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# Integrated Control

# of

# Scolytid Bark Beetles


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# MICROCLIMATE AS A FACTOR IN LODGEPOLE PINE (PINUS CONTORTA DOUGLAS) STANDS AND TREE SELECTION BY MOUNTAIN PINE BEETLES (DENDROCTONUS PONDEROSAE HOPKINS)

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## Abstract

Thinning lodgepole pine (Pinus contorta Douglas var. latifolia Engelm.) stands results in subtle changes in microclimate. It is believed these changes are a major factor in stand and tree selection by mountain pine beetles (Dendroctonus ponderosae Hopkins) during epidemic conditions. Bark and phloem temperatures were measured during the summers of 1986 and 1987 in both thinned and unthinned stands of lodgepole pine. In addition, wind speed, wind direction, and incident solar radiation were measured in 1986. Similar trends and consistent differences were found to exist between the two stands.

Thinned stands were usually warmer than the unthinned stands, with the largest difference occurring during the hottest part of the day. As expected, temperature was closely correlated with incident solar radiation. Wind speed was higher in the thinned stands, with a consistent 1 to 3.5 kph difference.

Thinning of lodgepole pine stands changes the microclimate sufficiently to make the stands less acceptable to mountain pine beetle. Fewer beetles (5% of total) were trapped in a thinned stand compared to an unthinned stand (95% of total).

## Introduction

Temperature is an important factor in the ecology of insects. It affects the physical conditions of habitats and the insects themselves (Wellington 1950). In the case of the mountain pine beetle (MPB), Dendroctonus ponderosae Hopkins (Coleoptera: Scolytidae), observations have been made on the effects of extremely high (Patterson 1930) and low temperatures (Yuill 1941; and Somme 1964). Between these extremes is an optimum zone of temperature that may be modified by other microclimatic factors (Rudinsky 1962).

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Thinning forests causes subtle changes not only in incident radiation, temperature, and light (Reifsnyder and Lull 1965) but also in wind speed. These climatic changes brought about by thinning lodgepole pine, *Pinus contorta* Douglas var. *latifolia* Engelmann, forests may have profound effects on MPB activity. Reduced tree mortality in thinned stands during MPB epidemics is thought due to increased vigor of trees caused by reduced competition, but sudden changes in stand microclimate could be more important.

The silvicultural practice of thinning has been used in the past as a way of increasing tree vigor (Graham and Knight 1965; and Keen 1958), which in turn should make the residual trees better able to resist attacks by MPB. The removal of the large-diameter lodgepole pine, which are preferred by MPB, can also result in reductions in tree loss during epidemics (McGregor et al. 1987). Amman et al. (in press) discuss the relationship of tree vigor and MPB infestation in partially cut lodgepole pine stands. They observed that, following partial cutting of lodgepole pine stands but before residual trees could express resistance through increases in growth and vigor, fewer trees were lost to MPB than in uncut stands. This phenomenon suggests that factors other than vigor are responsible for reduced MPB infestations. I propose that the controlling factor is the resultant microclimate of the altered stand.

This paper presents microclimate differences (primarily temperature) that were observed between thinned and unthinned lodgepole pine stands for the summers of 1986 and 1987. Also, I discuss beetle behavior in response to these differences.

## Methods and Materials

The study site is south of Mountain View, Wyoming, on the North Slope of the Uinta Mountains in northeastern Utah, at an elevation of 2,865 m. A thinned and an adjacent unthinned stand of lodgepole pine were selected for study.

### Monitoring microclimate

An automatic recording device (21X micrologger, Campbell Scientific[2]) was used to measure microclimatic parameters (figure 1). During the summer of 1986, temperature, incident solar radiation, wind speed, and wind direction were monitored for 21 days starting July 19 (Bartos and Amman in press). This period encompassed peak MPB flight, which occurred August 3, 1986 (Julian day 215). Because of the numerous parameters being measured, we were able to monitor only two

[2]The use of trade or firm names in this paper is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

FIG. 1. Tower and surrounding instrumentation of 21X as it appeared in the field during the summers of 1986 and 1987.

trees--one in a thinned and one in an unthinned stand. The trees were similar in height, crown length, and diameter at breast height (dbh) (about 23 cm). All parameters were measured every 15 minutes, and hour average were calculated.

Thermocouple psychrometers were connected to the micrologger to measure temperature at the following points on or near the sample trees for 1986:

1. At breast height (BH), 1.4 m, on the bark surface, and immediately below the surface for both the north and south sides of the trees. The below-bark surface probe was positioned to measure temperature of the tree phloem. Phloem is the substrata in which MPB adults mine and lay eggs; it also serves as the food source of developing larvae.

2. In the lower third of the crown on the bark surface, both on the north and south sides of the trees.

3. On the tower (about 3 m tall) where the micrologger was situated. This sample area was to represent air temperature of the interspace of the stand.

During the summer of 1987, a total of 21 days were sampled beginning on July 17. This period encompassed the traditional peak flight in this area for MPB, which usually occurs the first part of August. The peak period was not well defined for 1987 either because of low populations of beetles or poor weather conditions.

Sampling procedure was modified in 1987 so that samples could be replicated in the thinned and unthinned stands. Eight trees were selected in each treatment area. These trees were uniform in size and were within a 15-m radius of the recording device.

All samples were taken at BH (about 1.4 m) on the south side of the tree at two points: (1) on the bark surface and (2) immediately below the surface, to reflect the phloem temperature.

## Beetle Response

Beetle response to thinned and unthinned stands was determined during the summer of 1985 by using pheromone-baited traps in the same general vicinity as the microclimate study. Three Lindgren funnel traps were hung in a thinned stand and three in an adjacent unthinned stand. Traps were 100 m apart within stands and 300 m apart between stands. Those stands were approximately 1 km north of the stands where microclimatic observations were made in both 1986 and 1987. There were no beetle-infested trees in the two stands at the time of trapping. The traps were baited with the standard MPB lure (Phero Tech Inc.) consisting of <u>trans</u>-verbenol, <u>exo</u>-brevicomin, and myrcene. Beetles were collected from the traps weekly during a 3-week period, August 15 to September 5. Beetles were taken to a laboratory where they were sexed and counted.

## Data Analysis

In 1986, statistical analysis of data from the micrologger was not possible because we had enough equipment to monitor microclimate of only one tree in each of the two stands. However, in 1987 I was able to determine variability of two parameters by having eight replications in each of the two treatments. I used a time-series-analysis system software package for microcomputers to manipulate various combinations of parameters for both years' data. This technique allows me to show trends that exist between the thinned and unthinned stands as well as within the sampled tree for 1986 and among sampled trees for 1987. For 1987, a mean value of the eight trees was used to observe trends. This procedure should reduce any variation due to tree effects and give a better understanding of treatment effects.

The raw data were smoothed and then plotted to reduce some of the inherent variation. This smoothing was accomplished by calculating a moving average of the raw data. These smoothed curves were better able to show consistent trends between similar parameters in 1986 and among sampled trees in 1987. Because the version of the program used would accept only 550 data points, hour averages were used to look at the overall trends for the total time period each year. More variation was deleted from the curves when a larger time span (49-hour versus 5-hour) was used to obtain the smoothed average. A 24-hour period was smoothed and plotted to show trends for a single day; Julian days 215 (1986) and 208 (1987) were selected.

## Results

### Tree and Stand Characteristics

A synopsis of stand characteristics as reported by Bartos and Amman (in press) is useful to define the study area. The thinned stand had an average basal area of 22.1 $m^2$/ha, a density of 707.8 trees/ha, and an average diameter of 20.2 cm. Dominant and codominant trees averaged 15.1 m in height, with live crown 52% of total height. In contrast, the unthinned stand had a basal area of 37.0 $m^2$/ha, a density of 1,090.1 trees/ha, and an average diameter of 18.6 cm. Dominant and codominant trees averaged 15.1 m in height, with live crown 53% of total height. Of all the stand characteristics measured by Bartos and Amman (in press), only the stand density measures of basal area and trees per hectare were significantly different between stands ($P < 0.05$).

In 1987, eight trees were sampled in each of the two treatments. The mean dbh for the trees in the thinned stand was 23.9 cm, with a range from 20.6 to 26.9 cm. The unthinned stand was smaller, with a mean dbh of 20.4 cm with a range from 16.3 to 25.4 cm.

### Stand Microclimate: 1986

Temperature (23 days).--Curves for a 23-day period obtained via smoothing raw data appeared similar between the south and north sides of the sampled tree at BH in the thinned stand. The average temperature varied between $9^{o}$ C at the beginning of the 23 days to a high of approximately $18^{o}$ C, which occurred around August 5. Both sets of curves show close correlation between the surface and phloem temperatures. However, a slight separation ($<0.5^{o}$ C) was noticed for the south side of the tree.

Similar traces were observed between the thinned and unthinned stand. Subsurface temperatures reflect what occurs on the bark surface, but with slightly less magnitude. The phloem curve for the south side in the thinned stand was consistently $1^{o}$ to $2^{o}$ C higher than the phloem curve for the unthinned stand (figure 2a), while the surface temperature on the south side in the thinned stand (figure 2b) responded with a $1^{o}$ to $3^{o}$ C greater difference than in the unthinned stand.

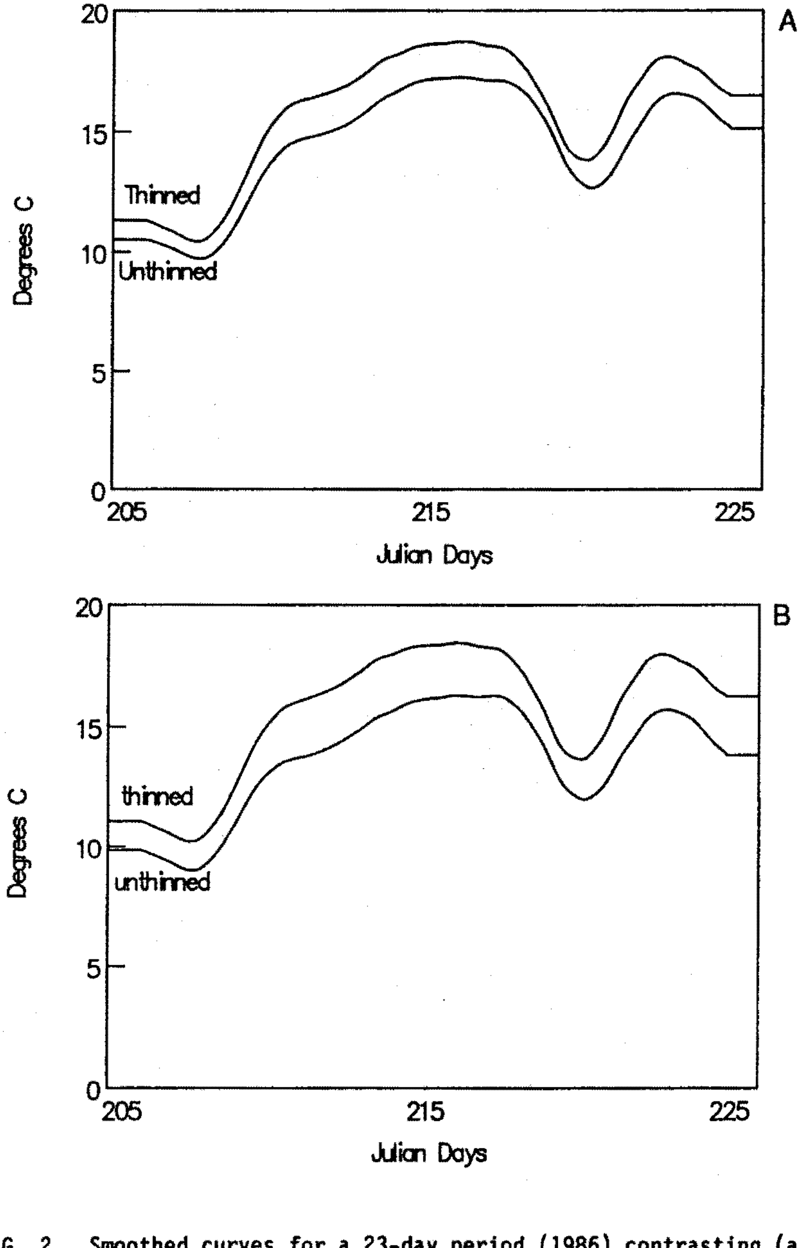


FIG. 2. Smoothed curves for a 23-day period (1986) contrasting (a) phloem and (b) bark surface temperatures at breast height on the south side of two lodgepole pine trees between a thinned and an unthinned stand.

Less difference was observed between the thinned and unthinned stands when comparisons were made on the north side of the sampled trees. Traces of the curves for the north side were similar to those seen on the south side. However, as expected, the south side was consistently 3° to 4° higher. On the north side, curves for the phloem temperature mimicked the surface temperature, and a difference of less than 0.5° C between the thinned and unthinned stand was observed.

Temperature (5 days).--Smoothing over a 5-day period was done to express more detail for any one 24-hour period. Initially, we looked at pairs of curves showing within-tree differences at BH in both treatments. Similar responses were observed, and figure 3 represents the various combinations. Over a 24-hour period, there is a reversal in dominance of the two temperature curves. From early afternoon through late evening, surface temperature is warmer than phloem temperature. However, for the rest of the period it is just the opposite. These trends are consistent from day to day over the 5 days. At the point of maximum separation, there is <0.5° C difference. More separation was observed in the averaged temperature curves (figure 4) when comparisons were made between the same sample points for the two treatments. (This information is an elaboration of the previous figure 2b.) The thinned stand always had the higher temperature. The difference ranged from 2 to 3.5° C, with the biggest difference occurring during the hottest part of the day.

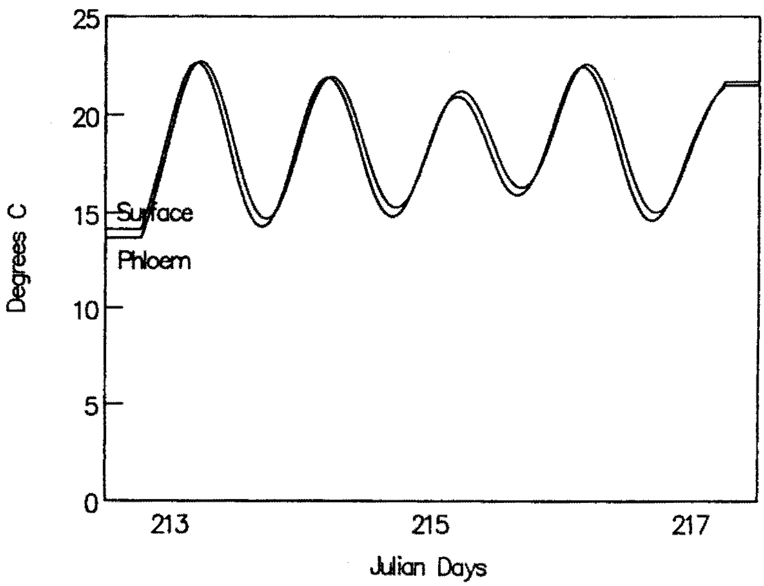


FIG. 3. Smoothed curves for a 5-day period (1986) contrasting pholem and bark surface temperatures on the south side of a lodgepole pine tree in a thinned stand.

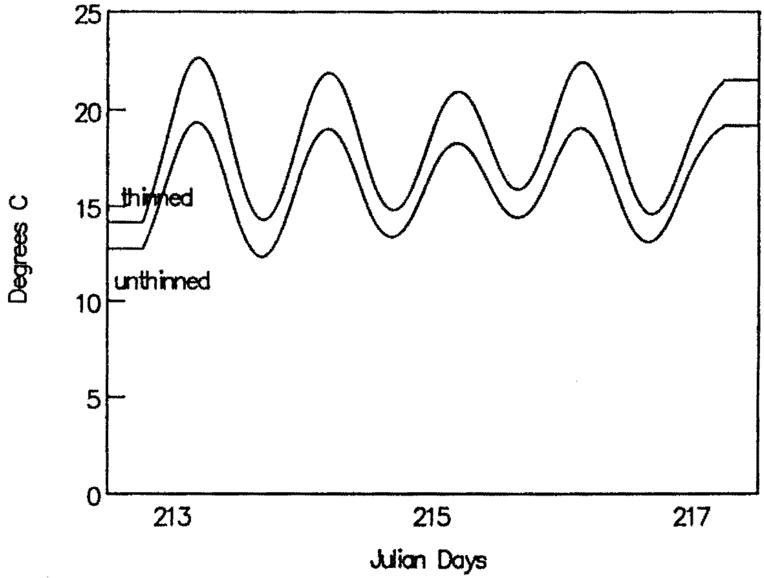


FIG. 4. Smoothed curves for a 5-day period (1986) contrasting bark surface temperatures on the south side of two lodgepole pine trees between a thinned an unthinned stand.

Temperature (1 day).--More dramatic details are shown when smoothing is done over a 24-hour period. Three typical curves (figure 5) are shown for temperatures recorded on the north side of the sample trees at BH. First, we see a reversal in dominance between surface and phloem temperatures in both the thinned stand (figure 5a) and the unthinned stand (figure 5b); magnitude varies between 0 and 7° C. After sunrise, there is a reversal, and curves for surface temperature are higher than those for the phloem temperature. The surface-heat buildup accelerates and dominates until sundown when the phloem temperature becomes higher.

Taking this comparison one step further, we contrasted the phloem temperature curves for the thinned and unthinned stands (figure 5c). The thinned stand had considerably more heat building up in the phloem than the unthinned stand. During late afternoon, there was a peak difference of 8° C, while during the remainder of the day the two smoothed curves are quite similar.

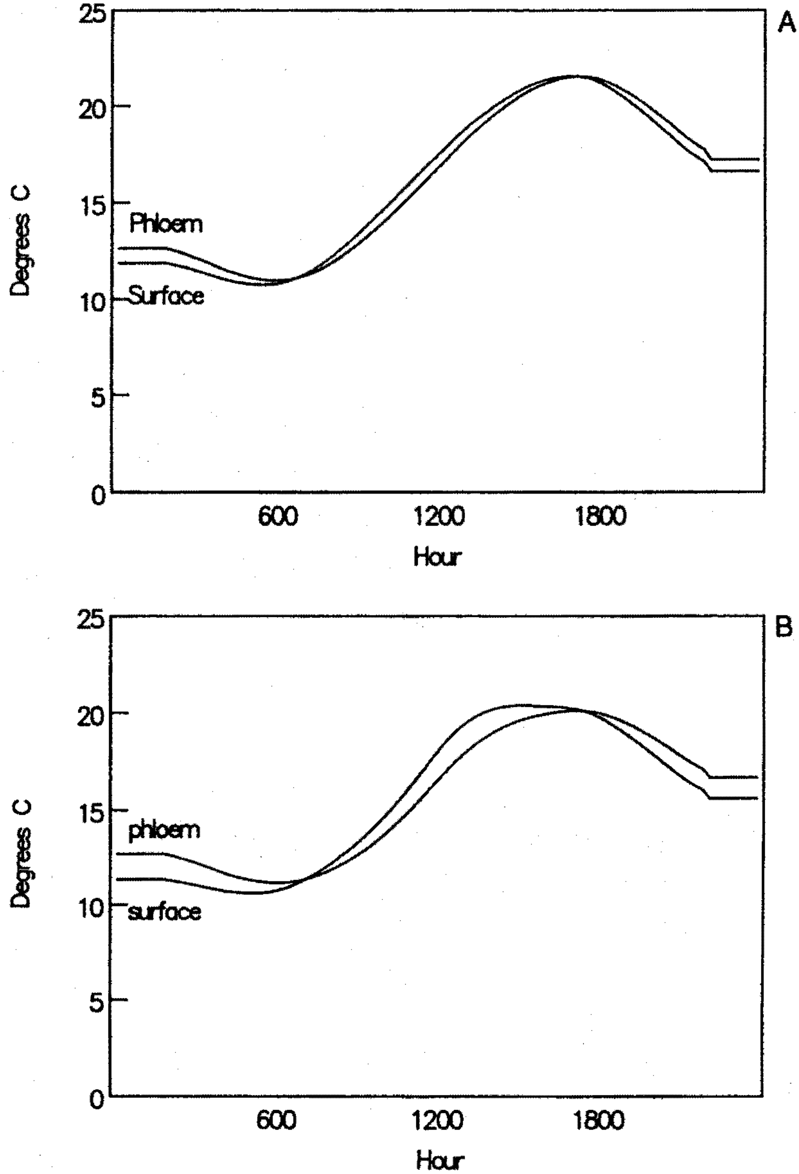


FIG. 5. Smoothed curves for a 24-hour period (August 3, 1986). Temperatures at breast height on the north side of the tree are contrasted between (a) bark surface and phloem-thinned, (b) bark surface and phleom-unthinned, and (c) thinned and unthinned phloem.

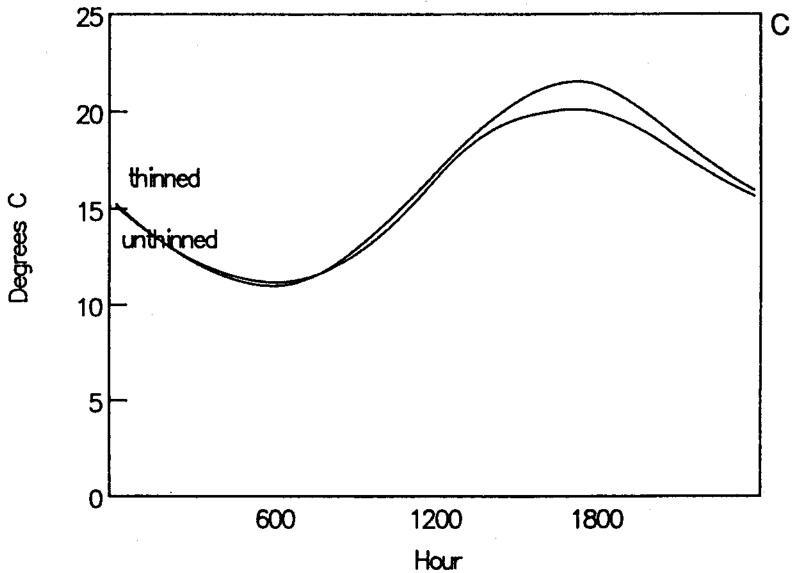


FIG. 5. Continued.

Stand Microclimate: 1987

Similar responses were seen in temperature patterns in 1987 as were reported in 1986. This observation would indicate that differences do exist between thinned and unthinned stands with respect to microclimate.

Temperature (21 days).--Similar traces were observed between the thinned and unthinned stands. However, phloem temperatures reflect what occurs on the bark surface, with only a slight difference in magnitude. The curve for phloem temperature for the south side in the thinned stand varied between $0.5^{\circ}$ to $1^{\circ}$ C higher than the curve for phloem temperature for the unthinned stand (figure 6a). The surface temperature on the south side produced curves that were similar in shape for both the thinned and unthinned stands (figure 6b). However, for most of the time the thinned stand was consistently warmer.

Temperature (5 days).--This 5-day period was chosen to show more detail for any one 24-hour period. Similar responses were observed when pairs of curves showing within-tree differences were plotted. There is a reversal in dominance of the two temperature curves, as was reported above for 1986.

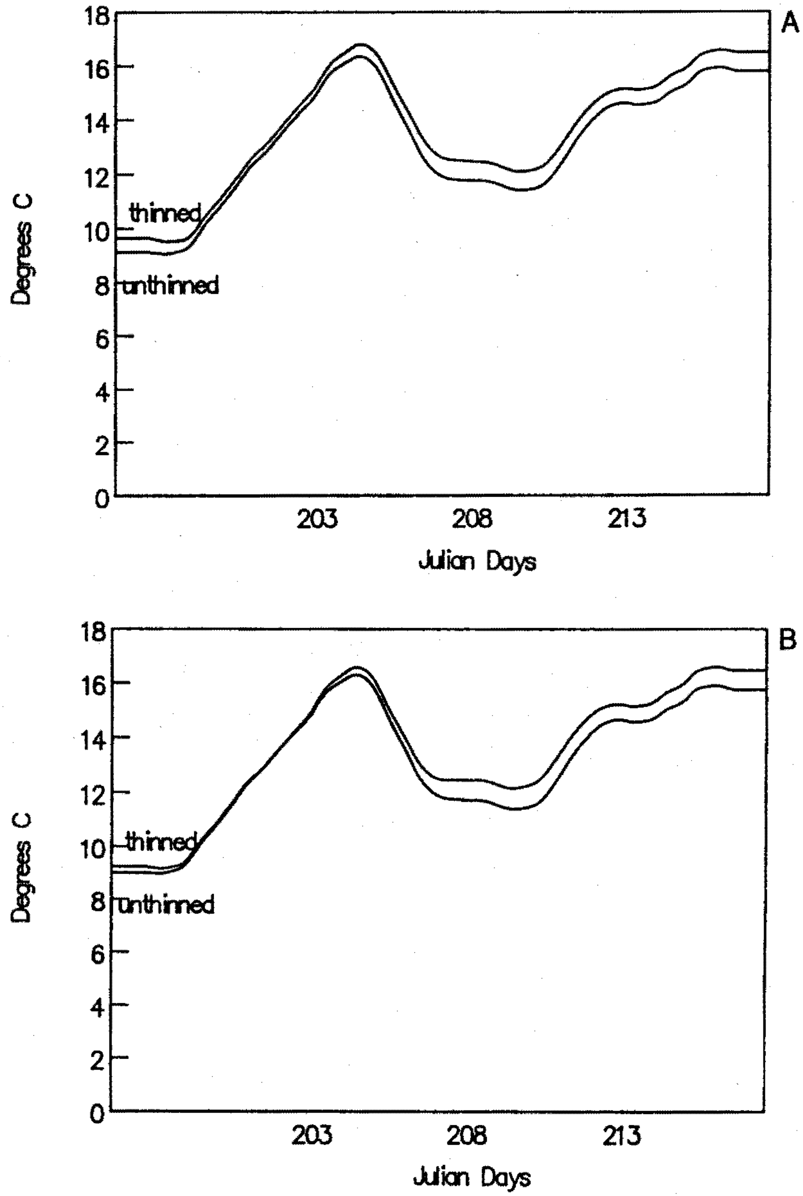


FIG. 6. Smoothed curves for a 21-day period (1987) contrasting (a) phloem temperature and (b) surface temperature between a thinned and unthinned lodgepole pine stand.

There is more separation in the averaged phloem temperature curves (figure 7) when comparisons are made between the two treatments. The thinned stand always had the higher temperature. The difference was always <1° C. Similar trends were observed for the surface temperatures between the thinned and unthinned stands, and the differences were approximately the same.

Temperature (1 day).--Additional details are shown when smoothing is done over a 24-hour period. The 1986 data show a reversal in dominance between surface and phloem temperatures in both the thinned and unthinned stands. Shortly after sunrise, there is a reversal in the temperature curves, with the surface temperature again being higher than the phloem temperature. The surface-heat buildup accelerates, and by midafternoon the surface temperature is dominant until nightfall when phloem temperature once again dominates until the following morning.

The phloem temperature curves contrast the thinned and unthinned stands (figure 8). During late afternoon, there was a peak difference of 2° C, while during the rest of the period the two were similar. For each treatment in 1987, the surface and subsurface temperatures were virtually the same.

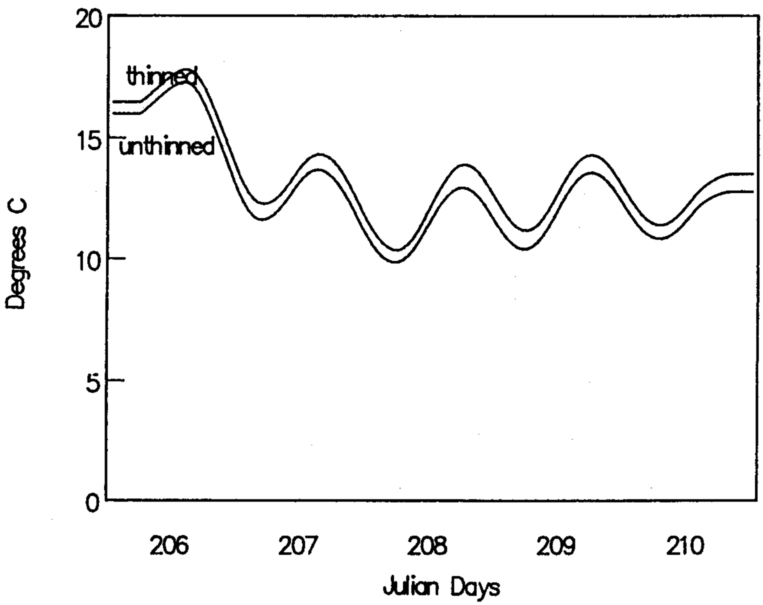


FIG. 7. Smoothed curves for a 5-day period (1987) contrasting phloem temperature at breast height between a thinned and unthinned lodgepole pine stand.

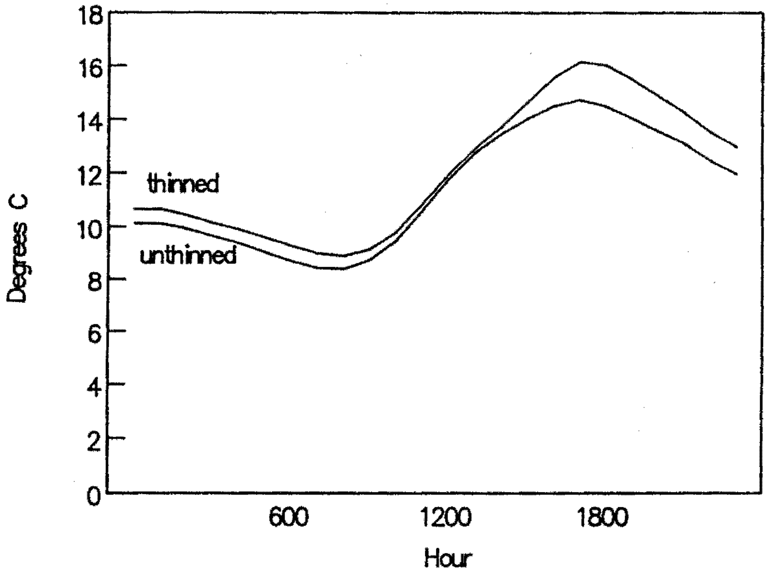


FIG. 8. Smoothed curves for a 1-day period (July 27, 1987) contrasting phloem temperature at breast height between a thinned and unthinned lodgepole pine stand.

Beetle response.--The number of MPB caught in pheromone-baited traps in a thinned stand was only about 5% of those caught in an unthinned stand 1 km from stands where microclimate measures were made. The average numbers of beetles caught per trap were: thinned $\bar{x}$ = 8.7; unthinned $\bar{x}$ = 159.3. Most trapped beetles were females, with a higher percentage being caught in thinned than unthinned stands (thinned = 88.5% female; unthinned = 81.2% female) (Bartos and Amman in press). Stands in which microclimate measures were made (in both 1986 and 1987) had 14.2 trees/ha (2.0%) killed by MPB in the thinned stands compared to 174.1 trees/ha (16.0%) killed in the unthinned stand.

## Discussion

### Stand Characteristics

The main differences between the thinned and unthinned stands were the two measures of density (Bartos and Amman in press). There were less basal area (14.9 $m^2$/ha) and fewer trees (382.3/ha) in the thinned stand when compared to the unthinned one. The average diameters of trees were the same in the two stands. Tree density is probably the biggest contributor to microclimate differences observed in this study.

Microclimate observations showed consistent differences between the thinned and unthinned stands for both 1986 and 1987. The more detailed sampling done in 1987 verified what was observed in 1986 and gave more credibility to those data. Thinning of lodgepole pine stands results in increased light intensity, wind movement, insolation, and temperature (Bartos and Amman in press). These parameters, either separately or in various combinations, appear to affect MPB activity. The differences observed between thinned and unthinned stands are sometimes quite subtle. However, even minor changes in microclimate could have profound effects on MPB.

The higher temperatures on the south sides of trees in thinned stands could be a deterrent to MPB landing and boring into the bark. Bartos and Amman (in press) reported that in 1986 the south side temperatures between 10 a.m. and 2 p.m. averaged 2.3° C higher than those on the north sides, with the maximum temperature being 12° C higher in the thinned than the unthinned stand. Similar responses were observed in 1987, but there was only a 2° C difference between the two treatments. The overall temperature for 1987 was cooler than for 1986. Powell (1967) reported subcortical temperatures were occasionally 35° C or higher on south sides of trees. Safranyik and Jahren (1970) observed that beetles emerged at a greater rate from south than north sides of trees. In contrast, the cooler temperatures on the north sides of trees apparently offer more favorable physical environment for attacking MPB. The beetles' attack densities are higher on north sides (Reid 1963; and Shepherd 1965), and when trees are strip attacked, the attacks usually occur on north and east sides (Mitchell et al. 1983).

The effect of temperature could be more than a direct inhospitable physical environment. Mountain pine beetle may have evolved behavior to avoid situations where beetle brood are not likely to survive. In thinned stands, where tree temperatures are a few degrees above those of trees in unthinned stand, MPB may proceed too far in their development before winter, thus entering winter in stages that are susceptible to freezing--for example, the pupal stage as observed by Reid (1963) and Amman (1973). Powell (1967) found the average daily temperature range in infested trees was higher than that in uninfested trees.

Additional modifications in MPB behavior as a result of thinning stands are presented by Bartos and Amman (in press). One of the main modifications is the disruption of the pheromone communication system that results from thinning lodgepole pine stands. When MPB do infest a tree in a thinned stand of lodgepole pine, usually only the single tree is infested, and occasionally a nearby tree when spacing is not maintained. The openness of the stand causes convection currents created by solar insolation to transport the pheromone plume from around infested trees vertically out of the stand rather than horizontally. Thus, the infestation of other trees would be dependent on the degree of thinning.

Mountain Pine Beetle Response

In 1985, prior to the beginning of the microclimate study, MPB response to baited funnel traps was much less in a thinned than in an unthinned stand. Of the total beetles caught, only 5% were caught in the thinned stand. Beetle abundance was also reflected in the percentage of trees killed, which was much less in the thinned stand than the percentage killed in the unthinned stand where the microclimate study was located. Schmitz et al. (in press) caught fewer beetles in passive traps in heavily thinned than in lightly thinned and check stands in Montana, and McGregor et al. (1987) found significantly fewer infested trees in heavily thinned than in lightly thinned and check stands in Montana. Because air temperatures in thinned and unthinned stands are about the same, beetles may sense the difference in light intensity or the greater air turbulence in thinned stands and avoid open stands. Light could serve as an integrator of other micrometeorological features such as temperature, humidity, and air turbulence. Shepherd (1966) showed in laboratory studies that MPB increased attempts to fly as light intensity and temperature increased.

In conclusion, microclimate appears to play a significant role in MPB behavior in lodgepole pine stands. Infestation risk of managed lodgepole pine stands could possibly be assessed by monitoring particular parameters of stand microclimate, specifically light and temperature. As crown closure begins to occur in partially cut or thinned stands, a favorable microclimate may occur and invite beetle attack, regardless of tree vigor. Additional studies are needed of MPB infestation in thinned stands to determine more definitively the microclimatic thresholds of MPB infestation and the association of these thresholds with tree vigor.

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