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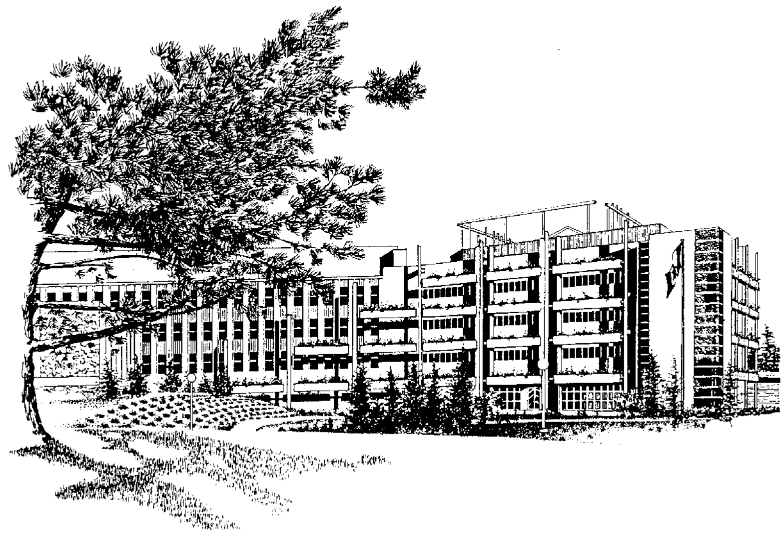

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Abstract

Incidence of attack and brood production by mountain pine beetle in lodgepole pine were assessed following a 600-ha controlled burn in Tweedsmuir Park in central British Columbia. The burn was conducted 20-23 September 1995. Varying levels of fire intensity resulted in various degrees of crown scorch and tree bole charring. Attack and brood production were assessed in five burn intensity classes in trees attacked prior to and following the burn. In trees attacked prior to the burn, brood density was significantly reduced in the two highest burn intensity classes compared to the other classes. On average, beetle production per tree in burned trees was reduced by 47.8% compared to trees with no evidence of bole charring and population increase in the burned area was reduced to a static level. The year following the fire, mean attack, egg gallery and brood density taken over all burn intensity classes were significantly lower than outside the burn. On average, attacks per tree and brood per tree were reduced by 48.5% and 56.5%, respectively. However, on a per attack basis brood survival in trees within the burn was similar to that in trees outside the burn.

Résumé

La fréquence des attaques et la production d’œufs par le dendroctone du pin ponderosa sur le pin tordu ont été évaluées après un brûlage dirigé de 600 hectares du parc Tweedsmuir dans le centre de la Colombie-Britannique. L’opération s’est déroulée du 20 au 23 septembre 1995. Différentes intensités du feu ont entraîné divers niveaux de roussissement du houppier et de carbonisation des troncs d’arbre. Les attaques et la production d’œufs ont été évaluées pour cinq classes d’intensité du feu chez des arbres infestés avant et après le brûlage. Dans le cas des arbres ravagés avant le brûlage, la densité d’œufs était considérablement réduite dans le cas des deux classes d’intensité les plus fortes comparativement aux résultats observés pour les autres classes. En moyenne, la production de dendroctones par arbre brûlé avait baissé de 47,8 % comparativement à celle dans les arbres dont le tronc n’était pas carbonisé, et l’augmentation de la population du ravageur a été freinée dans la zone brûlée. L’année suivant le feu, les moyennes des attaques, des galeries de ponte et de densité des œufs mesurées pour l’ensemble des classes d’intensité du feu étaient significativement moindres qu’à l’extérieur de la zone non brûlée. En moyenne, les attaques et la production d’œufs par arbre étaient réduites respectivement de 48,5 et de 56,5 %. Cependant, la survie des œufs dans les arbres de la zone brûlée par attaque était semblable à celle dans les arbres à l’extérieur de la zone brûlée.

Introduction

The mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera:Scolytidae), is the most destructive insect pest of mature lodgepole pine, *Pinus contorta* var. *latifolia* Engelmann, in British Columbia (Safranyik *et al.* 1974; McMullen *et al*. 1986; Unger 1993). Management to reduce losses consists of treatments to kill beetles, and forestry practices aimed at reducing tree and stand susceptibility. The strategies and tactics of mountain pine beetle management are described in the literature cited above.

The use of fire to destroy mountain pine beetles in individual felled or standing trees was one of the earliest methods of control (Keen 1952; Miller and Keen 1960). Controlled burning has also been proposed to treat multiple tree and concentrated infestations (Muraro 1978). Prescribed fire is potentially valuable in remote locations or those where other options are not permitted or feasible.

In the summer of 1994, an infestation of mountain pine beetle was identified in central British Columbia on the north shore of Eutsuk Lake within the boundaries of Tweedsmuir Provincial Park. In 1995 an attempt was made to control this infestation by baiting the area with synthetic pheromones (chemical attractants) and subsequently burning it.

In 1996, we initiated a project to evaluate the success of this burn in reducing the mountain pine beetle population. Our objectives were to determine the effects of the prescribed burn on survival rates of mountain pine beetle broods resident at the time of the burn, and to determine post-burn attack and brood production by mountain pine beetle in burned and unburned trees.

Methods

The area scheduled for prescribed fire was baited in early May, 1995, on a 50 m x 50 m grid. Baits were attached to the north side of a large diameter lodgepole pine located nearest to each grid point. A prescribed fire was initiated on Sept. 20, 1995 after two days of drying following a rainfall on Sept. 18, and the fire continued burning until Sept. 23. A complete description of the burning conditions is described by Ember Research Services (Tweedsmuir park mountain pine beetle control burn (1995). Report submitted to B.C. Parks, Smithers, B.C., November, 1995. 88 p.). Calm winds (3 km/h) and high fine fuel moisture contents (Fine Fuel Moisture Code [Van Wagner, 1987] increased from 73 on Sept. 20 to 81 on Sept. 23) limiting fire ignition and intensity. Crown fire only occurred: 1) where blowdown added to surface fuel loading; 2) on south-facing aspects and well-drained soil regimes; and 3) where slope exceeded 25-35%. Over the four-day period 600 ha were burned with varying levels of fire intensity that resulted in various degrees of crown scorch and charring of tree boles.

Bark beetle sampling within the burned area was carried out July 17-18, 1996, at two locations: (1) lat. N 53˚ 15' 20", long. W 126˚ 14' 30"; and (2) lat. N 53˚ 11' 01", long. W 126˚ 15' 52". Sampling was repeated in the same vicinity July 9-13, 1997.

Before sampling, a classification of burn intensity (Table 1) was created after examining several hundred trees in the burned stand. In order to assess the effect of burn intensity on brood survival, ten trees that had been attacked in July and August 1995 were selected within each burn intensity class, for a total of 50 trees. The sample trees were scattered throughout the burned areas (38 trees at location 1 and 12 trees at location 2).

Tree diameter (cm) at breast height (dbh), and heights (m) to top, bottom of crown, bole scorch, and attack were recorded for all sample trees. Heights were estimated using a Suunto clinometer. Trees were examined through binoculars (8×) or a spotting scope (20×) to find attack heights, using the presence of pitch tubes or evidence of woodpecker feeding as indicators. Brood density was assessed by taking two 14.8-cm-diameter discs or 15-cm squares of bark from each of the north and south sides of each sample tree at breast height (1.3 m). Half of the trees in 1996 and all trees in 1997 were also sampled at a height of 3 m. The bark samples were cut as described in Safranyik et al. (1999). In 1996, the 14.8-cm circular samples were put into plastic bags and stored at 0° C pending dissection and examination. In 1997, the 15-cm-square samples were processed in the field. Live mountain pine beetles in all stages of development were counted separately. Attacks (entrance holes through the bark which correspond to the lower ends of egg galleries) per sample were counted, and all gallery lengths were measured to the nearest cm and summed within each sample.

Table 1. Burn intensity class definitions.

Burn Intensity Class	Description
0	No visible burn effect on trees.
1	Touched. Very light singe was visible on the bark or the tree was incompletely burned around duff line only.
2	Singed. Duff was usually burned away. Trees were deeply burned at the duff line only, and tips of bark scales were blackened or singed to a height of 1 m.
3	Scorched. Bark scales are blackened above a height of 1 m. Bark is not burned through. (Percent of the circumference that was affected was noted.)
4	Burned. Bark was charred down to the wood or burned off to heights greater than 1 m on bole bole. The crown was frequently burned or scorched.

The frequency of trees by burn intensity class was determined in 1996 from 37 prism plots (BAF 10) established at 25-m intervals on three parallel lines 50 m apart in the burned area. The beginning of the first line was established at random with respect to distance and direction from the location (1) described earlier. Each included tree was examined for mountain pine beetle attack and classified by burn intensity as described above, and its dbh was measured.

The population trend ratio (R) (FIDS 1974) was estimated for the burned and unburned areas as follows. For each area averages per tree of brood, B, and attacks, A, were calculated based on the sampled trees. The trend ratio, R, was calculated as the ratio B/A. R values less than 2.5 indicate a decreasing population trend, values of 2.6-4.0 indicate a static population, and larger values indicate an increasing trend.

To study post-burn attack behaviour, 100 trees (50 within and 50 outside of the burned areas) that were attacked in 1996 were selected in September 1996. The two areas were contiguous as they formed part of the same infestation. In each area, the trees were selected at intervals of 5 m to 20 m along a transect line traversing the slope from a random point located near the lake shore. Sampling was done on July 9-13, 1997. Burned trees were classified for burn intensity. Bark samples (15-cm squares) were taken and all measurements and counts were done in situ.

Analysis

For 1996 trees that were not sampled at a height of 3 m, attack and brood density were estimated as follows: Mean gallery length at 3 m was estimated from samples taken on half of the sample trees at that height. Egg gallery length per disc was assigned by sampling from a normal distribution (range: mean egg gallery length at 3 m ± 2 standard deviations). Ratios of gallery length to attack and brood counts were calculated for the 1.3 m samples in each burn intensity category, and were multiplied by the assigned egg gallery lengths to give estimates of brood and attack counts at 3 m.

To estimate mean density and totals of attacks, brood, and egg gallery length per tree, the infested bark areas from below 2.1 m (half way between the low and high disk samples), and from 2.1 m to the infested height were calculated for each sample tree as given in Safranyik (1988). The two bark areas were multiplied by the corresponding densities of attacks, brood, and egg gallery lengths to estimate totals per tree. Corresponding means for the upper section were calculated based on the assumption that they declined linearly from 2.1 m to the top of the infestation.

Variations in the densities of attacks, brood, and egg gallery lengths among burn intensity classes and sample heights were compared by analysis of variance and means were compared by Tukey's test at a significance level of $p = 0.05$. All measurements and counts were converted to a per m^2 basis and transformed to $\sqrt{(x+1)}$ for analysis to rectify heteroscedasticity but untransformed means are presented. Total numbers per tree of brood, attacks and egg gallery lengths were not compared statistically because these were based on estimates rather than direct measurement as described above. Mean diameters and infested bark areas per tree for the burn and control areas in 1997 were compared by t-tests.

Results

Pre-burn (1995) mountain pine beetle attack

The physical characteristics of the sample trees are summarized in Table 2. The average height of burn was zero for classes 0 through 2 but was 3.9 m for class 3 and 6.7 m for class 4.

The overall mean attack density was 53.2/m^2. The mean attack density at breast height (40.9/m^2) was significantly lower (p = 0.003) than at 3 m (78.2/m^2). There were no statistically significant differences ($F_{4,44}$=2.09, p > 0.05) in pre-burn attack density among the burn intensity classes.

Brood density varied significantly among burn intensity classes (Fig. 1).

Estimates of pre-burn (1995) mountain pine beetle attack and total egg gallery per tree by burn intensity class

Table 2. Average Characteristics of infested lodgepole pine in the 1995 Tweedsmuir Park burn area. Sampled July, 1996.

Burn class	No. trees	DBH (cm)	Tree height (m)	Infested height (m)	Burn height (m)	Infested surface area (m^2)
0	10	27.6 (1.0) *	23.0 (0.6)	19.1 (6.0)	0.0 (0.0)	12.1 (0.7)
1	10	28.6 (1.3)	23.5 (0.8)	19.5 (6.2)	0.0 (0.0)	12.7 (0.6)
2	9	31.8 (1.8)	24.8 (1.4)	17.9 (2.1)	0.0 (0.0)	13.5 (4.5)
3	10	34.1 (3.0)	25.4 (2.1)	17.4 (2.2)	3.9 (1.2)	15.1 (2.9)
4	10	30.4 (1.4)	26.5 (2.2)	15.7 (0.9)	6.7 (2.1)	12.1 (0.9)

* Numbers in brackets indicate standard error.

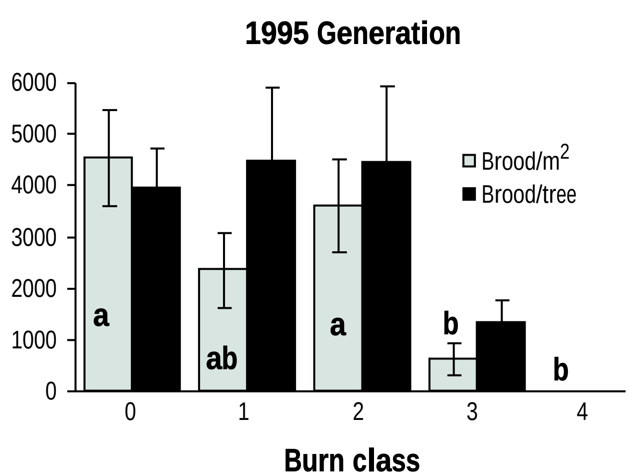

Figure 1. Mean 1995 generation mountain pine beetle brood per m^2 (all stages) and per tree by burn intensity class. Sampled July 1996. Mean brood densities designated by the same letter are not significantly different (Tukey's test, p > 0.05)

are given in Table 3. Total attacks and egg gallery lengths per tree varied little among the burn intensity classes. Both of these variables are correlated with egg production; therefore, this result indicates that on average the trees in all five burn intensity classes would have had similar egg densities and total eggs before burning.

After burning, mean brood density in classes 3 and 4 was significantly lower than in classes 0 and 2 (Fig. 1). Within classes, mean brood density at 3 m (306.7) was not significantly different ($p > 0.05$) from that at breast height (Fig. 1). Total mountain pine beetles per tree (Fig.1) were similar for classes 0 through 2, ranging from 3963 to 4484, indicating that a low intensity burn had no effect on beetle survival. In the more heavily burned classes 3 and 4, however, the estimated mountain pine beetle brood per tree was reduced to 1348 in class 3 and 0 in class 4.

Based on the stand cruise, the estimated percentages of 1995 infested lodgepole pines in burn intensity classes 0 to 4 were 27.3, 8.6, 8.6, 16.0, and 39.5. We applied these figures to the respective brood totals in Figure 1 to calculate the overall average brood production per burned tree (2068.9). The reduction in brood production due to the burn was calculated as the difference between the estimated number of beetles per tree in burn class 0 and the overall average number of beetles per tree (3963.4-2068.9=1894.4), a reduction of 47.8%.

The estimated overall average number of attacks per burned tree was 640.2. Thus the potential rate of beetle population increase ("R" value) (FIDS 1975) in the burned trees was 3.2 (2068.9/640.2), indicative of a static population. The R-value for the unburned trees was 7.0 (3963.4/566), indicative of an increasing population. The controlled burn therefore reduced the beetle population in the burned areas to a static level.

Post-burn mountain pine beetle attack

The distribution of mountain pine beetle life stages in July 1997 was as follows: larvae 1.3%, pupae 9.6%, callow (immature) adults 51.9%, mature adults 37.1%. These figures indicate that the sampling should fairly represent the population available for dispersal, as losses in the later life stages are generally low (Amman and Cole 1983).

There was no statistically significant difference ($p > 0.05$) in mean dbh of the attacked trees in the burned (30.88 cm, SD=7.7) and unburned (31.3 cm, SD=5.9) areas. However, the mean infested bark area of trees from the burned site (8.8 m^2, SD=4.4) was significantly different from that in the unburned (10.4 m^2, SD=3.7); $t_{98} = 2.15$, $p > 0.05$. The main reason for this difference was that beetles avoided attacking trees showing signs of burning, and therefore attacked a shorter length of the bole on burned trees.

There was significant variation among burn intensity classes and between sample heights in attack density per m^2 ($F_{5,128} = 3.52$, $p \leq 0.005$ for burn class; $F_{1,63} = 15.38$, $p \leq 0.0002$ for sample height) and egg gallery length per m^2 ($F_{5,128} = 6.29$, $p \leq 0.0001$ for burn class; $F_{1,63} = 48.06$, $p \leq 0.0001$ for sample height). Estimates for mean numbers of attacks and mean egg gallery length per m^2 are given in Table 4. Mean attack density and mean egg gallery length per m^2 at 1.3 m were significantly lower than at 3 m.

The differences between the mean densities of mountain pine beetle attacks, egg gallery lengths (Table 4) and brood (Fig. 2) were generally not statistically significant among the burn intensity classes. However, for each variable, the difference in the combined means for burn intensity classes 0-4 and the control was significantly different ($F_{1,98} = 8.55$, $p \leq 0.004$ for brood density; for attack density and egg gallery length/ m^2 see bottom row, Table 4).

Mean densities of these variables taken over all classes were significantly lower than the corresponding averages and totals (Table 5) in the control. These differences were generally due to the lower numbers in burn intensity classes 3 and 4.

In the burned area, 1996 attack density ranged from 26.7/m^2 in burn intensity class 4 to 48.9/m^2 in class 1 and averaged 45.7/m^2 over all classes. Mean attack density in the control was 70.7/m^2 (Table 4). Mean brood density ranged from 357.8/m^2 in class 3 to 796.9/m^2 in class 2 and averaged 494.8/m2 over all classes. Mean brood density in the control was 960.1/m^2 (Fig. 2). The R value for the burned area was 10.8, and was 13.6 in the control. The variability among burn intensity classes in egg gallery length density was similar to attack density.

Brood density varied significantly among burn intensity classes ($F_{5,128} = 3.29$, $p \leq 0.008$ (Fig. 2).

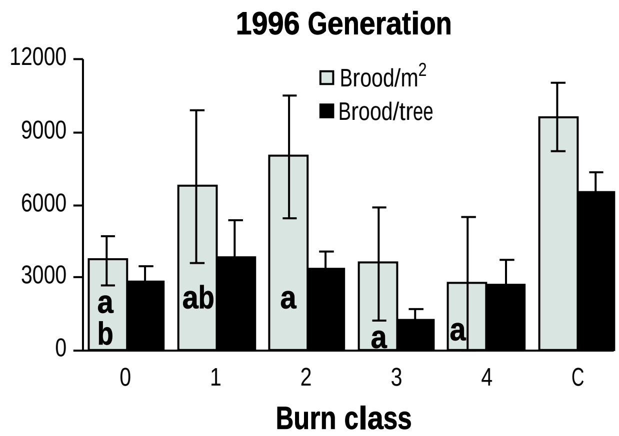

Figure 2. Mean 1996 generation mountain pine beetle brood per m^2 (all stages) and per tree by burn intensity class. Sampled July 1997. Mean brood densities designated by the same letter are not significantly different (Tukey's test, $p > 0.05$). (C = control).

Table 3. Mean 1995 generation mountain pine beetle attack and egg gallery length (m) and standard error (SE) for whole trees by burn intensity class. Sampled July 1996.

Burn intensity class	Number of trees	Number of attacks		Egg gallery length (m)	
		Mean	SE	Mean	SE
0	10	566	75	147	46
1	10	681	111	137	43
2	9	644	96	177	59
3	10	730	114	201	64
4	10	697	113	162	51

Table 4. Mean number of 1996 generation mountain pine beetle attacks, total gallery length per m^2 and standard error by burn intensity class (means for samples taken at 1.3 m and 3 m and north and south aspects combined). Sampled July 1997.

Burn intensity class	Number of trees	Attack/m^2		Egg gallery length (m/m^2)	
		Mean*	SE	Mean	SE
0	23	41.87a	36.4	10.87a	2.38
1	5	48.85ab	26.41	14.58ac	3.03
2	11	65.65ab	47.8	18.92bc	3.32
3	6	37.03a	25.97	10.35ab	2.19
4	5	26.67a	18.59	7.88ab	3.56
0-4 total (T)	50	45.69	34.87	12.64	1.38
Control (C)	50	70.71b	43.59	21.61c	1.54
$F_{1,98}$ (T vs C)		12.17		20.24	

* Means within columns designated by the same letter are not significantly different (Tukey's test, $p > 0.05$).

Discussion

Pre-burn mountain pine beetle attack in 1995

Sampling of the 1995 generation in July 1996 indicate that mountain pine beetle mortality was related to the intensity of burning as indexed by a burn intensity classification based on visible burn symptoms. Beetles in trees in the two highest burn intensity classes suffered severe mortality. We estimate that 47.8% of the population in the burned areas died from the effects of the controlled burn. This estimate is based on two fundamental assumptions: (1) survival to the summer following the burn was nil in those trees that had no live brood in the samples taken at breast height and at 3 m; and (2) the distribution of infested trees in the burn intensity classes found by the stand cruise, which covered 0.8% of the burn, was representative of the entire burned area. Furthermore, we observed that trees were attacked to heights considerably greater than the top sample height of 3 m (Table 2), and it is likely that some brood survived higher up on some trees. For these reasons, the estimated reduction in beetle numbers due to the control burn should be considered as a maximum figure.

These results support the conclusions reached by Stock and Gorley (1989) regarding the need for high fire intensity to cause appreciable brood mortality. Miller and Patterson (1927) (cited in Miller and Keen 1960) working with yellow pine stated "Fires which are not severe enough to burn the bark from infested trees are of little value in controlling bark beetle infestations. Fires of moderate severity do not kill bark beetle broods in infested trees at the time of the fire." Therefore, vigorous burns of rank 3 or greater covering the entire infestation would be needed if the main objective was suppression.

Post-burn mountain pie beetle attack in 1996.

Brood development

Over one-third of the 1996 generation of mountain pine beetle brood consisted of mature adults when sampled in July 1997. The timing of peak flight depends heavily on weather conditions. Mature adults emerge during precipitation-free periods, when air temperatures are at least 18-20 ˚C (Reid 1962). New adults feed under the bark for up to two weeks before they are ready to emerge (Reid 1962). Based on the distribution of the various brood stages, we estimated that none of the brood would have emerged prior to the completion of the field sampling.

Density of attack, brood and egg gallery length.

The mean attack density in the control site was significantly greater than the overall mean attack density in the burn site, although there were no statistically significant differences among burn intensity classes (Table 4). The corresponding mean per tree was also greater in the control site than in the burn site (Table 5). This indicates that there were generally fewer beetle attacks on trees in the burned areas. This could be due to either the reduced attractiveness of burned trees, or to lower local population levels, or a combination of these factors. There is evidence that reduced attractiveness is an important factor (Muraro, S.J. 1976. Preliminary results of using fire to control Mt. pine beetle (*D. ponderosae* (Hopk.)). Unpublished report. Canadian Forestry Service Pacific Forestry Centre, Victoria, B.C.). In agreement with Stock and Gorley (1989), we observed that beetles only attacked bark showing no evidence of having been burned. Mean attack densities were numerically lowest in burn intensity classes 3 and 4. The relative incidence of attacks on trees in class 4 (10%) was much lower than the relative incidence of trees (39.5%) falling into that class. In successfully attacked trees, the density of egg gallery length is usually correlated with attack density. Our results support this in that the ranking of mean egg gallery length on treatment was similar to that of attack density (Table 4). Mean brood densities in classes 3 and 4 were significantly lower than in the control, mainly because attack densities and egg gallery length densities were both lowest in these classes.

Comparison of mean attack density in the control trees and the overall mean attack density for the combined burn classes (Table 4) indicates that in the year following the burn, mountain pine beetle was less attracted to host trees in the burned area than to trees outside the burn. However, when compared separately, mean attack density in burn classes 2 and 3 were not different from the control. These results differ from reports in Miller and Keen (1960, p. 220) and in Stock and Gorley (1989) that burned areas are highly attractive to beetles soon after burning. The productivity of brood per attack in burned trees was similar to that in unburned trees. Therefore, the expectation that burned lodgepole pines will act as “population sinks”, as do burned yellow pines, is not supported by these results.

Total attack, brood, and egg gallery length per tree

The orders of the per tree means of attack, egg gallery length (Table 5), and brood (Fig. 2) by treatment were similar to those of the respective densities (Table 4, Fig. 2). Assuming that the numbers of trees sampled in the various burn intensity classes are representative of their relative frequencies in the burn, attacks per tree were reduced by 48.5% (100×(482-248)/ 482), and brood per tree was reduced by 56.5% (100×(6484-2821)/ 6484) (Table 5, Fig. 2). However, the “R value”, an index of beetle productivity, did not differ appreciably in the control and burn areas ($R_{control}$ = 13.6, R_{burn} = 10.8) indicating that on an individual attack basis, beetles in the burn area produced broods comparable to those in the control area.

Table 5. Mean number of mountain pine beetle attacks in the 1996 generation and mean total gallery length (m) per tree and standard error (SE) by burn intensity class. Sampled July 1997.

Burn intensity class	Number of trees	Attack / tree		Gallery / tree	
		Mean	SE	Mean	SE
0	23	280	48	79	15
1	5	264	40	72	9
2	11	240	47	78	14
3	6	175	59	46	12
4	5	186	50	59	21
0-4 total	50	248	25	72	7
Control	50	482	45	149	12

Summary

These investigations show that prescribed fire can result in an immediate average reduction of pre-existing beetle reproduction of up to about 50% in areas burned to the level we studied. Individual heavily burned trees will have up to 100% of the brood killed. Although mountain pine beetles attacked scorched and fire-stressed trees in the year following the burn, the incidence of attacks, average attacks and average brood production per tree were less in the two highest burn intensity classes, mainly because only limited portions of such trees were attacked. Trees in the burned area generally sustained fewer attacks and produced fewer beetles than trees outside the burn. Average brood production per tree in the burn area was reduced by 56.5%, but on a per attack basis, brood production was comparable to that in the control area.

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