BAITING AND CUTTING TO MANAGE MOUNTAIN PINE BEETLE INFESTATIONS

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ABSTRACT: Semiochemicals have gained wide acceptance in the past 8 years. Operational projects have demonstrated that synthetically produced semiochemicals are an effective tool to augment management of mountain pine beetle in spot baiting, containment, and concentration of beetle populations. Analysis of data from baited and check stands in the Kootenai and Flathead National Forests (NF) shows baiting significantly changes the number of infested trees per acre. Tree diameter is statistically significant. The relative difference in infestation shows the 7-8.9 inch and 9+ inch DBH size classes incur larger changes in infestation rate than 5-6.9 inch DBH size classes. Habitat type group did not influence infestation rates in baited stands in the Kootenai NF but was statistically significant in the Flathead NF. Analysis of build-up ratios shows that baiting and habitat type group are statistically significant for stands in the Flathead NF, but only baiting, and not habitat type, affected build-up ratios in baited stands in the Kootenai NF. Mortality due to baiting depends on the percent of lodgepole pine in the 5-6.9 inch DBH classes in baited stands.

INTRODUCTION

The current cycle of mountain pine beetle (MPB) infestations in the western U.S. and provinces of Alberta and British Columbia began in the early 1970s (Van Sickle 1982; McGregor 1982). Epidemic infestations are present in lodgepole pine (LPP) forests of four western USDA Forest Service Regions and four of the six forest regions in the Province of British Columbia. The other two regions in British Columbia have some infestation (Hall 1985). Further, extensive areas of susceptible pine are at risk as MPB infestations continue to expand and new epicenters develop.

Various management approaches to reduce or prevent pine losses have been discussed by several other participants during this symposium. Strategies to reduce stand susceptibility by creating a mosaic of age and size classes and develop species diversity over several decades are most desired. Short-term strategies of totally suppressing a mountain pine beetle outbreak are unreasonable and probably impractical (Hall 1985), because stand conditions conducive for outbreak development would remain unchanged. Therefore, infestations would recur as soon as control strategies ceased. Also, it may be unrealistic to say direct control is entirely inappropriate or useless (Hall 1985). Direct control practices in specific areas can slow the rate of expansion of beetle populations and tree mortality. Slowing developing infestations in selected areas will buy time for developing management plans and implementing long-term strategies. This should be considered when developing harvesting and silvicultural prescriptions for specific areas. Indirect practices depend on modifying stand conditions that are conducive to beetle population build-up. Eventually, harvesting stands before they become susceptible and developing age-class and species mosaics should limit infestations and tree losses.

Whether implementing short- or long-term management strategies, the use of pheromones can enhance the efficiency of various management programs.

Pheromones, more specifically aggregation pheromones (semiochemicals), have been tested since the mid-1970s in British Columbia and the western U.S.

Early tests using trans-verbenol with alpha-pinene, and sometimes with ethanol included, showed that attractiveness of these combinations although positive was less than expected. When combined with single-tree treatment, such as preflight treatment with contact insecticides, postflight treatment with arsenicals, and preflight treatment of infested trees with penetrating insecticides for brood reduction, there was marked reduction in subsequent attacks when compared to check areas (Hall 1985). However, it was necessary to refine the pheromone complex before the use of semiochemicals could be considered for operational stand baiting.

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RECENT TESTING

Following several years of field trials and testing of various combinations of potential synthetic chemicals by researchers at Simon Fraser University, notably Dr. John Borden, a consistently effective aggregation semiochemical was designed from a combination of *trans*-verbenol, *exo*-brevicomin, and myrcene (PMG/STRATFORD Project Ltd. 1983).

These formulations have been further field tested. By 1982, the use of tree bait semiochemicals was judged acceptable on an operational basis to enhance the effect of treatment (green stand harvest and sanitation cutting) in management of mountain pine beetle (Hall 1985).

A proven technique for tree-baiting with semiochemicals is to contain and concentrate infestations prior to logging (Borden and others 1983b). Originally developed for the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins (Pitman 1973), the technique was adopted for the mountain pine beetle. It is now used routinely as a prelogging treatment in high-hazard lodgepole pine stands in British Columbia (Borden and Lacey 1985).

Spot Baiting

Early detection of small spot infestations (up to 30 trees) and baiting two or more large-diameter trees should contain emerging beetle populations in the immediate vicinity (Borden and Lacey 1985). Following beetle flight, newly attacked trees can be removed by small sales, felled and burned, or felled and treated with chemicals. Direct control of developing small spot infestations can be expensive, but it can buy time until long-term management plans are implemented.

Grid Baiting

The tactic of baiting susceptible trees on a grid requires approximately two baits per acre. In smaller blocks or stands (up to 20 acres), baits are attached to large-diameter trees on a 50-meter grid, starting 25 meters in from the unit boundary. Beetles emerging from brood trees should be in close proximity to pheromone baits (Borden and others 1983a). Baits are applied prior to beetle flight and harvest of newly attacked trees or stands must be completed prior to beetle flight the following year.

Perimeter Baiting

The second method entails baiting trees 50 meters apart in two parallel lines, also 50 meters apart around the proposed block boundary (more than 20 acres). When groups of infested trees occur within the unit, grid baiting at 50 meters or closer, and baiting small infested groups, will further concentrate beetles within the cutting unit. Emerging beetles will be in close proximity to baits and the remaining population within the stand should either naturally find host trees or be contained by baits at the periphery of the stand. Both methods ensure that within stands either grid-baited or baited at the periphery, the dispersing beetles will fly into the attractant odor plume and respond upwind to a baited tree. This will result in mass attack and spillover into adjacent trees as the baited trees are mass attacked (Borden and others 1983a).

Tests in the Northern Region

Based on favorable results, by Borden and many others with management of mountain pine beetle, semiochemical baits were initiated in high-risk green and infested stands in the Northern Region of the USDA Forest Service (Montana and Northern Idaho) in 1984 and 1985. In 1984, approximately 7,090 MPB tree baits were applied at two/acre in lodgepole pine stands scheduled for logging in six National Forests (NF) and on Bureau of Indian Affairs (BIA) and Bureau of Land Management lands. Although baited and check stands were not surveyed systematically, general observations indicated baits worked well, particularly where beetle populations were not excessively high, and where susceptible trees remained for baiting and spillover.

In 1985, 6,950 tree baits were again applied at a rate of two/acre in 117 susceptible lodgepole pine stands in six National Forests and on BIA lands.

Stands baited in 1984 and 1985 were scheduled for harvest prior to beetle flight. Nearly all baited stands were logged prior to beetle flight both years. However, some were not logged due to sales being extended. Stands baited in 1984 that were not logged were rebaited in 1985. Stands baited in 1985 but not logged prior to beetle flight in 1986 were not rebaited because the Environmental Protection Agency stopped the use of tree baits.

During the 1985 season, data were collected from 71 baited stands and 29 check stands. Stands were surveyed, using 10 BAF Prism plots, and all trees 5 inches DBH and larger and tree mortality cause by year were recorded. It was not possible to survey all 117 stands baited in 1985 since many were logged soon following beetle flight.

The data are observations based upon number of beetle-infested trees per acre by DBH size classes (5-6.9 inches, 7-8.9 inches, and 9+ inches), in baited and check stands. Several measures of beetle infestation were used, depending on objectives of the analysis: (1) change in number of infested trees per acre by DBH size class and habitat type from pre- to posttreatment, (2) build-up ratio of infested trees pre- to posttreatment, and (3) percent lodgepole pine mortality as affected by percentage of trees in the 6-7.9 inch DBH size classes prebaiting.

The change in number of infested trees per acre from pre- to posttreatment was computed as posttreatment infested trees per acre minus pretreatment infested trees per acre. The build-up ratio was computed as infested trees/acre posttreatment divided by infested trees/acre pretreatment. Two other variables used in this analysis are percent susceptible LPP in the 5-6.9 inch DBH class, and percent mortality. Percent LPP in the 5-6.9 inch DBH class was computed as the number of LPP in the 5-6.9 inch DBH class at the pretreatment measurement date, divided by the total number of susceptible LPP in the stand. Percent mortality was computed as the total number of LPP killed by beetles following baiting, divided by the total number of LPP > 5 inches DBH in the stand.

Methods

The primary statistical procedure used in this analysis is the ANOVA (analysis of variance). In addition, Scheffe's multiple comparison test was used to determine the sources of variation in terms of specific treatment combinations (Snedecor and Cochran 1980, p. 232). Scheffe's test was carried out by computing a two-sample "t" statistic and comparing the value to the critical "t" specified by the test. Unfortunately, Scheffe's test has little power when sample sizes are small, but it does provide a method of separating very large differences from the merely large differences. For this reason, the primary use of Scheffe's test in this analysis was to rank differences between treatment combinations, and not as a formal test.

The computed value of a test statistic is noted as statistically significant if the p value associated with the statistic is less than 0.05.

Distribution of Samples and General Trends

Table 1 displays by habitat type group the number of stands sampled on the Kootenai NF. Sample sizes were restrictively small for most habitat type groups. Table 2 displays stands surveyed by habitat type group for the Flathead NF. This sample was quite small for comparative purposes.

Two habitat type groups in each National Forest have enough representation for formal analysis. For the Kootenai NF, the first habitat type group is the warm-wet (w-w) habitat type group consisting of habitat types 290, 420, 470, 520, 530, 591, 592, and 571. The second habitat type group is the cool-wet (c-w) habitat type group consisting of habitat types 620, 660, 663, 670, and 740.

Table 1--Number of observations for baited check stands by habitat type group, Kootenai NF, Montana, 1985

Habitat Type Group Number	ADP code	Name	Number of Stands Check	Baited
1	250	Psme/Vaca	0	1
1	260	Psme/Phma	0	1
1	262	Psme/Phma	0	1
2	290	Psme/Libo	1	2
2	420	Pice/Clun	0	2
2	470	Pice/Libo	0	1
2	520	Abgr/Clun	0	1
2	530	Thpl/Clun	0	1
2	591	Abgr/Libo-Libo	1	1
2	592	Abgr/Libo-Xete	1	0
2	571	Tshe/Clun	1	0
3	620	Abla/Clun	0	2
3	660	Abla/Libo	0	7
3	663	Abla/Libo-Vasc	1	0
3	670	Abla/Mefe	1	9
3	740	Abla/Alsi	1	0
4	650	Abla/Caca	0	1
5	690	Abla/Xete	1	5
5	720	Abla/Vagl	0	1
6	730	Abla/Vasc	0	2

Table 2--Number of observations for baited and check stands by habitat type group, Flathead NF, Montana, 1985

Habitat Type Group Number	ADP Code	Name	Number of Stands Check	Baited
1	750	Abla/Caru	0	1
1	280	Psme/Vagl	0	1
1	290	Psme/Libo	0	1
1	730	Abla/Vasc	0	1
2	620	Abla/Clun	0	2
2	621	Abla/Clun-Clun	1	1
2	624	Abla/Clun-Xete	1	1
2	625	Abla/Clun-Mefe	4	4
2	660	Abla/Libo	3	1
2	662	Abla/Libo-Mefe	3	1
2	670	Abla/Mefe	0	2
3	640	Abla/Vaca	1	2
3	663	Abla/Libo-Vasc	0	1
3	690	Abla/Xete	1	5
3	692	Abla/Xete-Vasc	6	7
4	654	Abla/Caca	0	1
5	312	Psme/Syal	1	0

Table 3--Factors affecting infestation rates, and their levels.

Factor	Levels 1	 2	 3
Treatment	baited stands	check stands	
DBH class (in.)	5 - 6.9	7 - 8.9	9+
HT group (Flathead NF)	cool-wet	cool-dry	
HT group (Kootenai NF)	warm-wet	cool-wet	

In the Flathead NF, the cool-wet (c-w) habitat type group consists of habitat types 620, 621, 624, 625, 660, 662, and 670. The cool-dry (c-d) habitat type group consists of habitat types 640, 663, 690, and 692.

Factors used in the analysis are displayed in table 3.

To obtain a general picture of the distribution of the data, pretreatment infestation (trees per acre) was plotted versus posttreatment infestation (trees per acre). Figure 1 displays infested trees/acre from pre- to postbaiting and pre- to post-flight for check stands for the Flathead NF, and figure 2 displays infested trees/acre from pre- to postbaiting and pre- to postflight for check stands for the Kootenai NF.

There is clearly a significant increase in infestation for both baited and check stands in both forests. Also, the relative lack of check stands is apparent. Observations made in the Flathead NF are substantially larger on the average, in both pre- and posttreatment conditions, than in the Kootenai NF.

Determination of Differences in Infested Trees Per Acre

This analysis attempts to determine the sources of variation in change in infested trees per acre from pre- to posttreatment.

Kootenai NF--Table 4 presents the ANOVA table for the three-way analysis of variance.

Treatment is a statistically significant factor in explaining the variation in change in infested trees per acre from pre- to posttreatment. The average increase in infestation rate for baited stands is 37.1 trees per acre, and 7.8 trees/acre for check stands. DBH is also statistically significant, and the relative differences in infestation rates show that the 7-8.9 inch and 9+ inch DBH classes incur larger changes in infestation rate than the 5-6.9 inch DBH class.

Habitat type group was not found to be a significant factor in explaining changes in infestation rates. The fraction of unexplained variation (50619.93) relative to the total variation (81028.52) is fairly large. This indicates that while treatment and DBH class explain a significant amount of the variation, there is still a large variation unexplained.

Changes in Infestation Rate by DBH Class and Treatment

Table 5 shows specific differences between baited and check stands in change in infested trees per acre within each DBH class. Significance at the 0.05 level was tested by Scheffe's test.

Results of the two sample t-tests show that there are very large differences in infestation rate change associated with treatment in the 7-8.9 inch and 9+ inch DBH classes. Data are insufficient to provide strong evidence of differences between treatments in the 5-6.9 inch DBH class.

Flathead NF--Table 6 presents the ANOVA table for the three-way analysis of variance.

Treatment is a statistically significant factor in explaining variation in the change in infestation rate from pre- to posttreatment. The average change in infestation rate for baited stands is 52.9 trees per acre, and 23.1 trees/acre for check stands. Also, DBH and habitat type are statistically significant. The average change in infestation rate is greater in the cool-dry habitat type group (56.0 trees per acre) compared to the cool-wet habitat type group (26.5 trees per acre). As in the analysis of the Kootenai NF data, there was a substantial amount of unexplained variation.

Changes in Infestation Rate by DBH Class, Habitat Type Group, and Treatment

Table 7 shows specific differences between baited and check stands in change in infested trees per acre within each level of DBH class and habitat type group.

No treatment differences were found to meet the critical t for Scheffe's test. This is attributed to the small degrees of freedom available for the tests, the large amount of unexplained variation, and the conservative nature of Scheffe's test. There is some evidence of a consistent trend relating DBH class and the difference between baited and check stands. Both tables 5 and 7 show the difference between check and baited stands to be smaller in the 5-6.9 inch DBH class than the 7-8.9 inch DBH and 9+ inch DBH classes, except in the c-d habitat type group (Flathead NF), 9+ inch DBH class. This number may be small due to a large portion of the trees in the 9+ inch DBH class having been attacked before baiting, and because the 5-6.9 inch DBH classes are not as susceptible as

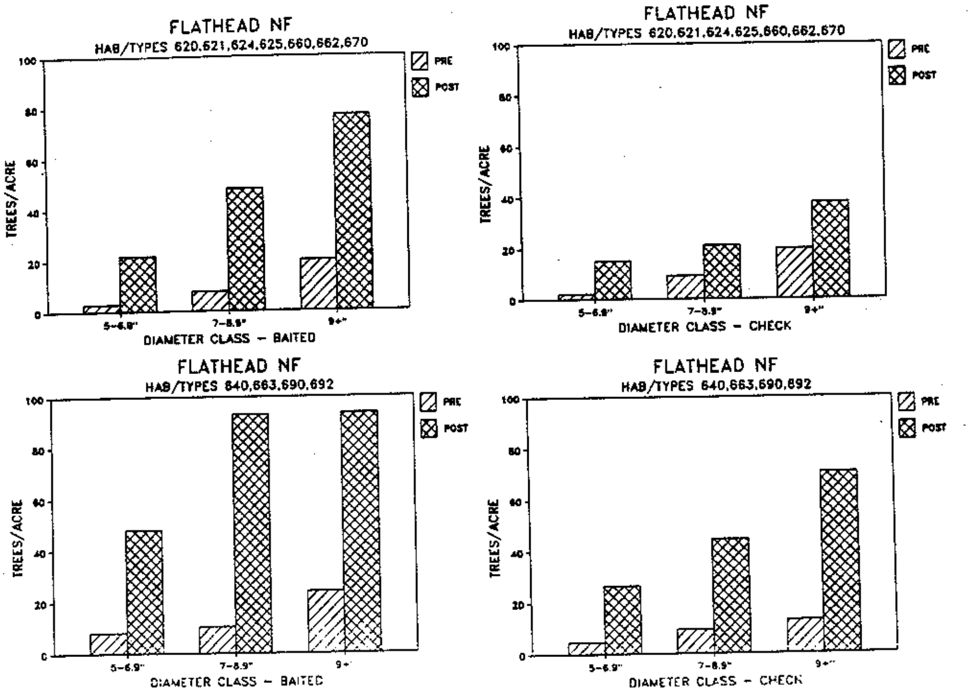

Figure 1--Trees killed per acre by diameter class from pre- to post-baiting, and pre- to postbeetle flight in check stands, Flathead National Forest, Montana, 1985

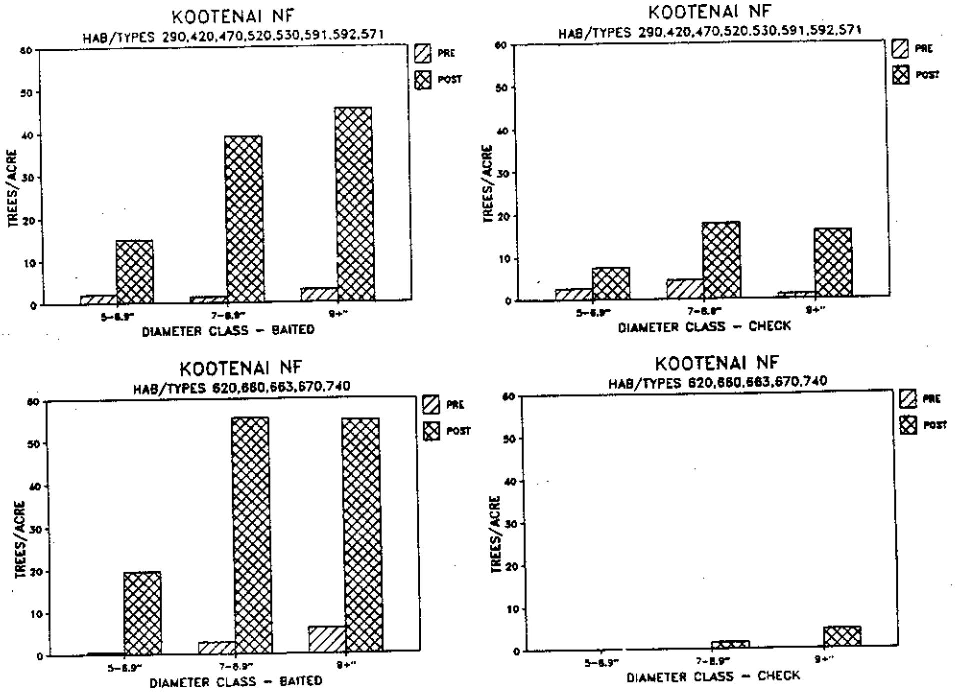

Figure 2--Trees killed per acre by diameter class from pre-to post-baiting, and pre- to postbeetle flight in check stands, Kootenai National Forest, Montana, 1985

Table 4--Analysis of variance table--Kootenai NF, Montana, 1985

Source of Variation	DF	Sums of Squares	Mean Square	F-ratio	P-value
Mean	1	81028.52			
Treatment	1	14811.09	14811.09	28.674	0.000
DBH	2	14902.74	7451.37	14.426	0.000
HT group	1	694.75	694.75	1.345	0.265
Error	98	50619.93	516.53		

Table 5--Average change in infestation rate from pre- to posttreatment within each DBH class on the Kootenai NF, Montana, 1985

DBH class	Infested Trees/Acre Baited	Infested Trees/Acre Checks	Difference	DF	Significance at 0.05 level
5 - 6 in.	16.98	2.37	14.62	31	ns
7 - 8 in.	47.65	8.92	38.72	33	s
9 + in.	46.79	10.97	35.81	33	s

Table 6--Analysis of variance table--Flathead NF, Montana, 1985

Source of Variation	DF	Sums of Squares	Mean Square	F-ratio	P-value
Mean	1	223894.03			
Treatment	1	29548.59	29548.59	24.983	0.000
DBH	2	17793.82	8896.91	7.522	0.001
HT group	1	20431.86	20431.86	17.275	0.000
Error	132	156119.77	1182.72		

Table 7--Average change in pre- to posttreatment infestation rate within each DBH class on the Flathead NF, Montana, 1985

HT group	DBH	Infested Trees/Acre Baited	Infested Trees/Acre Checks	Difference	DF	Significance at 0.05 level
c-w	5 - 6.9 in.	18.69	12.95	5.74	22	ns
c-w	7 - 8.9 in.	40.45	11.99	28.47	22	ns
c-w	9 + in.	56.77	18.16	38.62	22	ns
c-d	5 - 6.9 in.	40.16	21.66	18.55	20	ns
c-d	7 - 8.9 in.	82.66	35.30	47.36	20	ns
c-d	9 + in.	69.33	57.47	11.86	20	ns

larger diameter classes (Cole and Amman 1969; Cole and others 1976; Klein and others 1978; Rasmussen 1972).

Examination of the sample means, displayed in tables 5 and 7, also suggests that DBH class is a major determinant of infestation rate (larger DBH classes suffer larger increases in infestation rates irrespective of treatment).

Conclusions

There is strong evidence that treatment was a factor in determining the change in infested trees per acre, and that the effect of baiting substantially increases the number of infested trees per acre. The fact that differences between specific treatment combinations are not statistically significant can be attributed to the small sample sizes available for these multiple comparison tests, and the amount of unaccounted for variation. There is a clear pattern of larger changes in infested trees per acre in the larger DBH classes. Further, it appears that the effect of baiting is greater in the larger DBH classes. Habitat type group is not a consistent factor in explaining variation in the change in infested trees per acre. However, a larger sample of habitat type groups probably would reduce variation.

Determination of Differences in Build-up Ratio

This analysis attempts to determine sources of variation in the build-up ratio. One drawback to the use of ratios is that a ratio cannot be computed if the denominator of the ratio has a zero value. In these data, there are numerous stands in which the pretreatment infestation rate is 0.0, particularly for the Kootenai NF. These stands are omitted in the following analysis. The distribution of sample observations is displayed in table 8.

The use of build-up ratios instead of the pre- to posttreatment change as a measure of infestation trend has the effect of reducing the relative importance of the stands in which pretreatment infestation was high. For example, consider two stands with pretreatment infestation rates of 10 and 50 trees per acre. Suppose infestation in both stands increases by 50 trees per acre. The change in infestation rates (pre- to posttreatments) is 50.0 in both stands; however, the build-up ratios are 5.0 and 1.0 for each stand, respectively. Consequently, ANOVA using the build-up ratio is more sensitive in detecting factors that affect stands with low initial infestation rates, compared to factors that affect stands with high initial infestation rates.

Kootenai NF--Variation in build-up ratio is shown in table 9. The sensitivity of this analysis is reduced relative to the previous analysis of the Kootenai NF data (using the change in infested trees per acre) because of the reduction of sample size from 103 to 46 observations.

Treatment is the only statistically significant factor. The mean build-up ratio for check stands is 2.6, compared to 14.0 for baited stands. The data are insufficient to conclude that there are substantial differences in the build-up ratio between different DBH classes. This result, contradicting the previous results using the change in infestation rate, may be attributable to sample size differences. The fraction of variation that remains unexplained is large relative to the total variation.

Changes in Build-up Ratio by DBH Class and Treatment

Table 10 shows specific differences between baited and check stands within each DBH class for the Kootenai NF data. Significance tests are not computed since the analysis of variance did not find DBH to have a statistically significant effect upon build-up ratio. The trend of DBH and build-up ratio is not inconsistent with previous results.

Flathead NF--Variation in build-up ratio is described by table 11. Both treatment and habitat type group are statistically significant. The mean build-up ratio for check stands is 4.9, compared to 8.9 for baited stands. DBH was not a significant factor in determining build-up ratio. Unexplained variation is again a substantial fraction of the total variation.

Specific differences between baited and check stands are not identified as statistically significant.

Changes in Build-up Ratio by Habitat Type Group and Treatment

Table 12 shows differences between baited and check stands within each habitat type group for the Flathead NF data.

Changes in Build-up Ratio by DBH Class and Treatment

Table 13 displays the trends in build-up ratio by DBH class for the Flathead NF.

Tables 10 and 13 show that the 7-8.9 inch DBH class is observed to have the largest difference in build-up ratio among the three diameter classes.

Table 8--Number of valid observations based upon build-up ratio

Flathead NF		Baited Stands			Check Stands		
		DBH Class			DBH Class		
		5 - 6.9	7 - 8.9	9 +	5 - 6.9	7 - 8.9	9 +
HT group	c - w	7	9	12	3	9	10
	c - d	9	14	15	4	7	8

Kootenai NF		Baited Stands			Check Stands		
		DBH Class			DBH Class		
		5 - 6.9	7 - 8.9	9 +	5 - 6.9	7 - 8.9	9 +
HT group	w - w	3	4	6	1	3	3
	c - w	2	10	15	0	0	0

Table 9--Analysis of variance table for build-up ratio--Kootenai NF, Montana, 1985

Source of Variation	DF	Sums of Squares	Mean Square	F-ratio	P-value
Mean	1	7513.74			
Treatment	1	788.40	788.40	5.292	0.026
DBH	2	591.50	295.75	1.985	0.150
HT group	1	26.23	26.23	0.176	0.677
Error	41	6107.61	148.97		

Table 10--Mean build-up ratio for each DBH class on the Kootenai NF, Montana, 1985

DBH class	Baited Stands Trees/Acre	Check Stands Trees/Acre	Difference
5 - 6 in.	4.34	0.54	3.80
7 - 8 in.	18.40	1.27	17.13
9 + in.	13.52	6.54	6.97

Table 11--Analysis of variance table for build-up ratio--Flathead NF, Montana, 1985

Source of Variation	DF	Sums of Squares	Mean Square	F-ratio	P-value
Mean	1	7028.40			
Treatment	1	347.62	347.62	5.602	0.020
DBH	2	175.63	87.82	1.415	0.248
HT group	1	299.73	299.73	4.830	0.030
Error	100	6205.37	62.05		

Table 12--Differences between treatments in the mean build-up ratio within habitat type groups--Flathead NF, Montana, 1985

HT group	Baited Stands Trees/Acre	Check Stands Trees/Acre	Difference	DF	Significance at 0.05 level
c-w	7.32	2.86	4.46	57	ns
c-d	10.00	7.40	2.60	54	ns

Table 13--Mean build-up ratio for each DBH class on the Flathead NF, Montana, 1985

DBH class	Baited Stands Trees/Acre	Check Stands Trees/Acre	Difference
5 - 6.9 in.	18.77	5.57	3.20
7 - 8.9 in.	11.84	4.29	7.55
9 + in.	6.38	5.29	1.09

Conclusions

The analysis shows baiting substantially increased the number of infested trees per acre. Differences between specific treatment combinations were not found to be statistically significant using Scheffe's test. Using the build-up ratio as a response variable apparently has the effect of reducing the influence of stands with large pretreatment infestation rates since these stands cannot experience very large build-up rates. It is suggested that high pretreatment infestation rates have reduced the difference in build-up ratios between the 7-8.9 inch and 9+ inch DBH classes, and the 5-6.9 inch DBH class.

Effect of LPP in the 5-6.9 inch DBH Class

This analysis attempts to determine whether the effectiveness of baiting is affected by the percentage of LPP in the 5-6.9 inch DBH class. Field observations suggest that stand composition is a major factor in determining the effectiveness of baiting. Specifically, the percentage of lodgepole pine in the 5-6.9 inch DBH class is thought to affect infestation and response to baiting. The objective of this analysis is to determine if the percentage of lodgepole pine in the 5-6.9 inch DBH class influences the effectiveness of baits.

In this analysis, the percent LPP in the 5-6.9 inch DBH class is compared to the percent of total LPP mortality (all DBH classes). All stands are used in this analysis instead of restricting the analysis to the major habitat type groups since the intent is not to determine the effect of specific factors, but to determine a general trend applicable to all stands in a National Forest.

Figures 3 and 4 are plots of percent LPP in the 5-6.9 inch DBH class versus percent mortality. A regression equation is graphed on each figure, summarizing the trend in baited and check stands in the Flathead NF, but only baited stands in the Kootenai NF. The regression equations are computed by regressing percent LPP mortality on percent LPP in the 5-6.9 inch DBH class. The appendix provides the statistics for the regression equations.

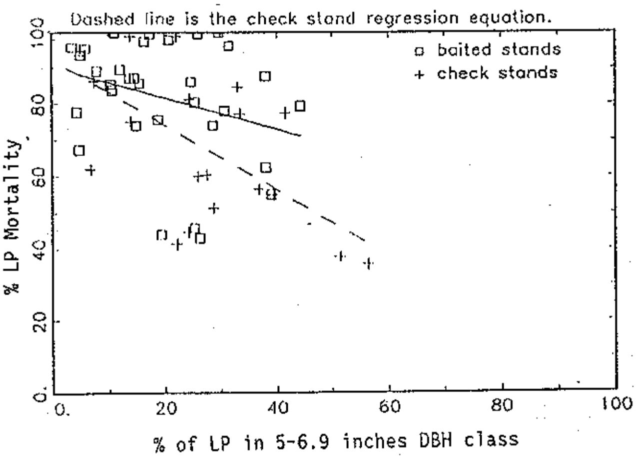

Figure 3--Plot of percent of LP in the 5-6.9 inch DBH class versus percent LP mortality observed at remeasurement, and the graph of the regression equations. Flathead National Forest, Montana, 1985

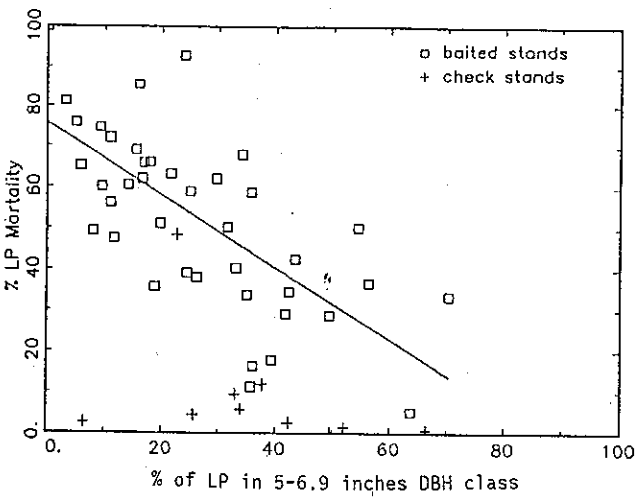

Figure 4--Plot of percent of LP in the 5-6.9 inch DBH class versus percent of LP mortality observed at remeasurement, and the graph of the regression using baited stands. Kootenai National Forest, Montana, 1985

Results--Flathead NF

Figure 3 shows the plotted data and the fitted regression equation for the Flathead NF. The range of the data is unfortunately small as there were no baited stands with more than 44 percent of the pretreatment LPP in the 5-6.9 inch DBH class. Data show that stands with small percent LPP in the 5-6.9 inch DBH class suffer higher mortality rates. The mortality rate declines as the percent LPP in the 5-6.9 inch DBH class increases. The mortality rate is still quite high at the largest observed percent LPP in the 5-6.9 inch DBH class. The regression analysis in the Appendix shows that percent LPP in the 5-6.9 inch DBH class is not a statistically significant predictor of percent LPP mortality since the t statistic testing the significance of the independent variable is 1.663 and the associated p value is 0.107.

Percent LPP in the 5-6.9 inch DBH class is a statistically significant (p value = 0.001, Table 3 Appendix) predictor of LPP mortality in the check stands. However, the relationship is not strong because of the low r2 (0.435). For check stands, as percent LPP in the 5-6.9 inch DBH class increased, average DBH declines, thus decreasing overall stand susceptibility (Cole and Amman 1969; Cole and others 1976; Klein and others 1978).

Results--Kootenai NF

Figure 4 shows the plotted data and the fitted regression equation for the Kootenai NF. The range of susceptible LPP in the 5-6.9 inch DBH class is 0 to 70 percent; a substantial difference compared to data from the Flathead NF. Data show a clear tendency for the mortality rate to decline as the percentage of the LPP in the 5-6.9 inch DBH class increases. The regression analysis in the Appendix shows that percent LPP in the 5-6.9 inch DBH class is a statistically significant predictor of percent LPP mortality since the t statistic testing the significance of the independent variable is 16.109 and the associated p value is 0.000.

Conclusions

Data from baited stands in the Kootenai NF show percent mortality due to baiting does depend upon percent LPP in the 5-6.9 inch DBH class, and the effect is to retard posttreatment mortality. The data are insufficient to support this conclusion for the Flathead NF. A possible reason is that the range of the data is limited and beetle infestation in the vicinity of Flathead NF stands was so great that the beetles attacked the majority of trees larger than 5 inches DBH prior to baiting. Data from baited stands in the Kootenai NF and check stands in the Flathead NF suggest a strong preference for larger DBH classes.

Figure 4 can be used to establish a maximum percent LPP in the 5-6.9 inch DBH class such that baiting is effective. For example, to obtain at least 50 percent mortality following baiting requires that no more than 29 percent of the LPP is in the 5-6.9 inch DBH class. On the other hand, if 60 percent of the LPP is in the 5-6.9 inch DBH class, then only 23 percent mortality is expected after baiting. Caution ought to be exercised in the use of the regression equations in figures 3 and 4 since LPP diameter distribution in stands of other forests are likely to be different.

One can rest assured that semiochemical baiting and sanitation logging will not remove all infested trees in localized areas. Many instances can be brought to mind that following cutting and removing infested trees, one later finds individual attacked trees or small patches of infested trees around the periphery of cut blocks. Whether these beetles come from brood trees not included in the cut block or from a population remaining in stumps following cutting is not really important. What does matter is that these newly infested trees or groups of trees do represent the potential for building beetle populations in the surrounding stands and should be dealt with if the stand is in a beetle management area. Where infested trees are detected late in the year following cutting, baits can be placed around the block during spring or early summer the following year. Baits should be attached to large-diameter trees, 25 meters in from the edge, and if the cut unit boundary is more than a spot, baits can be spaced at 100-meter intervals around the edge. Baited trees will serve as aggregation centers for the residual beetle population; following flight, newly attacked trees can be harvested with small sales, felled and burned, or treated with chemicals (Borden and others 1983b; Hall 1985).

Diversion Baiting

Baiting to divert beetles away from leave strips (riparian areas or other high-value stands) may be an additional option (Borden and Lacey 1985); however, this strategy has not been tested to our knowledge. It is possible to use it in conjunction with antiaggregation pheromones (verbenone) and possibly repellents, but field testing of this strategy is needed prior to it being recommended for operational use. Baiting stands scheduled for harvest adjacent to or near stands protected by use of ground or aerially applied antiaggregates or repellents may prove to be a useful tool.

It must be emphasized that semiochemicals will not control beetle populations. They may in fact aggravate the problem. Aggregation pheromones manipulate beetle populations by restricting dispersal, or may possibly enhance it in the case of antiaggregates or repellents. If not used in conjunction with harvesting or single-tree treatment, the infestation will probably expand more than if pheromones were not used. Where semiochemical tree baits are used, beetles normally lost during dispersal may have a better chance of finding suitable host trees, thereby increasing the number of trees successfully attacked over the number of trees attacked had baits not been used (Hall 1985). Careful selection and baiting of larger diameter trees, which the beetle naturally prefers, will increase effectiveness of baiting and probability of mass attack. Baits should be placed in the field well ahead of any beetle flight that might result in establishment of natural competing attraction centers. It is unlikely that any semiochemical tree bait will compete or outcompete a natural attractant.

Semiochemical tree baits are past the stage of just being a scientific curiosity. However, it should be kept in mind that pheromones, whether attractants, antiaggregates, or repellents, must be used in coordination with other appropriate management strategies.

We are all involved in management programs to reduce or avoid losses to bark beetles. We should employ those strategies that reduce the long-term impacts of bark beetles through harvesting or other short-term methods. Semiochemicals should be incorporated into our "bag of tricks" to help meet these management objectives.

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Appendix. Regression Equations Shown in Figures 3 and 4.

A regression equation is fit to the data in figure 3 to summarize the expected percent mortality given the percent susceptible LP in the 5-6 inch DBH class. The regression model specifies that the dependent variable is percent mortality, and the independent variable is percent susceptible LPP in the 5-6 inch DBH class. The regression statistics are displayed in table 14.

The same regression equation is fit to the data in figure 4 from the Kootenai NF. The regression statistics are displayed in table 15.

Table 14--Statistics for the regression of percent LPP mortality on percent susceptible LPP in the 5-6 inch DBH class using baited stands on the Flathead National Forest, Montana

Observations:	32	Degrees of freedom:	30
R-squared :	0.084		
Residual SS :	7830.292	Std error of est :	16.156
Total SS :	8552.402	F(2 ,30)=2.7666	P-value=0.08

Variable	Coeff.	Std. Error	t-Stat	P-Value
CONSTANT	90.154	5.838	15.441	0.000
% LPP 5-6	-0.428	0.257	-1.6633	0.107

Table 15--Statistics for the regression of percent LPP mortality on percent susceptible LPP in the 5-6 inch DBH class using baited stands on the Kootenai National Forest, Montana

Observations:	40	Degrees of freedom:	38
R-squared :	0.479		
Residual SS :	9664.144	Std error of est :	15.947
Total SS :	18562.058	F(2 ,38)=34.9871	P-value=0.00

Variable	Coeff.	Std. Error	t-Stat	P-Value
CONSTANT	75.653	4.696	16.109	0.000
% LP 5-6	-0.882	0.149	-5.915	0.000

Table 16--Statistics for the regression of percent LPP mortality on percent LPP in the 5-6.9 inch DBH class using check stands on the Flathead National Forest, Montana

Observations:	21	Degrees of freedom:	19
R-squared :	0.435		
Residual SS :	5239.637	Std error of est :	16.606
Total SS :	9266.386	F(2, 19)=14.6081	P-value=0.00

Variable	Coeff.	Std. Error	t-Stat	P-Value
CONSTANT	92.204	6.811	13.538	0.000
% LP 5-6	-0.898	0.236	-3.821	0.001