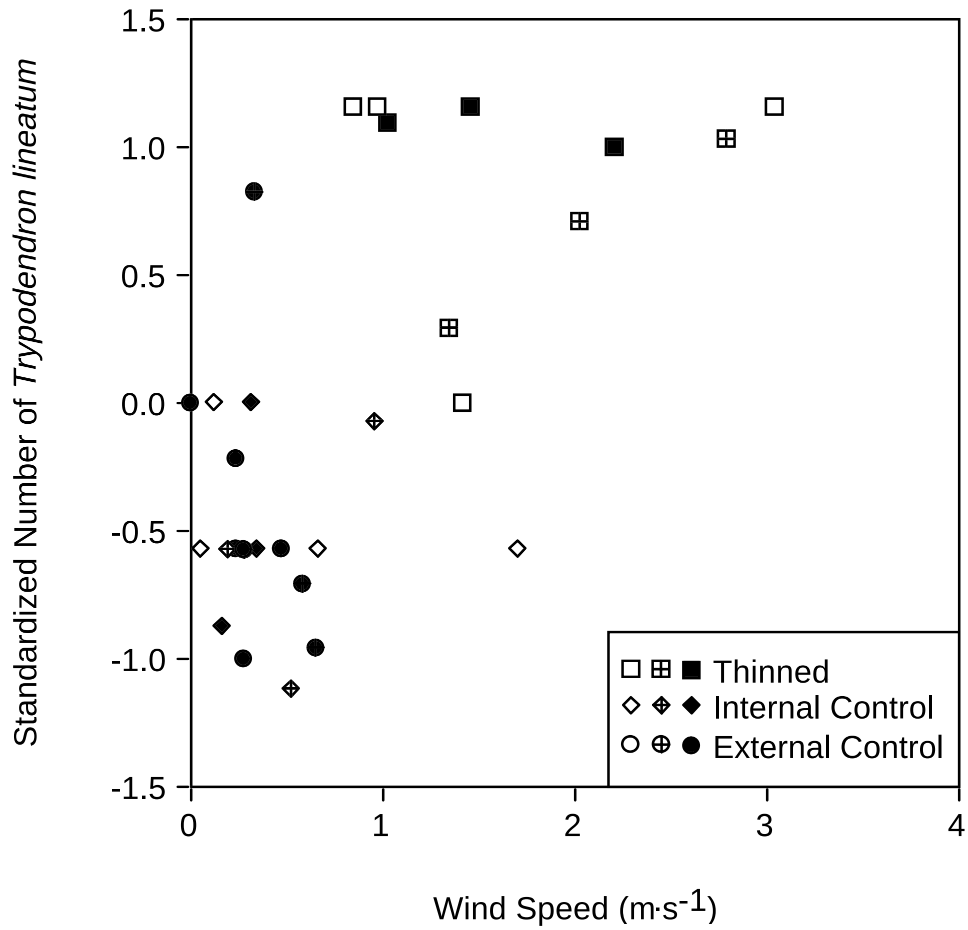

Figure 6. Abundance of striped ambrosia beetles was related to wind speed (ANOVA, $F_{1,26} = 4.30$, $p < 0.05$). Open symbols indicate first year after thinning, crossed symbols the second year, and filled symbols the third year.

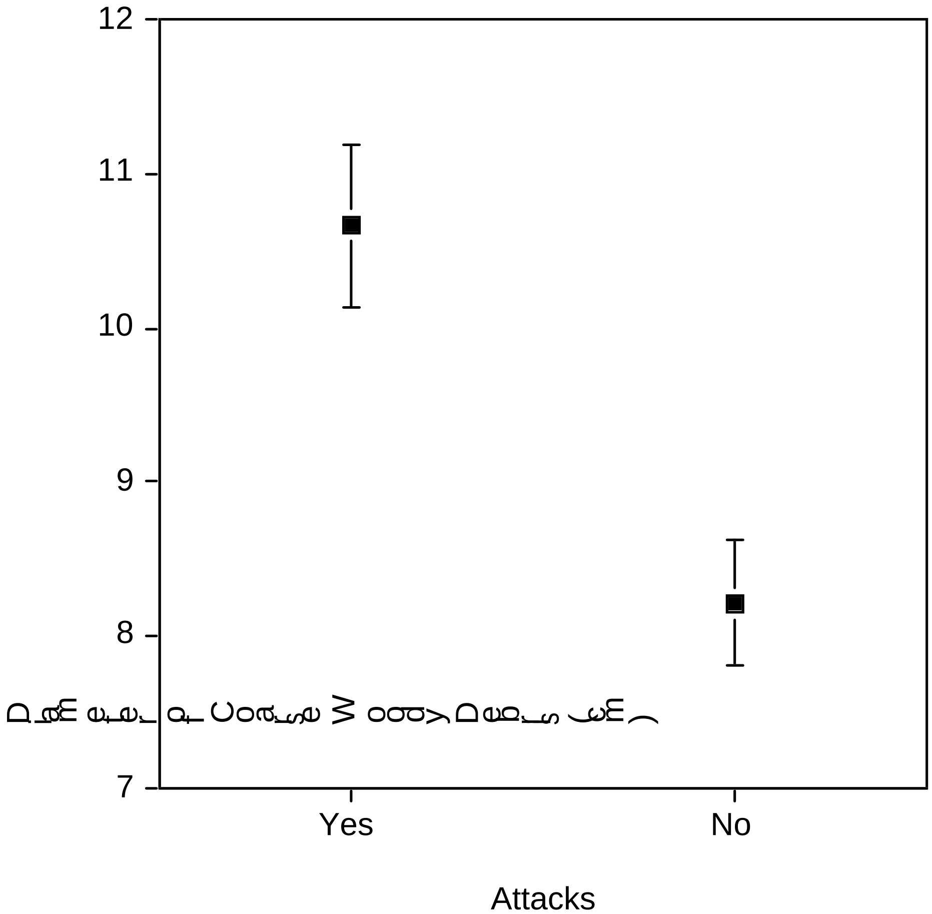

Figure 7. Attacked logs of a given species were larger than those available at a site (ANOVA, $F_{1,554} = 31.68$, $p < 0.0001$). Means are shown $\pm$ SE.

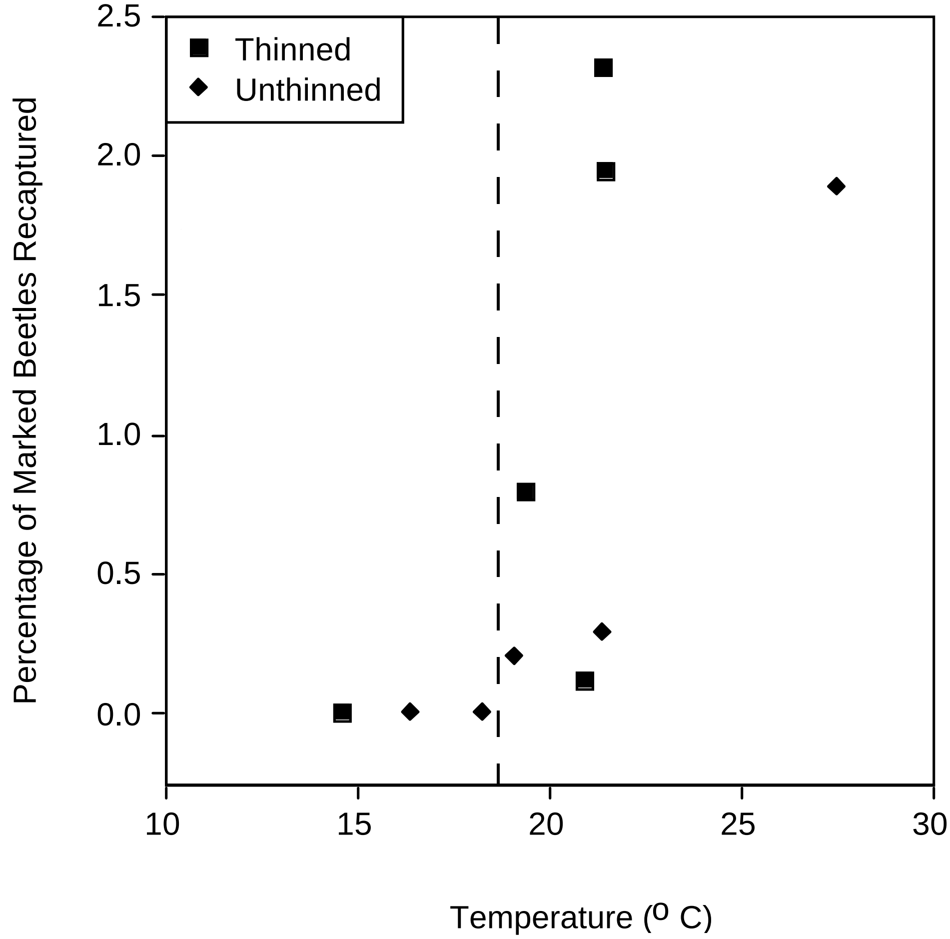

Figure 8. Relationship between percent of released beetles that were recaptured on the first day of each trial and temperature. Vertical dashed line suggests a 19^{o} C temperature threshold for flight activity.

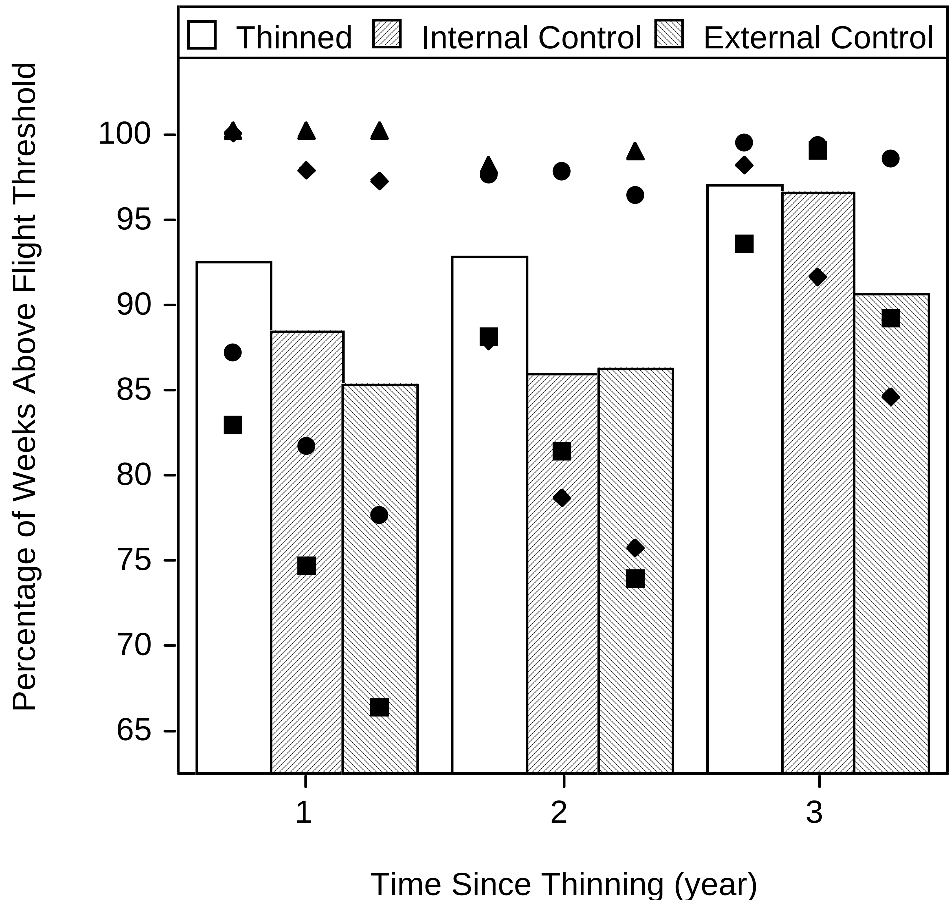

Figure 9. Comparison of the percentage of weeks above the flight threshold of 19^{o} C at each site. The percentage of weeks above the flight threshold was generally higher in thinned stands than in unthinned stands.

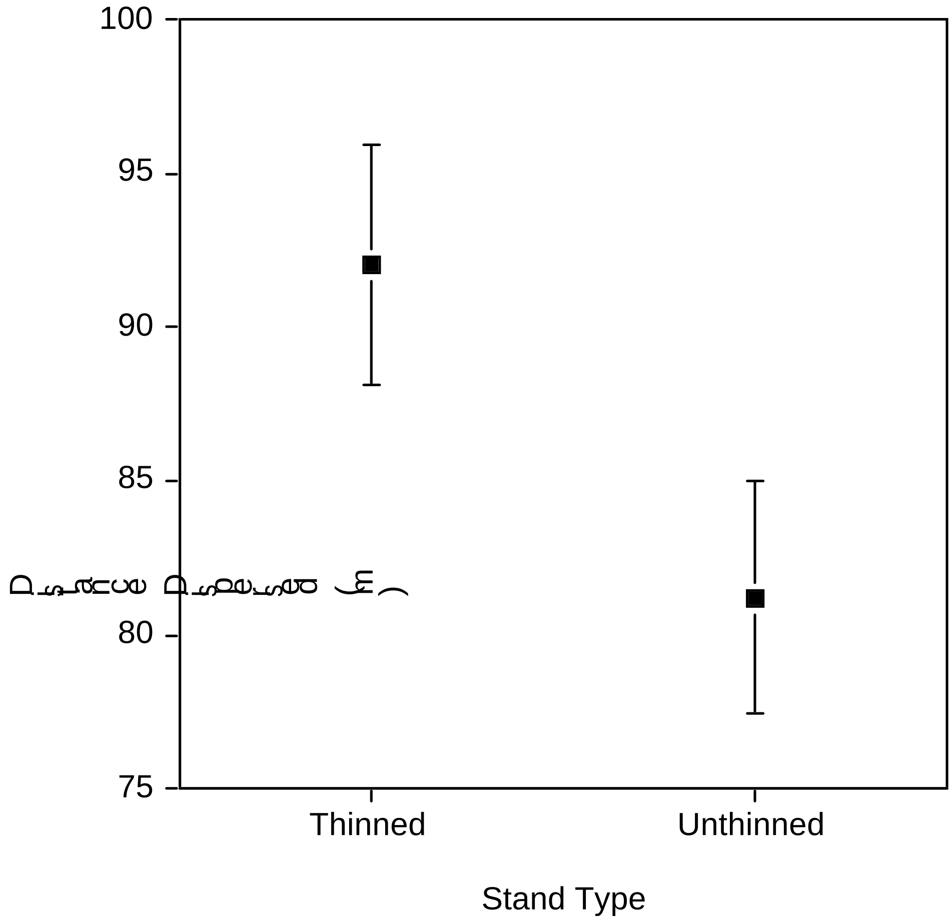

Figure 10. Marked beetles were recaptured further from the release point in thinned stands than in unthinned stands ($\chi^2_{0.05\ [12]} = 11.14$, $p < 0.05$). Means are shown ± SE.

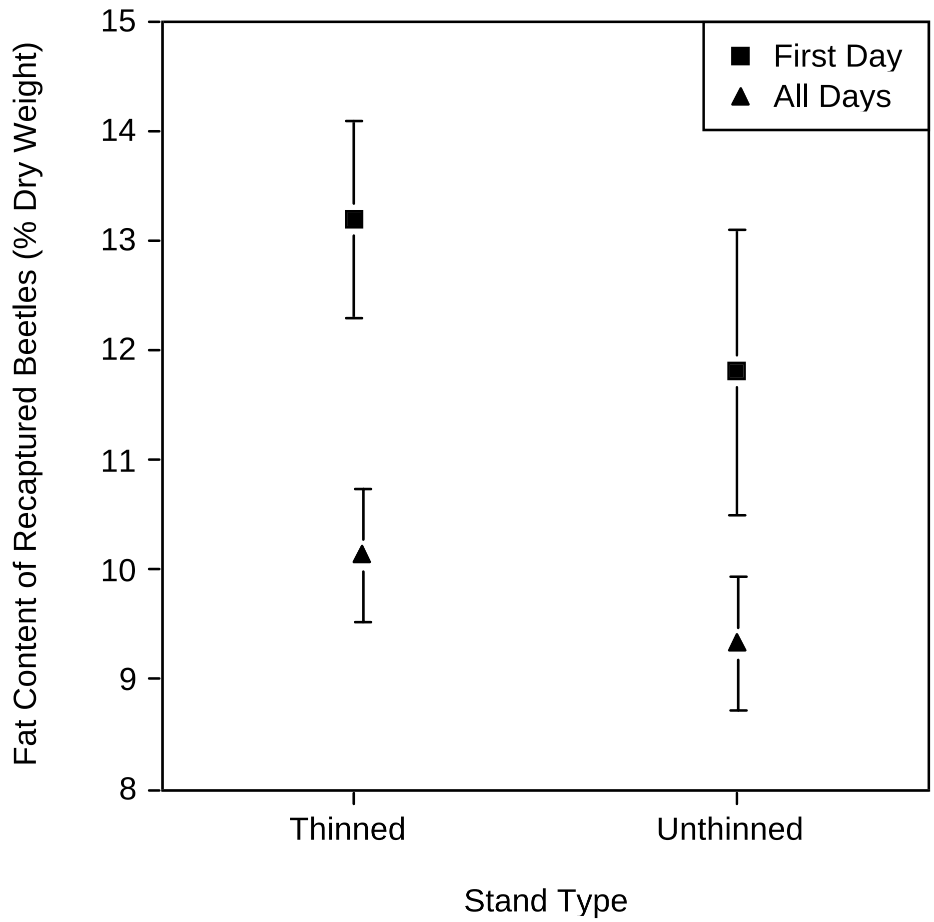

Figure 11. Beetles recaptured in thinned stands were fatter than those recaptured in unthinned stands on the first day of each trial, and over the duration of each trial. This relationship depended on distance dispersed, as indicated by the significant interaction between stand type and distance dispersed (ANOVA, $F_{1,86} = 6.81$, $p < 0.05$, and ANOVA, $F_{1,268} = 5.07$, $p < 0.05$ for the first day of each trial and the duration of each trial, respectively). Means $\pm$ SE are shown.