Partial cutting lodgepole pine stands to reduce losses to the mountain pine beetle

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Partial cutting prescriptions were applied in the fall of 1978 through the early winter of 1980 to lodgepole pine stands (*Pinus contorta* Douglas var. *latifolia* Engelmann) threatened by mountain pine beetle (*Dendroctonus ponderosae* Hopkins) in the Kootenai and Lolo National Forests in western Montana, U.S.A. Partial cutting prescriptions consisted of removing from separate stands all trees 17.8, 25.4, and 30.5 cm and larger diameter at breast height (dbh), and prescriptions leaving 18.4, 23.0, and 27.6 m^2 basal area per hectare. In thinned stands, the first 5 years' results following cutting showed greatly reduced tree losses to mountain pine beetle when compared with untreated stands ($P < 0.01$) on both forests. There were no significant differences in tree losses among partial cut treatments ($P > 0.05$). Post treatment mortality of lodgepole pine 12.7 cm and larger dbh to mountain pine beetle averaged 4.0 to 38.6% on the Kootenai and 6.0 to 17.1% on the Lolo in treated stands, compared with averages of 93.8 and 73.1% in untreated stands. Partial cutting appears to be useful for reducing lodgepole losses to mountain pine beetle.

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Des descriptions de coupes partielles ont été appliquées entre l'automne 1978 et le début de l'hiver 1980 à des peuplements de pin tordu (*Pinus contorta* Douglas var. *latifolia* Engelmann) endommagés par le dendroctone du pin (*Dendroctonus ponderosae* Hopkins) dans les forests nationales de Kootenai et de Lolo dans l'ouest du Montana, aux États-Unis. Ces prescriptions consistaient à extraire de divers peuplements, dans certains cas tous les arbres d'un dhp égal ou supérieur à 17,8, 25,4 et 30,5 cm et, dans d'autres, à laisser des surfaces terrières de 18,4, 23,0 et 27,6 m^2/ha. Dans les peuplements traités, les premiers résultats quinquennaux ont indiqué que les pertes causées par le dendroctone avaient été fortement réduites lorsqu'on les compare à celles survenues dans les peuplements demeurés intacts ($P < 0{,}01$) dans les deux forêts. Aucune différence significative quant aux pertes n'a été décelée parmi les diverses méthodes de coupe partielle ($P > 0{,}05$). La mortalité postérieure aux traitements chez les pins de 12,7 cm et plus de dhp causée par le dendroctone s'est élevée de 4,0 à 38,6% à Kootenai et de 6,0 à 17,1% à Lolo dans les peuplements traités, alors qu'elle était en moyenne de 93,8 et de 73,1% dans les peuplements intacts. Il semble que la coupe partielle soit utile pour diminuer les pertes en pin tordu provoquées par le dendroctone.

[Traduit par la revue]

Introduction

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (MPB) continues to kill millions of lodgepole pine (*Pinus contorta* Douglas var. *latifolia* Engelmann) annually in the western United States and western Canada (Loomis et al. 1985; Sterner and Davidson 1982). The beetle kills all other species of pines throughout its range as well, including exotics planted for forest or ornamental purposes (Amman and Cole 1983).

Until about 1970, the principal way of managing MPB infestations consisted of applying insecticide to infested trees or felling and burning infested trees (Safranyik et al. 1974; Klein 1978). However, where control efforts have destroyed local MPB populations but stand conditions conducive to MPB infestation have not been changed, reinfestation is likely within a few years (Amman and Baker 1972). Generally, infestations of MPB are influenced by weather, site, stand, and tree conditions (Amman and McGregor 1985). The importance of individual factors may vary geographically (e.g., Katovich and Lavigne 1986). Therefore, until stand or tree conditions are altered, either by forest managers or beetles, mature trees will continue to be infested until most are killed (Amman and Baker 1972).

Different strategies can be integrated in commercial forests and used throughout the infestation cycle. These include logging and beetle attractants coupled with logging (Borden et al. 1986). In addition, use of fire, although untested, has been suggested. Even in commercial forests, economical, environmental, and political reasons may preclude implementation of all or even a few of the possible strategies (McGregor and Cole 1985; McMullen et al. 1986; Roe and Amman 1970) in many susceptible or infested areas. Even if treatment of all susceptible high risk stands at any one time were possible, it might not be desirable. Treating all stands at once would preclude creating a mosaic of age and size classes, which appears to be one of the best long-term strategies for dealing with MPB (Roe and Amman 1970).

Clear-cutting may be the preferred option for the majority of high risk lodgepole pine stands in a specific drainage. However, concern for other resource values (i.e., riparian areas, wildlife

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hiding, thermal and escape cover, watershed protection, and view areas) limits the amount of clear-cutting and frequently permits only partial treatment of many susceptible stands. Therefore, partial cutting offers potential for reducing stand susceptibility to MPB and for being compatible with management of other resources as well.

Partial cutting lodgepole pine stands to reduce MPB infestations has been tested by others (Cahill 1978; Cole et al. 1983; Hamel 1978). These studies included diameter limit cuts, a phloem limit cut, and only one spaced thinning treatment. Diameter limit and phloem limit cuts alter the food supply of MPB by removing large diameter trees where the beetles' reproductive success is best (Cole et al. 1976). However, such practice may select against lodgepole of fastest growing genotype.

This paper reports on the first 5 years' results of studies investigating diameter limit cuts and mechanically spaced thinnings. The principal objective of these studies was to test the effectiveness of partial cuts, consisting of three levels of diameter limit cuts and three levels of mechanically spaced thinnings, in reducing tree mortality to MPB. This study differs from other studies testing the effectiveness of partial cuts in two important ways: (*i*) MPB populations have been larger and caused much more tree mortality in the Kootenai and Lolo National Forests, and (*ii*) several levels of mechanically spaced thinnings were included.

Methods

Study areas

Study areas were just coming under MPB attack when selected in 1976 (McGregor 1979). One area was on the Yaak Ranger District, Kootenai National Forest. The other area was on the Plains Ranger District, Lolo National Forest. The Kootenai study area was in Waper, Hensley, and Benefield Creek subdrainages, forming part of the upper Yaak River drainage. Age at breast height of lodgepole in the study stands averaged 102 ($N = 188$; SD = 6.77). The Lolo study area was in Mantrap Fork, Radio, Coolman, and Beartrap Creek subdrainages, forming part of the upper Thompson River drainage. Average age of the lodgepole component was 76 ($N = 314$; SD = 10.88).

Study design

Two partial cutting treatments of three levels each and an unthinned check treatment were randomly assigned to stands in 1976. Partial cutting began in the fall of 1978 and was completed in early winter of 1980, due to logging contracts that precluded harvesting all stands in a single year. Three levels of diameter limit cutting removed all lodgepole pine ≥17.8, ≥25.4, and ≥30.5 cm dbh. The three levels of spaced thinning left 18.4, 23.0, and 27.6 m^2/ha of residual basal area (BA) for all species. Unthinned check stands were within each study area immediately adjacent to some thinnings. Treatments were replicated three times on each national forest. During the study, active beetle infestations were present in check stands and in almost all stands designated for thinning.

Stand surveys

Variable plot surveys, using 10 basal area factor, were conducted each year from 1976 through spring 1985. Variable plots were located in a systematic random grid pattern. The number of plots ranged from 14 to 20 per stand, proportional to stand size (4.0 to 11.3 ha). A Relaskop was used to determine trees to be tallied. The diameter of all trees 12.7 cm and larger was measured and the trees were categorized as live, killed by MPB, or killed by other causes.

Analysis of variance using SAS procedure GLM for unequal numbers of observations determined whether percent tree mortality (untransformed) differed significantly among treatments and forests. Tukey's studentized range test was used to test for significant differences among means for percent tree mortality.

Results

The examination of the effect of partial cutting treatments in the spring of 1985 marked the first 5 years following the completion of harvest. All stands in which trees 17.8 cm and larger dbh were removed windthrow the first year following thinning. In addition, in the Kootenai study area, one stand in each of the partial cutting treatments was so heavily infested by MPB prior to partial cutting that the entire stand had to be harvested, except for partial cuttings, leaving 23 m^2 basal area from which two stands had to be harvested. In the Lolo study area only one stand, designated for 25.4 cm diameter limit cut, became so heavily infested that the entire stand was removed. Because of the logistics involved in selection of stands, arranging sales, and thinning, no attempt was made to replace harvested stands. Therefore, 29 of the original 42 stands remained for the study. Characteristics for the remaining stands are presented in Tables 1 and 2.

Tree mortality by silvicultural treatment

Tree losses for all treatments and checks were 46.4 and 27.0% for the Kootenai and Lolo, respectively; these losses were not significantly different ($P > 0.3$). Average losses for both forests combined ranged between 5.5% for partial cuts leaving 23.0 m^2 BA/ha and an average of 23.3% for treatments leaving 27.6 m^2 BA/ha. Check stands averaged 83.5% loss of lodgepole.

Analysis of variance showed percent tree loss among treatments in the Kootenai study area was significantly different ($P < 0.01$). Tukey's studentized range test showed the check stands had significantly more mortality than all partial cut treatments except residual of 27.6 m^2 BA/ha ($P < 0.05$). Average losses among partial cutting treatments varied greatly, ranging from 4.0% in the stand partial cut to 23.0 m^2/ha to 38.6% in partial cuts leaving 27.6 m^2/ha (Fig. 1). However, losses did not differ significantly ($P > 0.05$). Untreated check stands averaged 93.8% loss of lodgepole (Table 3).

Tree mortality in the Lolo study area also was significantly greater in the check stands than in partial cut treatments ($P < 0.001$). Losses among the partial cutting treatments did not differ significantly ($P > 0.05$). Tree losses ranged between an average of 6.0% in partial cuts leaving 23.0 m^2 BA/ha and an average of 17.1% in the 30.5 cm diameter limit cuts (Fig. 1). Untreated check stands averaged 73.1% tree loss (Table 4).

Tree mortality over time

All stands were subjected to MPB infestation either before or after treatment, as indicated by tree losses (Tables 3 and 4). In the Kootenai, one stand had no beetle infestation prior to thinning and one stand in both the Kootenai and Lolo had no beetle infestation following thinning. Most stands showed reduced losses following thinning. However, losses then increased, reaching a peak in 1982, and then declined sharply in 1983 with no losses in 1984. Check stands showed highest losses in 1980 in the Kootenai and in 1982 in the Lolo.

Discussion

Losses to MPB were greatly reduced, regardless of the type of partial cutting prescription used, when compared with check stands. Although tree losses among partial cutting treatments were not significantly different, losses were expected to be greater in stands partial cut to a residual of 27.6 m^2 BA/ha on both forests and the 30.5 cm diameter limit on the Lolo, because these stands contained more large diameter trees. Losses are related generally to the number of large diameter trees;

TABLE 1. Characteristics of lodgepole pine stands used in test of partial cuts to reduce losses to mountain pine beetles, Kootenai National Forest, Montana, U.S.A.

Treatment	Area (ha)	Volume removed (m^3), all species	Live basal area after treatment (m^2): All species	Live basal area after treatment (m^2): Lodgepole	Lodgepole basal area (%)	Live lodgepole pine after treatment: No./ha	Live lodgepole pine after treatment: dbh (cm)
25.4 cm diam. limit							
Unit B5	6.5	168.5	13.1	8.7	66.4	217.5	20.3
Unit B6	7.3	83.3	37.9	30.3	79.9	805.6	18.8
30.5 cm diam. limit							
Unit H4	4.0	35.6	17.9	14.0	78.2	299.0	23.4
Unit H5	5.7	104.8	20.9	17.0	81.3	462.1	23.4
18.4 m^2 residual BA							
Unit B4	6.5	182.4	17.2	14.5	84.3	331.1	23.1
Unit W3	5.7	70.7	12.6	6.2	49.2	123.6	25.4
23.0 m^2 residual BA							
Unit B3	7.7	105.0	22.7	22.7	100.0	780.9	19.1
27.6 m^2 residual BA							
Unit B2	11.3	38.1	25.7	24.1	93.8	701.8	19.8
Unit B8	7.3	164.8	25.5	10.6	41.6	170.4	26.9
Untreated check							
Unit B10	9.3	0.0	55.6	49.6	89.2	1477.7	20.3
Unit B11	10.1	0.0	56.5	49.6	87.8	1314.6	20.3
Unit W4	10.1	0.0	34.4	6.2	18.0	118.6	25.9

NOTE: BA, basal area.

TABLE 2. Characteristics of lodgepole pine stands used in test of partial cuts to reduce losses to mountain pine beetles, Lolo National Forest, Montana, U.S.A.

Treatment	Area (ha)	Volume removed (m^3), all species	Live basal area after treatment (m^2): All species	Live basal area after treatment (m^2): Lodgepole	Lodgepole basal area (%)	Live lodgepole pine after treatment: No./ha	Live lodgepole pine after treatment: dbh (cm)
25.4 cm diam. limit							
Unit 4	7.7	14.1	24.3	20.7	85.2	758.6	17.8
Unit 7	8.5	26.4	22.3	19.3	86.5	731.4	16.8
30.5 cm diam. limit							
Unit 2	6.9	19.0	25.0	19.5	78.0	551.0	20.1
Unit 3	6.9	26.4	23.4	21.3	91.0	602.9	20.6
Unit 8	6.1	24.0	25.9	25.0	96.5	696.8	20.3
18.4 m^2 residual BA							
Unit 1	6.1	21.5	18.4	8.0	43.5	269.3	20.3
Unit 5	6.1	24.0	19.5	17.2	88.2	602.9	19.1
Unit 12	6.1	24.0	17.9	10.8	60.3	318.8	20.3
23.0 m^2 residual BA							
Unit 9	7.3	0.0	23.0	17.9	77.8	308.9	25.9
Unit 11	6.1	24.0	23.9	18.6	77.8	494.2	21.6
Unit 13	8.9	13.9	23.0	19.5	84.8	625.2	20.1
27.6 m^2 residual BA							
Unit 6	6.9	15.8	29.8	28.9	97.0	897.0	18.8
Unit 10	6.1	17.9	25.0	19.7	78.8	422.5	22.6
Unit 14	6.1	23.9	27.5	24.8	90.2	311.4	20.6
Untreated check							
Unit 7A	8.5	0.0	31.0	30.8	99.4	879.7	21.1
Unit 18	6.1	0.0	30.1	21.8	72.4	672.1	20.3
Unit 27	8.5	0.0	32.1	24.1	75.1	654.8	21.6

NOTE: BA, basal area.

TABLE 3. Lodgepole pine killed per hectare each year by mountain pine beetles in a partial cutting demonstration. Partial cuts were made in late 1978 and 1979, Yaak River Drainage, Kootenai National Forest, Montana, U.S.A.

Treatment	Trees killed before treatment, 1976–1979		Trees killed after treatment												
			1980		1981		1982		1983		1984		1980–1984		
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	SD
25.4 cm diam. limit															
Unit B5	17.3	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.3	0.0	
Unit B6	0.5	0.5	16.8	17.4	0.0	0.0	78.8	81.6	0.5	0.5	0.0	0.0	96.6	11.9	
Average*	8.9	15.8	8.4	14.7	0.0	0.0	39.4	69.0	0.3	0.5	0.0	0.0	57.1	6.0*a*†	8.4
30.5 cm diam. limit															
Unit H4	23.5	49.1	13.8	28.8	0.0	0.0	10.6	22.1	0.0	0.0	0.0	0.0	47.9	8.2	
Unit H5	26.7	39.1	8.6	12.6	14.1	20.6	19.0	27.7	0.0	0.0	0.0	0.0	68.4	9.0	
Average	25.1	43.2	11.2	19.2	7.1	12.2	14.8	25.4	0.0	0.0	0.0	0.0	58.3	8.6*a*	0.6
18.4 m^2 residual BA															
Unit B4	4.9	33.1	0.0	0.0	3.7	25.0	6.2	41.9	0.0	0.0	0.0	0.0	14.8	3.0	
Unit W3	19.0	55.3	3.0	8.7	3.0	8.7	9.4	27.3	0.0	0.0	0.0	0.0	34.4	12.5	
Average	12.0	48.8	1.5	6.1	3.3	13.4	7.8	31.7	0.0	0.0	0.0	0.0	24.6	7.8*a*	6.7
23.0 m^2 residual BA															
Unit B3	3.7	10.5	0.0	0.0	5.5	15.7	25.9	73.8	0.0	0.0	0.0	0.0	35.1	4.0*a*	—
27.6 m^2 residual BA															
Unit B2	0.0	0.0	4.9	7.4	0.0	0.0	61.1	92.6	0.0	0.0	0.0	0.0	66.0	9.4	
Unit B8	28.4	19.7	100.3	69.8	0.0	0.0	15.1	10.5	0.0	0.0	0.0	0.0	143.8	67.7	
Average	14.2	13.5	52.6	50.2	0.0	0.0	38.1	36.3	0.0	0.0	0.0	0.0	104.9	38.6*ab*	41.2
Untreated check															
Unit B10	430.3	35.7	595.3	49.6	22.7	1.9	122.1	10.2	31.1	2.6	0.0	0.0	1201.5	81.3‡	
Unit B11	396.2	30.2	292.6	22.2	283.4	21.6	229.3	17.4	113.2	8.6	0.0	0.0	1314.6	100.0	
Unit W4	43.5	36.7	60.0	50.6	15.1	12.7	0.0	0.0§	0.0	0.0	0.0	0.0	118.6	100.0	
Average	290.0	33.0	316.0	36.0	107.1	12.2	117.1	13.3	48.1	5.5	0.0	0.0	878.3	93.8*b*	10.8

*Percent distribution by year of trees killed during the study.
†Means followed by same letter not significantly different ($P > 0.05$); Tukey's studentized range critical value = 5.63.
‡Figures for check stands include losses of 1976 to 1984.
§Stand was logged in 1982.

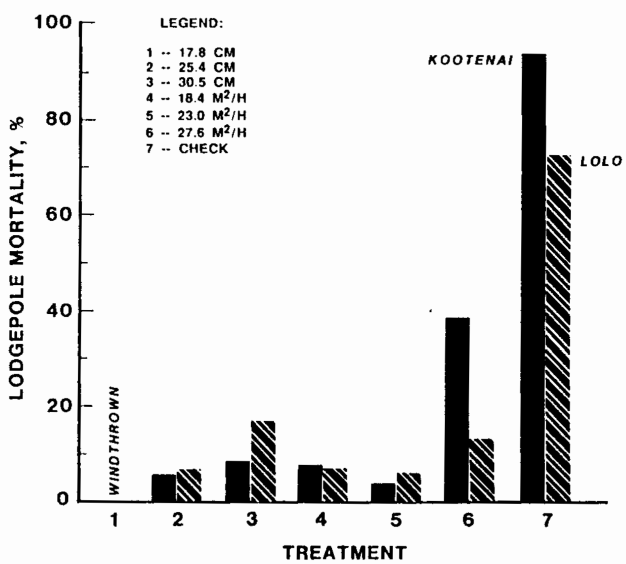

FIG. 1. Average percent lodgepole pine killed by mountain pine beetles in partial cutting treatments on the Kootenai and Lolo National Forests, Montana, U.S.A. Legend indicates diameter limit cuts (1, 2, 3), spaced thinnings (4, 5, 6), and untreated check (7).

lodgepole is highly susceptible when the average tree diameter is 20.3 cm or larger (Amman et al. 1977; Cole and Amman 1969; Hopping and Beall 1948; McGregor et al. 1981; Safranyik et al. 1974). Also, tree mortality following cutting occurred more frequently where trees had a clumpy distribution, particularly in the less uniformly distributed trees in partial cuts based on diameter limit and those based on a residual of 27.6 m^2/ha. Infestations in stands containing many large diameter trees suggest partial cuts may not be as effective in such stands as in those of smaller average diameter. Mitchell et al. (1983) also found considerable mortality in the stand having the largest average tree diameter in their study. In addition, tree losses associated with unequal distribution of trees suggest the need to maintain relatively even spacing when using partial cuts to reduce tree losses to MPB.

Tree losses in both forests were similar in the 25.4 cm diameter limit cut and residual stands of 18.4 m^2 and 23.0 m^2 BA/ha. However, partial cutting based on leaving BA of 18.4 m^2 or 23.0 m^2/ha is preferable from a stand growth and vigor standpoint to that based on diameter limit. Reducing stand density to these levels with spacing thinnings allows the forest manager better opportunity to maintain even spacing and allows for considerable growth to occur before the stand is expected to

TABLE 4. Lodgepole pine killed per hectare each year by mountain pine beetles in a partial cutting demonstration. Partial cuts were made in 1979 and early 1980, Lolo National Forest, Montana, U.S.A.

	Trees killed before treatment, 1976–1979		Trees killed after treatment												
			1980		1981		1982		1983		1984		1980–1984		
Treatment	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	SD
25.4 cm diam. limit															
Unit 4	38.0	36.9	0.0	0.0	25.9	25.1	36.6	35.4	2.7	2.6	0.0	0.0	103.2	8.6	
Unit 7	18.8	33.3	0.0	0.0	37.6	66.7	0.0	0.0	0.0	0.5	0.0	0.0	56.4	5.1	
Average	28.4	35.5	0.0	0.0	31.8	39.8	18.3	22.9	1.4	1.8	0.0	0.0	79.8	6.9*a*†	2.5
30.5 cm diam. limit															
Unit 2	27.2	17.4	0.0	0.0	0.0	0.0	128.2	82.0	1.0	0.6	0.0	0.0	156.4	23.4	
Unit 3	41.8	28.4	0.0	0.0	26.9	18.3	75.9	51.6	2.5	1.7	0.0	0.0	147.1	17.5	
Unit 8	6.7	8.4	0.0	0.0	7.4	9.3	59.6	74.9	5.9	7.4	0.0	0.0	79.6	10.5	
Average	25.2	19.8	0.0	0.0	11.4	8.9	87.9	68.9	3.1	2.4	0.0	0.0	127.7	17.1*a*	6.5
18.4 m^2 residual BA															
Unit 1	2.4	16.0	0.0	0.0	6.4	42.7	6.2	41.3	0.0	0.0	0.0	0.0	15.0	4.7	
Unit 5	0.0	0.0	0.0	0.0	38.5	41.2	48.4	51.9	6.4	6.9	0.0	0.0	93.3	15.5	
Unit 12	20.6	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.6	0.0	
Average	7.7	17.9	0.0	0.0	15.0	34.9	18.2	42.3	2.1	4.9	0.0	0.0	43.0	6.7*a*	7.9
23.0 m^2 residual BA															
Unit 9	21.3	68.9	0.0	0.0	0.0	0.0	9.6	31.1	0.0	0.0	0.0	0.0	30.9	3.1	
Unit 11	1.2	2.1	6.7	11.9	14.8	26.3	33.6	59.7	0.0	0.0	0.0	0.0	56.3	11.1	
Unit 13	6.4	20.8	0.0	0.0	7.2	23.5	17.1	55.7	0.0	0.0	0.0	0.0	30.7	3.9	
Average	9.6	24.7	2.2	5.6	7.3	18.6	20.1	51.1	0.0	0.0	0.0	0.0	39.3	6.0*a*	4.4
27.6 m^2 residual BA															
Unit 6	16.3	6.3	0.0	0.0	56.8	21.9	185.6	71.6	0.5	0.2	0.0	0.0	259.2	27.1	
Unit 10	4.7	14.2	14.3	43.5	2.0	6.1	11.9	36.2	0.0	0.0	0.0	0.0	32.9	6.7	
Unit 14	3.7	32.3	16.8	81.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.5	5.4	
Average	8.2	7.9	10.4	10.0	19.6	18.8	65.7	63.1	0.2	0.2	0.0	0.0	104.2	13.1*a*	12.2
Untreated check															
Unit 7A	12.1	3.2	0.0	0.0	18.8	5.0	345.7	91.8	0.0	0.0	0.0	0.0	376.6	42.8‡	
Unit 18	96.8	18.6	52.4	10.1	146.0	28.1	162.6	31.3	61.8	11.9	0.0	0.0	519.6	77.3	
Unit 27	650.3	99.3	0.0	0.0	0.0§	0.0	0.0	0.0	0.0	0.0	0.0	0.0	650.3	99.3	
Average	253.1	49.1	17.5	3.4	54.9	10.6	169.4	32.9	20.6	4.0	0.0	0.0	515.5	73.1*b*	28.5

*Percent distribution by year of trees killed during the study.
†Means followed by same letter not significantly different ($P > 0.05$); Tukey's studentized range critical value = 4.82.
‡Figures for check stands include losses of 1976 to 1984.
§Stand was logged in 1982.

be reinfested by MPB. However, the type of prescription used will depend upon the manager's objectives.

The objective of thinning is to reduce competition and therefore increase growth of residual trees. However, the 1st or 2nd year following thinning, one might expect residual trees to suffer from thinning shock or delayed stem growth until new root and shoot growth, thus rendering the trees still susceptible to MPB. Continued tree mortality in most stands on the Kootenai suggests this may have happened, but on the Lolo most stands showed no mortality the 1st year following thinning. Treatments in both forests included removing all infested trees so that developing beetles in the stands were removed at the time of thinning. Although data were not collected on MPB populations in the areas surrounding each treatment, populations may have been low enough around the Lolo study area so that little tree mortality occurred in treatment plots the 1st year following cutting. Almost all plots contained MPB-infested trees the 2nd and 3rd years after cutting.

The results of our study demonstrate that partial cutting can be used to reduce tree losses to MPB. Prior studies (Cahill 1978; Cole et al. 1983; Hamel 1978) concentrated on removing trees providing the most food for MPB, i.e., large diameter and thick phloem. Our results show that properly spaced lodgepole of any size can be left in the stand, thus preserving the faster growing genotypes associated with large trees. However, care should be used in applying partial cuts. Partial cutting guidelines by Alexander (1975) should be followed to avoid certain problems, for example, excess windthrow and an increase in dwarf mistletoe infection. When partial cutting is elected as part of the overall management strategy, managers must carefully select stands. Site attributes and considerations for evaluating lodgepole pine stands for partial cutting are available (Alexander 1975; Bollenbacher and Gibson 1986).

Managers can benefit several resource values by including partial cutting in their control strategies. The residual green stands can increase overall wildlife habitat by creating better age-class diversity and maintain long-term habitat quality for hiding cover and forage. A mix of regeneration harvests and partial cuts can also reduce potentially adverse visual impacts. Although increases in water yield cannot be totally eliminated by utilizing a mix of regeneration harvests and partial cuts, yields can be reduced enough in critical areas to protect water quality. When faced with an impending MPB epidemic, inclusion of partial cuts in the overall strategy appears to be a reasonable alternative to wide-scale regeneration harvests or extensive MPB-caused mortality.

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