USING EXPLOSIVES TO DESTROY MOUNTAIN PINE BEETLE BROODS IN LODGEPOLE PINE TREES

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ABSTRACT

The effectiveness of explosives for the destruction of mountain pine beetles in individual lodgepole pine trees was investigated. Two types of detonating cord, and various placements, were tested on infested bolts and trees, and a plastic explosive was tested on bolts. Explosives killed broods directly, and indirectly by habitat disruption. Direct effects extended about 9 cm from the explosion and mortality was inversely related to distance. Indirect effects via extensive loosening and shedding of bark caused far greater mortality than direct effects. On trees, summer and fall treatment was much more effective than spring treatment, regardless of cord placement. Fall treatment using 10 g/m detonating cord helically wrapped onto the boles at 10, 20 and 30 cm spacings caused 100%, 98% and 70% mortality of broods respectively. Generally, vertical placement of the cord into grooves cut through the bark caused more bark disruption and therefore, more brood destruction than did helically wrapped cord placed on the surface.

RÉSUMÉ

Les auteurs ont etudie l'efficacité d'explosifs pour la destruction du Dendroctone du Pin ponderosa sur differents Pins lodgepole. Deux types de fil détonateur, places à divers endroits, ont été experimentés sur des grumes et des arbres infestes, puis un explosif au plastique a été essayé sur des grumes. Les explosifs ont tué les couvées directement, et, indirectement par la dislocation de l'habitat. Les effets directs se sont étendus à environ 9 cm du lieu de l'explosion et la mortalité était inversement proportionnelle à la distance. Les effets indirects par suite du relâchement et du déchiquetage de l'écorce ont causé une mortalité de loin supérieure aux effets directs. Sur les arbres, le traitement printanier et estival s'est avéré beaucoup plus efficace que le traitement automnal, peu importe l'emplacement du fil. Le traitement d'automne, utilisant 10 g/m de fil détonateur enroulé en spirale sur les grumes espacés, à 10, 20 et 30 cm, a causé 100%, 98% et 70% respectivement de mortalité des couvées. Généralement, lorsque le fil était placé verticalement dans des incisions pratiquées dans l'écorce, causant ainsi une plus importante dislocation de l'écorce, on notait une destruction plus accentuée des couvées que lorsqu'il était disposé en spirale à la surface des arbres.

INTRODUCTION

Since the turn of the century, there have been many direct control attempts against mountain pine beetles *(Dendroctonus ponderosae* Hopkins) in lodgepole pine *(Pinus contorta* Douglas var. *latifolia* Englemann), both in Canada and the United States. The effectiveness of these control attempts in reducing or preventing tree mortality was recently reviewed and questioned (Klein 1979). However, Whitney *et al.* (1979) noted that most documented examples of direct control action have been directed against epidemic infestations. Recent advances in understanding the epidemiology of mountain pine beetle populations indicate that outbreaks may be avoided if the populations are kept below a critical threshold level, especially during periods of temporary tree stress (Berryman 1979). Whitney *et al.* (1979) agreed that prevention of population buildup is a sound strategy for which tactics can be developed.

There are only a few published reports of explosives used for pest control, apart from pyrotechnics to modify bird behavior (Frings and Frings 1967). Dynamite has been used to kill pile worms underwater (Quayle 1942) and in attempts to control predacious fishes

(Kuroki and Komanda 1961). Termite eradication has been attempted using explosives (Gray and Buchter 1969) and bee colonies were reported injured from nearby explosions (Kara 1974). It was observed in 1926 that pupae in mountain pine beetle galleries were killed only when in close proximity to exploding TNT (Klein 1979). Exposing bark beetle broods by debarking is an effective control procedure, especially in thin bark pines (Evenden *et al.* 1943). Bark removal with detonating cord was used by Taylor (1973) to simulate lightning strikes on ponderosa pine. We now report on the biological effects of using detonating cord to destroy mountain pine beetles directly, and indirectly by physically disrupting their habitat. A preliminary report describing the strategy for using detonating cord and its effectiveness for bark disruption has been published (Whitney *et al.* 1979).

METHODS

Experiments testing the effectiveness of explosives to kill large larvae, pupae and adults of mountain pine beetle in naturally infested bolts were carried out during the summer of 1977. These bolts were from Riske Creek, B.C., and the tests were conducted on a military site near Victoria, B.C. This work was followed between mid-October 1977 and the end of June 1978 by field experiments on direct and indirect brood mortality caused by different explosives, placements, and timings of treatments relative to brood development. Hazards of misfire of explosives and of ignition of combustible material beneath treated trees were reduced by

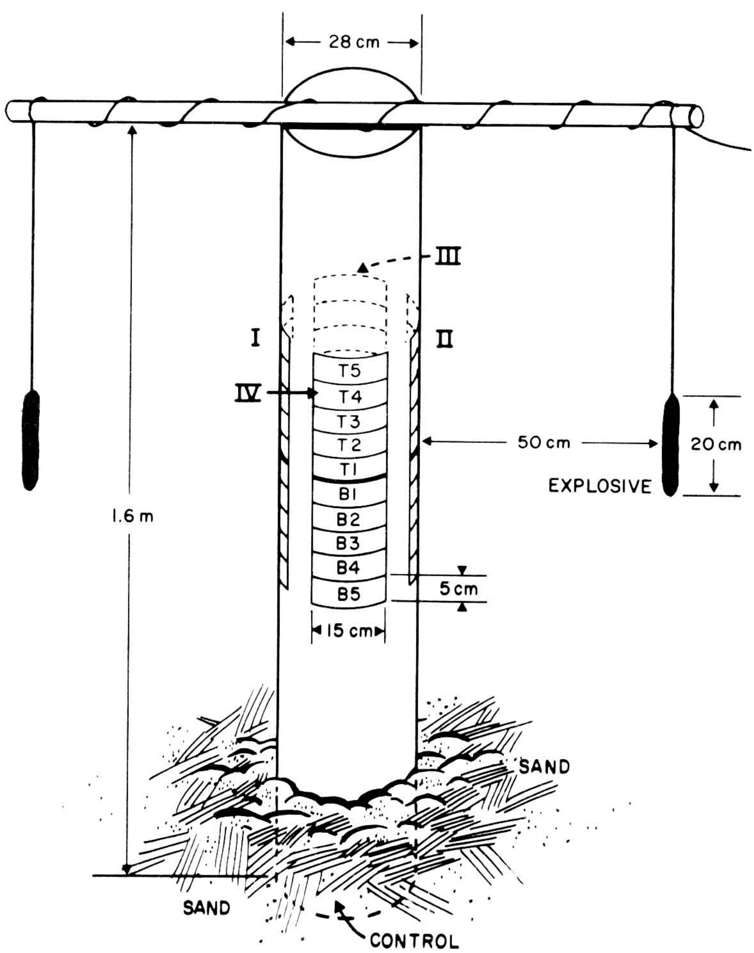

Fig. 1. Diagram of concussion treatment and sampling design. Five bark samples T_1 - T_5 and B_1 - B_5 were taken from each of four aspects (I - IV) following detonation. Bark sample for control was taken from the protected, below-ground portion of the bolt.

employing qualified blasters and a fire suppression crew.

Effect of distance from detonation. In the first experiment, a naturally infested bolt, 1.5 m long and 30 cm in diameter, was dug into sand to a depth of 20 cm in an upright position. Broods were mostly young adults and pupae. The exposed part of the bolt was wrapped tightly with a reinforced C-3 yellow plastic (Military) detonating cord containing 10 g/m of explosive. The cord was wrapped onto the bolt in a helical pattern at about 20 cm spacing between wraps. Seven days after detonation, three 855 cm^2 strips of bark, each 3 cm wide and with the long axis running parallel to the detonating cord, were removed and sampled for live and dead beetles. The distances (X_i) between the mid-lines of strips one to three and the mid-line of the cord were 1.5, 4.5 and 8.5 cm, respectively. A 756 cm^2 bark sample, taken from the below-ground portion of the bolt, at least 15 cm from the nearest wrap of detonating cord was used as control and examined in the same manner as the bark strips. In the second experiment, six 1.5 m long and 25- to 30-cm-diameter infested bolts were brought to the laboratory in late August and kept at room temperature until most of the broods were in late larval and pupal stages. Four bolts were then selected randomly and treated as described above. Following treatment, total bark area and area of remaining undisturbed bark were measured and the bolts were placed in separate emergence cages at room temperature. The numbers of emerged beetles were converted to 100 cm^2 for statistical analysis.

Effects of concussion. An infested lodgepole pine bolt, 1.6 m long and 28 cm is diameter, was used to determine direct mortality caused by detonating explosives that were not touching the bolt. This bolt containing mostly young adults, was held upright in the firing-hole, as described previously. Military plastic explosive C-4 was molded into two cylindrical charges, about 3 cm thick by 20 cm long, to give an estimated explosive weight of 170 g/m. These charges were suspended from a harness fixed to the top of the bolt so that their centers were located about mid-distance to the ground and 50 cm distant from opposite sides of the log (Fig. 1). Twelve days after detonation, five 15 x 5 cm contiguous bark samples, with long sides perpendicular to the long axis of the bolt, were removed from each aspect above (samples T_1 - T_5) and below (samples B_1 - B_5) the level of the center of the explosive charge, two aspects facing the charges and two being at 90° to the charges. The numbers of dead and live brood were tallied. A 750 cm^2 bark sample, taken from the below-ground portion of the bolt, was used as a control.

Effect of a mesh-work pattern of detonating cord. An infested lodgepole pine bolt, 1.6 m long by 28 cm diameter, was used for determining brood mortality under bark islands left on the bolt following detonation. The bolt was held in an upright position, as described, and 10 g/m military cord was fixed vertically to its four sides and also wrapped around it in a helical pattern, as described earlier. Bark islands left on the bolt after firing were measured for area and sampled for dead and live broods, 7 days after detonation. A 1735 cm^2 bark sample taken from the below-ground portion of the bolt at least 15 cm from the nearest wrap of detonating cord was used as the control. **Spring treatment using vertical and helical placement, grooving, tamping, and two cord types.** The experiments were conducted in mid-April, 1978, near Riske Creek, B.C. The experiment on vertical placement of the detonating cord compared two types of cords, Scuf-Flex® and No-Flash-50®, that have about the same explosive force as the military C-3 cord. No-Flash-50® is a low fire hazard cord. Scuf-Flex® was placed on the surface and in shallow grooves, tamped and untamped (Fig. 2A-C). No-Flash-50® was similarly placed, but without tamping. For convenience, only the lower 2.0 m of the tree boles were used. Cords were placed at about 20 cm intervals around the circumference of the boles. Grooves through the bark and phloem, were cut with a small chainsaw and Plasterers' putty (joint filler) was used for tamping. For the untamped detonations, cords were held in place by a few wrappings of flagging tape. Each of the six treatment combinations were applied at random to three infested lodgepole pines, ranging from 27.4 to 36.2 cm in dbh. Following detonation, trees were photographed and bark removal and disruption were assessed visually from the photos, and by direct observation on June 20, 1978.

Helical wrapping of Scuf-Flex® was applied without grooving or tamping to the lower boles of six infested lodgepole pines at 20 cm spacing, in the manner described. Following detonation, results were evaluated, as described for the experiment with vertical placement.

Fall treatment using helical placement of detonating cord. In late October 1977, on about 5 hectares near Riske Creek, B.C. five groups (blocks) of eight infested lodgepole pine trees each were chosen to have similar diameter, bark characteristics, attack intensity and attack success. Within the blocks two trees were assigned at random to each of four bark disruption treatments. Treatments 1 to 3 corresponded to helical wrappings with 10 g/m Scuf Flex® detonating cord at, 10, 20 and 30 cm spacings between wraps. Treatment 4, no detonating cord, was the control. The helical wrapping was made in the same manner as

Fig. 2. Vertical placement of detonating cord on lower bole of mountain pine beetle infested lodgepole pine. A Surface placement (No-Flash-50®), B. Shallow groove (Scuf-Flex®), C. Surface placement tamped with Plasterers' joint filler (Scuf-Flex®). The cords were secured with flagging tape.

TABLE 1. Mortality of mountain pine beetle broods in 3-cm-wide bark strips parallel to detonating cord that was wrapped onto the bolt in a helical pattern with 20 cm spacings.

Mid-distance of strip (X_i) from explosive (cm)	Live	No. brood dead	Totals	Proportion dead(p_i)	p_i x Dead
1.5	0	110	110	1.000	110.000
4.5	11	118	129	0.915	107.938
8.5	151	65	216	0.301	19.560
Control	88	16	104	0.154	2.462
Totals	250	309	559		239.960
			$\bar{p}$= 309/559 = 0.5528		170.807

$$\chi^2 = \frac{239.960-170.807}{0.5528\ (1-0.5528)} = 279.73 \text{ with 3 df, } (p < 0.01)$$

described in Whitney *et al.* (1979). Trees were sampled prior to treatment by removing one 20x30 cm bark sample from each of the NE and SW aspects at the 1.35 m height and tallying the live brood by stages of development. Following brood sampling, branches were cleared from each sample tree to a height of 3.3 m; cord was wrapped onto the cleared bole and detonated. The treated portions of the boles were then individually covered with wire netting cages to prevent woodpecker predation. The cages were removed June 20, 1978, when most of the broods had become pupae and teneral adults. Post-treatment sampling was done on the same aspects as the pre-treatment sampling using the same size bark samples, located 10 cm below the pre-treatment samples. Brood counts from the two aspect-samples taken per tree were combined.

RESULTS AND DISCUSSION

Effect of distance from detonation. Upon firing, the detonating cord removed a strip of bark 0.5 to 1.5 cm wide where it contacted the bolt. A few larger pieces of bark were also blasted off (Fig. 3A). Margins of the strip were charred and tiny fragments of cord-casing and bark were embedded in exposed sapwood. Bark was loosened up to 1.5 cm from the edges of the strip. Young adults and pupae adjacent to the disrupted margin were physically injured to varying degrees. Some were dismembered (Fig. 3B) and others were moist as though body fluids had issued from ruptured intersegmental membranes. Brood mortality decreased significantly ($p < 0.01$) with increasing distance from the detonating cord (Table 1). The slope of the regression of the proportion dead (p) on an index of mid-distances ($z_i = (x_i/1.5)^2$) for bark strips one to three was significantly different ($p < 0.01$); from zero (Cochran 1954), the equation being $p_i = 1.0674 - .0239z_i$. Assuming that the p_i for the control (0.154) in Table 1 is a good estimate of natural mortality, we can derive an estimate of the maximum distance (x_m) of treatment effectiveness (*i.e.*, the distance beyond which the treatment had no effect on mortality) by substituting 0.154 for p_i in the equation and solving for x_i. Thus, $x_m = 9.3$ cm. This finding indicates that even if little or no bark was blasted off by the detonating cord, some mortality could be expected up to about 9 cm from the location of the explosive.

The four bolts in the second experiment had an average of 41.9% of the bark removed by the 10 g/m explosive, and bark removal ranged from 20% to 67.2% on individual bolts (Column 3, Table 2). In addition to bark removal, bark disruption in terms of loosening and shedding of bark was also extensive. However, the area of loose bark on the treated bolts was not determined. An average of 0.44 adults /100 cm² residual bark emerged from the treated bolts, or 7.8% of the density that had emerged from the control bolts (Columns 5 and 6, Table, 2). Based on total bark area of the treated bolts, average survival was only 4.8% of that in the control bolts.

Survival in the treated bolts of the second experiment was considerably lower than in the aforementioned identically treated bolt of the first experiment. The most probable reasons for this difference are that the single treated bolt contained broods on the verge of emergence, and bark was dry, tightly appressed to the surface, and very little was removed by the treatment. This bolt was sampled 1 week after treatment and contained a high proportion of young adults (90%), whereas the four treated

Fig. 3. Destruction of late spring brood habitat and injury of young adult mountain pine beetles caused by firing detonating cord wrapped on the bark surface. A. Strip of bark removed by explosion exposed the sapwood directly beneath detonating cord, B. Mangled young adult (arrow) near the margin of disrupted bark.

Fig. 4. Bark disruption by detonating cords on lodgepole pine infested by mountain pine beetle. The cords were placed in shallow vertical grooves, April 14, 1978. A and B. No-Flash-50® and Scuf-Flex® , respectively, 1 day after detonation, C. Scuf-Flex® treatment 10 weeks later, just prior to beetle emergence.

Fig. 5. Effect of tamping with Plasterers' joint filler on bark removal by Scuf-Flex® detonating cord. A. Cord placed in vertical grooves, B. Cord placed on bark surface.

Fig. 6. Bark disruption on an infested lodgepole pine in late spring, 7 months after treatment, with Scuf-Flex® helically wrapped on the surface with 20 cm spacing. Note dryness of beetle brood habitat as indicated by checking and shed bark. This treated area was protected from woodpeckers.

Fig. 7. Comparison between seasons of bark disruption by surface placement of Scuf-Flex® . A. Applied in spring, B. Applied in fall.

TABLE 2. Bark disruption and emergence of mountain pine beetle from 4 bolts treated with 10 g/m military detonating cord helically wrapped, with 20 cm spacing, and two control bolts.

Treated bolt no.	Bark left on bolt (100 cm^2)	% bark removed	No. emerged beetles	No. emerged[b]/ 100 cm^2	% of control emerged	Survival (%)[c]
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	77.48	28.4	39	0.50	9.0	6.4
2	67.74	20.0	8	0.12	2.1	1.7
3	49.94	67.2	23	0.46	8.2	3.1
4	42.39	45.9	35	0.83	14.5	7.9
Average	53.39	41.9	26.2	0.44	7.8	4.8
Controls[a]	225.81	0.0	1270	5.62	100.00	100

a/ The two control bolts were combined.
b/ Density of emerged beetles from bark left following treatment.
c/ Survival (s) was calculated as follows:

$$s = \frac{\text{Column (4)} \times 100}{\text{Total bolt area} \times \text{column (5) for control}}$$

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TABLE 3. Mortality of mountain pine beetle broods on the four sides of a 1.6 m lodgepole pine bolt that had two 20-cm-long plastic charges detonated on opposite sides, 50 cm from bolt (Fig. 1).

	Treatment	No. brood Live	Dead	Total	Proportion dead (p_i)	p_i x Dead
Facing explo- sive charge	Side 1	24	69	93	0.742	51.194
	Side 2	1	4	5	0.800	3.200
90° from explo- sive charge	Side 3	27	89	116	0.767	68.284
	Side 4	20	89	109	0.816	72.670
	Control	65	33	98	0.337	11.112
	Totals	137	284	421		206.460
				$\bar{p}$= 284/421=.6746		191.582

a/ Sides 1 + 2 and 3 + 4 designate respectively, all samples taken on the two sides of the bolt facing the explosive charge and all samples taken on the other two sides.

$$X^2 = \frac{206.460 - 191.582}{0.6764 \quad (1-0.6764)} = 67.75 \text{ with 4 df } (p < 0.01)$$

$$X^2 \text{ (within sides)} = \frac{195.348 - 195.050}{0.777 \quad (1-0.777)} = 1.72 \text{ with 3 df } (p > 0.05)$$

bolts contained mostly large larvae and pupae at the time of treatment and were kept in cages for over a month before the broods matured and emerged. In the first experiment, nearly all adults appeared dead within about a 5-cm bark strip adjacent to the detonating cord, but their bodies were not broken. By the next day, a high proportion of the beetles had revived and moved about normally. However, the long-term effects of this injury may have been fatal.

Effects of concussion. Average brood mortality did not vary significantly within samples on the four sides of the bolt treated with plastic explosive on two sides. However, the chi-square

TABLE 4. Mortality of mountain pine beetle broods in bark samples located at different distances from the center of explosive charge on a 1.6 m lodgepole pine bolt (Fig. 1).

Sample location on bolt[a]	Mortality (%)
T_5	41.4[b]
T_4	92.8
T_3	87.8
T_2	97.4
T_1	100.0
B_1	100.0
B_2	100.0
B_3	94.3
B_4	63.6
B_5	18.2
Control	33.7

a See Fig. 1.
b Each figure represents an average over the four sides of the bolt.

TABLE 5. Size of bark islands and mountain pine beetle mortality on an infested lodgepole pine bolt following detonation of 10 g/m detonating cord placed vertically and helically with 20 cm spacing.

Bark Island area (cm^2)	No. brood Live	Dead	Total	Proportion dead (p_i)	p_i x Dead
50.0	0	1	1	1.000	1.000
128.1	0	1	1	1.000	1.000
187.7	0	11	11	1.000	11.000
225.0	1	30	31	0.968	29.022
265.6	1	13	14	0.928	12.074
1743.1(Control)	25	28	53	0.528	14.792
Total	27	84	111		68.896
			$\bar{p}$ = 84/111=0.7567		63.568

$$\chi^2 = \frac{68.896 - 63.568}{0.75667(1-0.7567)} = 28.95 \text{ with 5 df } (p<0.01).$$

$$\chi^2(\text{within bark islands}) = \frac{54.1040 - 54.0689}{0.9655\ (1-0.9655)} = 1.04 \text{ with 4 df } (p>0.05).$$

value within treatments and control was significantly different ($p < 0.01$) (Table 3). These results indicate that mortality in the control was significantly less than treatment mortality and that lethal concussion from the explosion travelled around the entire circumference of the bolt, within the section that was sampled. The explosion did not remove bark, but split it longitudinally 10-15 cm on both sides near the center of the detonation. In the three samples closest to the center of the explosion, below and above center, the broods suffered nearly complete mortality on all four sides of the bolt (Table 4). Mortality declined rapidly with distance beyond the third samples T_3 - B_3, which were located 15 cm from the center of the explosive charge, and it was not significantly different from control mortality in the samples located farthest (20-25 cm) from the center of the explosion. Eighty-three percent of the brood were young adults. Since the bolt was sampled 12 days after treatment, the results reflect only direct mortality.

Effects of a mesh-work pattern of detonating cord. Bark islands left following treatment with military C-3 cord placed vertically and helically, ranged from 50.0 to 265.6 cm² (Table 5). There was a significant difference in brood mortality ($p < 0.01$) within bark islands and control, but not within bark islands when control was excluded. Thus mortality in the control was significantly different from that in the bark islands. There was an indication that mortality was inversely related to the size of the bark islands (p_i vs. bark island size, Table 5), but this relation was not tested because too few beetles were found in some bark islands. Even though the largest bark island was 66% of the area of the mesh formed by the detonating cord, brood mortality was severe. Seventy-seven percent of the brood were young adults and there were too few larvae and pupae for testing for differences in mortality between them and the adults.

Spring treatment using vertical and helical placement, grooving, tamping, and two cord types. No-Flash-50® placed in vertical grooves cut through the bark at 20 cm intervals around the circumference of the lower boles of infested lodgepole pine was just as effective in removing and loosening bark as was Scuf-Flex® (Fig. 4 A, B). There was no observable flash on detonation of the No-Flash-50® cord and it was apparent that this cord would be advantageous in high fire hazard conditions. Extensive loosening and shedding of the bark by either cord was apparent immediately following detonation, but bark deterioration was even more pronounced at the end of June, just a few weeks before the beginning of beetle emergence (Fig. 4 C). Exceptions were patches of dry bark that had been worked by woodpeckers prior to treatment, this bark adhered tightly to the sapwood and the treatment caused little bark loosening or removal. Ridgy bark and extensive scarring of the lower bole tended to reduce the bark disruption. However, broods were sparse in these bark types; therefore, it was unlikely that they would contribute significantly to population growth. On ungrooved

TABLE 6. Tree statistics and mountain pine beetle brood data before and after treatment with 10 g/m 'Scuf-Flex'® detonating cord helically wrapped at 3 spacings. The treatments were applied one day after the fall brood sampling.

Treatment	DBH(cm)	$s_{\bar{x}}$	Attacks/ 100 cm^2	$s_{\bar{x}}$	Fall brood/ 100 cm^2	$s_{\bar{x}}$	Spring brood/ 100 cm^2	$s_{\bar{x}}$	Fall to spring mortality	$s_{\bar{x}}$	% control after allowing for natural mortality
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Control	30.17(10)[a]	1.875	1.20	0.069	17.36	2.137	3.59	1.292	0.796	0.058	0.0
10cm spacing	31.72(10)	1.638	1.33	0.098	21.72	2.175	0.00	0.000	1.000	0.000	100.0
20cm spacing	29.69(10)	1.328	1.47	0.120	20.13	1.265	0.09	0.047	0.996	0.002	98.13
30cm spacing	30.17(10)	1.502	1.41	0.139	17.45	2.409	1.06	0.721	0.939	0.029	70.08
Mean	30.44(40)	0.770	1.35	0.056	19.16	0.721	1.18	0.425	0.938	0.018	----

[a] Sample size.
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bark, the treatments caused considerably less immediate bark disruption, but the end of June (10 weeks later) much bark flaring and loosening was evident. Grooving of the bark, however, was definitely superior in causing immediate extensive bark disruption and subsequent bark deterioration through weathering.

Tamping of Scuf-Flex® detonating cord into grooves cut into the bark (Fig. 5A) increased bark loosening and removal, compared to the untamped cord placed into grooves, but tamping Scuf-Flex® on the surface of ungrooved bark was much less effective than the tamped or untamped cord placed in grooves (Figs. 4A, 5B). Tamping, however, required much joint filler and was especially difficult and time consuming to apply onto ungrooved bark.

Fall treatment using helical placement of detonating cord. Results of this experiment are summarized in Table 6. There were no statistically significant differences among the treatments in average tree dbh, attack density or fall brood density, nor was there significant correlation between any of these variables and spring brood density. Therefore, in the analysis of variance of spring brood density (Table 7), these variables were not used as co-variates. The 10-cm spacing treatment was omitted because it caused complete mortality. There were significant differences, ($p < 0.05$) in live brood density among the five blocks (groups of treated trees) as well as between the pairs of trees to which the treatments were applied within blocks. Since the treated trees did not differ in dbh, attack density or fall brood density, it is likely that block to block differences in survival are due to site- and tree-specific bark characteristics that affected the sub-cortical brood habitat, as well as the degree of bark disuption by the treatments (Fig. 6).

There were significant differences ($p < 0.01$) among all combinations of treatments for mean spring brood density (Column 8, Table 6). Mortality (Column 10, Table 6) decreased with increased detonating cord spacing. However, the fall to spring mortality shown in Column 10, Table 6, was caused by treatment effects plus natural factors, the most important of which was winter mortality. These two classes of mortality factors are not mutually exclusive and if we assume they acted independently the probability of an individual beetle's death (p_d) can be expressed in terms of the probability of death from the treatment (p_t) and natural factors (p_n) as follows:

$$p_d = p_t + p_n - p_t \times p_n.$$

Solving for p_t; $p_t = (p_d - p_n)/(1 - p_n)$. Estimates of pd and the p_n values are given by the mortality figures in Column 10, Table 6, for control and various spacing treatments, respectively. The percent control figures owing to treatment (Column 12, Table 6) were obtained by calculating p_t from the above equation for each spacing treatment and multiplying the result by 100. Thus, even the 20 cm spacing of detonating cord caused nearly complete mortality (98%) acting alone but the estimated mortality caused by 30 cm spacing was only about 70%. The 20 cm spacing of detonating cord caused similar mortality as the same treatment applied to four bolts in the preliminary experiment (Column 7, Table 2). These findings indicate that 10 g/m Scuf-Flex® detonating cord, wrapped onto the infested bole with 20 cm spacing between wraps, is effective in destroying mountain pine

TABLE 7. Analysis of variance of the effects of detonating 10 g/m 'Scuf-Flex'® detonating cord, helically wrapped at 3 spacings on mountain pine beetle survival in lodgepole pine. Survival was measured in spring following fall treatment.

Source of variation	Df	Sum squares	Mean squares	F-value
Blocks (areas)	4	3718.80	927.70	4.82*
Treatments[a]	2	9518.70	4759.35	24.69**
Sampling error	15	13168.70	877.91	4.55*
Experimental error	8	1542.10	192.77	
Total	29	27,948.30		

a The 10-cm spacing treatment was omitted because it caused complete mortality.
* $p < 0.05$.
** $p < 0.01$.
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beetle broods in individual trees when applied during the fall season.

In the field spring treatment with Scuf-Flex® helically wrapped, at 20 cm spacing only superficially scored the bark, removing none (Fig. 7). This was in marked contrast to application of the same treatment in the previous fall, which ultimately resulted in extensive bark loosening and shedding (Fig. 7B). The main reason for this difference was that by spring the dried bark of infested trees adhered tighter to the wood than in the fall (Reid *et al.* 1967). Therefore, generally much more extensive dark disruption would be required to cause the same mortality as by fall treatment. In the spring period, 10 g/m detonating cord, placed in vertical grooves cut through the bark at 20 cm intervals, will generally cause extensive bark removal and loosening and probably destroy directly a high proportion of the broods. However, until a tool is developed to groove bark and apply the tamping material, or a self-tamped detonating cord is developed, spring treatment will be limited by time-consuming application.

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