The Influence of Partial Cutting on Mountain Pine Beetle-caused Tree Mortality in Black Hills Ponderosa Pine Stands

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United States Department of Agriculture / Forest Service
Rocky Mountain Research Station
Research Paper RMRS-RP-68
November 2007

Schmid, J.M.; Mata, S.A.; Kessler, R.R.; Popp, J.B. 2007. **The influence of partial cutting on mountain pine beetle-caused tree mortality in Black Hills ponderosa pine stands.** Res. Pap. RMRS-RP-68 Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 19 p.

Abstract

Ponderosa pine stands were partially cut to various stocking levels at five locations, periodically surveyed, and remeasured during the 20 years after installation. Mean diameter generally increased 2 inches over the 20-year period on most partially cut plots and less than 2 inches on unmanaged controls. Average diameter growth for diameter classes in partially cut plots was generally significantly greater than average diameter growth for the same diameter classes in uncut control plots. Basal area increased 20 to 40 ft^2/acre in partially cut plots and 5 to 21 ft^2/acre in unmanaged controls at four locations over a 20-year period. Beetle-caused mortality ranged from 0 to 51 percent of the trees in partially cut plots and from 1 to 77 percent of the trees in control plots although mortality was generally $\leq$8 percent in partially cut plots. Beetles attacked trees ranging from 8 to 18 inches in partially cut stands and from 7 to 19 inches in unmanaged stands. Beetles did not exclusively attack $\geq$16-inch diameter trees, so some trees $\geq$16 inches may be selected as leave trees. However, if an infestation persisted in a stand, trees in diameter classes $\geq$16 had the highest percentage mortality. The effectiveness of partial cutting for minimizing mountain pine beetle-caused mortality is influenced by: residual stocking level, size of the partial cut, amount of time since the area was cut, and proximity of beetle populations. Partial cuts of $\leq$10 acres may not minimize beetle-caused mortality if the cut stands are surrounded by unmanaged forest. Management to minimize beetle-caused mortality should be considered the top priority in mature ponderosa pine stands.

Keywords: mountain pine beetle, partial cutting, ponderosa pine

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Cover photo: *October 2007 photo of the southside of Odakota Mountain on the Black Hills National Forest. Note the abundant number of beettle-killed spots in the unmanaged stands above and below the partially cut area and the general lack of beetle-killed spots in the partially cut area.*

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Acknowledgments

R. Cain, Forest Health Management, Lakewood, CO; B. Cook, Timber Staff Officer, Black Hills National Forest, Custer, SD; and K. Gibson, Forest Health Management, Missoula, MT, provided critical and helpful reviews of the initial draft of the manuscript.

R. King, Biometrican, Rocky Mountain Research Station, Ft. Collins, CO, provided statistical and critical review of the manuscript. Over the past 20 years that Mata and Schmid have prepared manuscripts, King has consistently provided beneficial reviews that enhanced their manuscripts. For that, they cannot thank him enough.

Contents

Introduction

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is well known as an important mortality agent in unmanaged ponderosa pine (*Pinus ponderosa* Lawson) and lodgepole pine (*P. contorta* Douglas) stands (Furniss and Carolin 1977). Mountain pine beetle (MPB) epidemics have killed millions of trees in ponderosa pine (PP) stands in the Black Hills (see Blackman 1931, Thompson 1975). Since Thompson's 1975 report, additional epidemics have occurred in each subsequent decade. The most recent epidemic, beginning about 1997, has caused extensive tree mortality throughout the Black Hills with annual mortality averaging about 300,000 trees per year in 2001, 2002, and 2003 (see Johnson and others 2001; Johnson and Long 2003; Schaupp and others 2004). That MPB epidemic continues and shows no sign of subsiding.

Most MPB epidemics have originated in even-aged, high density stands. Although numerous factors contribute to epidemic MPB populations, over-stocked PP stands are the major contributor to MPB epidemics (Thompson 1975). Stands with basal areas exceeding 150 ft^2/acre and average diameters ≥8 inches are considered highly favorable for MPB epidemics (Sartwell and Stevens 1975).

In 1984, the Rocky Mountain Forest and Range Experiment Station began a study to determine the relationship between stand density and MPB-caused tree mortality in lodgepole (LPP) and PP stands in the central Rockies and the Black Hills. The study was conducted by establishing sets of plots in susceptible LPP stands in Colorado and Wyoming, and PP stands in the Black Hills. Beginning in 1985 and continuing for the next 8 years, sets of plots were established on the Black Hills National Forest (BHNF) in South Dakota. This paper reports on diameter and basal area growth, MPB-caused mortality by stocking level and by year, and MPB tree selection in partially cut and associated unmanaged PP stands at five locations in the Black Hills.

Methods

When the study began, even-aged, single-storied stands with basal areas (BA) ≥150 ft^2/acre and average diameters at breast height (DBH) ≥8 inches were considered the most susceptible to MPB infestation. Therefore, stands with these characteristics were considered most preferable for the study. Because of the density of such stands, trees with diameters ≤4 inches were generally absent and seedlings, when present, were usually found around openings.

Sets of growing stock level (GSL[1]) plots were installed in susceptible-sized PP stands in the Black Hills of South Dakota (Schmid and others 1994). Each set of plots usually consisted of four 2.47-acre plots (in other words, 10 acres)—three plots partially cut to different GSLs and a fourth plot left uncut to serve as a control and to represent the unmanaged stand condition. Hereafter, we use "control" and "unmanaged" interchangeably, so the reader should understand that control refers to the unmanaged forest condition. Individual plots within a set were generally in the form of a square 100m x 100m or a rectangle 80m x 125m.

Although stands with BAs ≥150 ft^2/acre and average diameters ≥8 inches were considered ideal, it became apparent that these BA and average diameter characteristics were rarely uniform in 10-acre parcels (in other words, for all four plots in a set). One or two plots in a set may have occasionally had the initial BA <150 ft^2/acre or an average DBH <8 inches. Further, as the study progressed, pertinent information on the stand density/MPB relationship appeared to be available from stands partially cut under BHNF management plans so a single plot was installed at one location. The C-C plot is the exception to the study's general design of four plots per location because only one 2.47-acre plot was established at the C-C location. See separate sections for each specific area for more details and exceptions to general design.

When the plots were installed, the central 1.235 acres of each plot was designated as the central inventory plot (CIP). Diameters for all trees >3 inches within the CIP were measured at breast height (DBH) to the nearest 0.1 inch. DBH and information on the presence or absence of MPB, crown form, defects, and diseases were also recorded. Following inventory of each CIP, GSL, BA, and quadratic mean diameter were calculated. Initially, GSLs for plots to be partially cut at each location were assigned on the basis of site index—GSLs of 60, 80, and 100 when site index was <65, and 80, 100, and 120 when site index was ≥65. Because stand BAs were rarely uniform throughout the 10 or more acres in the various locations, lower post-cutting stocking levels

[1] Growing Stock Level (GSL) equals BA when average diameter is ≥10 inches. Because GSL and BA are equal when average diameter is ≥10 inches, we use GSL and BA interchangeably. Although the GSL method is outmoded, the plots were installed using it so the results are reported in a like manner.

(GSL 60, GSL 80) were assigned in some instances to plots where pre-cutting BA was <150 ft^2/acre.

Leave trees within cut plots were selected on the basis of DBH, spacing, crown development, and visually apparent good health. Tree selection emphasized leaving the best and largest trees as evenly spaced as possible. Smaller diameter trees (<6 inches) were generally marked for cutting and eliminated during partial cutting. The marking crew tried to leave the GSL for each partially cut plot within $\pm$1 ft^2/acre of the designated level (for example, a GSL 100 stand would be between 99 and 101). Metal tags were placed on the designated leave trees in the CIP to facilitate record keeping in regard to MPB infestation and the determination of individual tree growth in subsequent years. Trees in the CIP provided growth information and were the basis for DBH and BA growth statements for each 2.47-acre plot. When the diameter measurement at remeasurement was less than the preceding measurement, we assigned zero growth to that tree rather than a negative growth value, because we believe the difference was due to measurement error rather than negative growth. Trees dying during the period prior to remeasurement were not included in calculations of average DBH and BA at remeasurement.

The remaining 1.235-acre area of each plot surrounding the CIP (in other words, buffer strips) was marked and cut to the same GSL as within the CIP. Leave trees in the buffers were selected on the same basis as those within the CIP but were not tagged. The buffers were established in hopes of mitigating mortality caused by MPBs emigrating from adjacent plots into plots (treatments) that might not have otherwise occurred.

Subsequent to installation and cutting, plots were surveyed for MPB activity and other mortality-causing events. Surveys were conducted annually or at 2- to 3-year intervals depending on MPB activity during the previous survey. All trees in the plots were examined for the presence of MPB attacks. Trees with MPB attacks were classified as "successfully attacked" (tree killed) or "pitchout" (a tree that has external evidence of MPB attacks, but usually survives the attacks). Our definition of pitchout includes trees with attacks on all sides of the bole and trees with attacks on just one side of the bole (strip attacks). Attacked trees were examined the following year to verify the classification. However, statements on the number of MPB-attacked trees per plot and per 1-inch diameter class are derived only from surveys of the CIPs.

Sets of plots were generally remeasured 10 and 20 years after installation. BAs and quadratic mean diameters were calculated. After the first remeasurement, partially cut plots were remarked, at which time GSLs for some sets of plots were increased by 10 ft^2/acre (for example, a GSL 60 was increased to GSL 70, and so forth). GSLs of partially cut plots were increased because we wanted to learn more about the susceptibility of stands with GSLs between 80 and 120.

With one exception, partial cutting usually occured 1 to 2 years after plot installation and the first remeasurment. Thus, diameter and BA growth for the first and second decades after installation reflects stand growth 1 to 2 years at the GSL existing when marked and 8 to 9 years at the GSL after cutting.

Diameter measurements at installation were sorted into 1-inch diameter classes. Each 1-inch class ranged from 0.4 less than the specific diameter to 0.5 more than the diameter (in other words, the 9-inch class ranged from 8.6 to 9.5). One-way analysis of variance was used to determine if arithmetic mean DBH growth in the various diameter classes varied significantly among GSLs within each diameter class at each location and among diameter classes within each GSL at each location. If significant variation was found, Tukey's multiple comparison procedure was used to determine which means were significantly different, alpha = 0.05. We did not analyze growth rates at the C-C plot because only one plot was present and comparison of the growth rates between different stocking levels could not be made.

The number of MPB-attacked trees (successfully attacked and pitchouts) were determined for each 1-inch diameter class in each plot and then inserted in a tree distribution table for the plot to show the distribution of MPB-attacked trees by diameter class. DBH was estimated for the year that each tree was attacked.

The number of successfully attacked trees (pitchouts excluded) in each plot was compared against the number of live trees in the same plot after installation to determine the percent of MPB-caused tree mortality during the 20-year life of the plot. For control plots, the number of live trees equaled the number recorded during the initial inventory when the plots were installed. For partially cut plots, the number of live trees equaled the number of residual trees left after tree selection and marking was initially completed.

Plot Information

Bear Mountain 1 Plots

The Bear Mountain 1 (BM1) plots were established in June 1986. Three plots were partially cut via horse logging to GSL 60, 80, and 100 in June and July 1987, while the fourth plot was left uncut at GSL 155. Plots were remeasured in late August 1997 and in September 2006. Stocking levels for the GSL 60, GSL 80, and GSL

100 plots were increased 10 ft^2/acre when they were remarked and cut again in 2000. The BM1 plots were surrounded by unmanaged stands with densities and tree sizes estimated to be about the same as the control plot.

Border Plots

The Border plots (BOR) were established in May 1986 and were cut in July 1987. Partially cut plots were established at GSL 60, 80, and 100. The GSL 60 and GSL 80 plots were superimposed on a stand that had been previously cut to about BA 80. Plots were remeasured in August 1997 and September 2006. The partially cut plots were re-cut in October 1998, at which time the GSLs were increased to GSL 70, 90, and 110. The plots are surrounded by BHNF that was cut prior to the establishment of the plots. The 5 acres used for the GSL 60 and GSL 80 was part of this cut. For more information on plot location and history, see Obedzinski and others (1999).

Brownsville Plots

The Brownsville plots (BRN) were established in September 1985. Three plots were cut to GSL 60, 80, and 100 in May 1986, while the fourth plot was left uncut at GSL 146. Plots were remeasured in September 1995 and September 2005. GSLs for the GSL 60, 80, and 100 were raised to GSL 70, 90, and 110, respectively, before the plots were scheduled to be re-cut in October 1998. The plots are bordered by BHNF land on the west, north, and east sides and by an undesignated gravel road on the south side. The BHNF land surrounding the plots was cut soon after the plots were cut, while the land across the road to the south is private and has not been cut.

Crook Mountain Plots

The Crook Mountain plots (CRK) were established in March 1985 and were cut in December 1986. Partially cut plots were established at GSL 80, 100, and 120 with the GSL 120 plot being 20 ft^2/acre greater than the highest GSL in most sets of PP plots established at that time. Loggers did not cut all trees marked for cutting on the GSL 80 and 100 so those plots actually had GSLs 3 ft^2/acre greater than our usual upper limit. These trees were not incorporated in the GSL values and growth results in Obedzinski and others (1999), but are incorporated in the GSL values for 1986 and 1996 in this report.

Plots were remeasured in September 1996 and September 2006. The partially cut plots were re-cut to their designated level in October 1998. Trees left by loggers in 1986 were cut during the second cutting. The plots are surrounded by BHNF land on the west and north sides and private land on the east and south sides. Surrounding BHNF land was cut at the same time the plots were cut as part of the Nasty Timber sale, while the private land has not been cut. For more information on plot location and history, see Obedzinski and others (1999).

C-C Plot

The C-C plot was established in 1985 in a stand previously partially cut in a BHNF commerical timber sale in 1983. The plot was remeasured on May 16, 1996, and on May 15, 2006. It has not been re-cut since it was established. In contrast to other sets of plots, only one 2.47 acre plot was established. The plot was subdivided into 10 subplots of equal size. All trees within the plot were inventoried and tagged. Analysis of tree inventories for each subplot provides information on variability of GSL and BA within the 2.47 acres. The plot is bordered by BHNF on all sides. Lands on the south, west, and north sides were cut as part of the 1983 timber sale. The east side of the plot is bordered by a 100- to 200-ft wide strip of uncut PP that separates the plot from Highway 385.

Results and Discussion

Diameter Growth

Quadratic mean diameters generally increased about 2 inches or more over the 20-year periods in partially cut plots and <2 inches in control plots (table 1). Part of the increase in mean diameters in partially cut plots during the second decade resulted from the second cutting that occurred after the 10-year remeasurement. Those cuttings generally removed smaller diameter trees, which increased mean diameter while maintaining desired GSL levels. The decrease in mean diameter on the BM1 control plot from 10 years versus 20 years (table 1) resulted from a MPB epidemic. As the epidemic progressed, percent mortality was greater in the larger diameter classes so mean diameter decreased.

The interaction between diameter growth and GSL was significant in BOR and BRN plots, marginally insignificant in BM1 plots, and insignificant in CRK plots. This interaction indicates variation in growth patterns for diameter classes among GSLs. With minor exceptions, the growth patterns were:

1) Average diameter growth was not significantly different among diameter classes within each partially cut GSL,
2) Average diameter growth was significantly different among diameter classes in control (unmanaged)

Table 1. Quadratic mean diameters by GSL for the Bear Mountain 1, Border, Brownsville, Crook Mountain, and C-C plots at installation and 10 years and 20 years after installation.

Location	Installation	10 years	20 years
Bear Mountain 1			
GSL 60/70	11.0	12.6	14.3
GSL 80/90	10.1	11.2	13.0
GSL 100/110	10.5	11.5	12.4
Control	10.0	10.6	10.3
Border			
GSL 60/70	10.9	13.1	15.0
GSL 80/90	10.8	12.9	14.7
GSL 100/110	10.7	12.3	13.7
Control	8.9	9.8	10.5
Brownsville			
GSL 60/70	12.4	13.8	15.4
GSL 80/90	11.5	12.5	13.6
GSL 100/110	12.8	13.5	14.7
Control	12.7	13.2	13.4
Crook Mountain			
GSL 80	13.7	15.3	17.1
GSL 100	11.9	12.8	14.2
GSL 120	13.7	14.9	16.6
Control	12.6	13.3	14.4
C-C Plot			
GSL 80	12.8	13.8	14.9

plots with the greater rates being in the larger diameter classes, and

3) Average diameter growth in each specific diameter class was generally greater in partially cut plots than in controls.

BM1 Plots

Average diameter growth in the partially cut plots for the 20 years was ≥2 inches in all diameter classes except for two classes in the GSL 60/70 that were represented by only one tree (table 2). Average diameter growth in diameter classes in the GSL 60/70 generally exceeded 3 inches, while average diameter growth in diameter classes in the control was generally <1.5 inches (table 2).

Average diameter growth for the 20 years was not significantly different among diameter classes within each GSL. For diameter classes 7 to 11 inches, average diameter growth was significantly greater in partially cut plots than in the same diameter classes in the control. Diameter growth in the 12-inch class could not be compared between the partially cut plots and the control because there were no 12-inch trees in the control. Average diameter growth for the 13-inch class was not significantly different between partially cut plots and the control.

BOR Plots

Average diameter growth in partially cut plots for the 20 years was ≥2.6 inches in all diameter classes except the 15-inch class in the GSL 100/110 that had only one

Table 2. Diameter growth by 1-inch diameter class for the Bear Mtn. 1 plots for the 20 years following installation. Under each GSL, N equals the number of trees used in calculating mean diameter for each diameter class.

	GSL 60/70		GSL 80/90		GSL 100/110		Control	
Diameter	N	X±S.D.	N	X±S.D.	N	X±S.D.	N	X±S.D.
5							1	0.8
6							1	0.6
7	1	3.1			1	2.6	11	0.6±0.4
8	6	3.0±0.8	10	2.6±0.4	15	2.0±0.5	15	1.1±0.4
9	16	3.1±0.5	15	2.9±0.5	19	2.1±0.7	18	1.2±0.7
10	22	3.4±0.6	15	2.5±0.5	21	2.5±0.7	16	1.2±0.5
11	20	3.3±0.6	14	2.4±0.6	16	2.6±0.9	6	1.4±0.9
12	15	3.0±0.6	7	2.6±0.4	6	2.4±0.6		
13	2	2.6±0.9	3	2.6±0.3	5	2.2±1.3	4	2.1±0.7
14	3	2.9±0.8	2	3.2±0.4	1	2.7		
15	2	3.6±0.1						
16	1	1.3						
17	1	2.7						
18	1	2.7						
19								
20	1	1.0						

Table 3. Diameter growth by 1-inch diameter class for the Border plots for the 20 years following installation. Under each GSL, N equals the number of trees used in calculating mean diameter for each diameter class.

	GSL 60/70		GSL 80/90		GSL 100/110		Control	
Diameter	**N**	**X±S.D.**	**N**	**X±S.D.**	**N**	**X±S.D.**	**N**	**X±S.D.**
3							2	0.4±0.0
4							6	0.4±0.5
5							14	0.2±0.2
6							38	0.4±0.5
7					1	3.3	57	0.8±0.5
8	5	4.1±0.5	6	3.7±1.1	13	2.6±0.8	79	1.0±0.6
9	15	4.6±1.4	20	4.0±0.5	28	2.9±0.7	86	1.4±0.6
10	21	4.3±0.8	26	4.0±1.0	28	3.1±0.8	70	1.4±0.6
11	19	4.0±0.8	22	3.7±0.7	29	2.3±0.9	44	1.6±0.5
12	19	3.7±1.1	23	3.3±0.7	20	2.6±0.8	35	1.7±0.6
13	10	3.4±1.2	17	3.5±1.0	18	2.8±1.0	13	2.0±0.5
14			4	3.5±0.5	12	2.6±1.1	5	2.4±0.6
15	1	3.7			1	1.6	4	1.8±1.1
16								

tree (table 3). Diameter growth in the GSL 60/70 and GSL 80/90 exceeded 3.3 inches in all diameter classes (table 3). Average diameter growth in the control was ≤2 inches in all diameter classes except in the 14-inch class.

Average diameter growth for the 20 years was generally not significantly different among diameter classes within each partially cut GSL except in the GSL 60/70 where growth in the 9-inch class was significantly greater than in the 13-inch class, and in the GSL 80/90 where growth in the 10-inch class was significantly greater than in the 12-inch class. Average diameter growth in the control was significantly greater in diameter classes ≥9 inches than in diameter classes ≤8 inches.

BRN Plots

Average diameter growth in partially cut plots for the 20 years was ≥1.7 inches in all diameter classes except for a single tree in the 16-inch class in the GSL 80/90 (table 4). Diameter growth in the GSL 60/70 averaged ≥2.8 inches in all diameter classes. Average diameter growth in the control was ≤1.9 inches in all diameter classes, but most classes grew ≤1.6 inches (table 4).

Table 4. Diameter growth by 1-inch diameter class for the Brownsville plots for the 20 years following installation. Under each GSL, N equals the number of trees used in calculating mean diameter for each diameter class.

	GSL 60/70		GSL 80/90		GSL 100/110		Control	
Diameter	**N**	**N±S.D.**	**N**	**X±S.D.**	**N**	**X±S.D.**	**N**	**X±S.D.**
6							4	0.3±0.6
7							1	0.0
8			4	2.3±0.2			3	0.8±0.6
9			11	2.3±0.6			3	0.3±0.3
10	2	2.8±0.8	22	1.8±0.6	3	2.4±0.3	11	0.8±0.5
11	14	2.9±0.6	35	1.9±0.6	21	1.7±0.6	23	1.2±0.6
12	28	2.9±0.6	29	2.0±0.5	39	1.7±0.6	37	1.2±0.5
13	21	2.8±0.6	19	2.4±0.7	33	1.8±0.5	33	1.4±0.6
14	11	2.9±0.5	5	2.0±0.5	23	2.0±0.5	26	1.4±0.5
15	2	2.9±0.9	2	1.8±0.9	11	1.9±0.7	15	1.6±0.5
16			1	1.2	3	2.0±0.5	13	1.9±0.7
17			1	2.5			1	1.7
18								
19							1	0.7

In partially cut plots, average diameter growth was not significantly different among diameter classes in each GSL except for the GSL 80/90 where growth in the 13-inch class was greater than in the 10-inch class. In the control plot, average diameter growth in the 6-, 9-, 10-, and 12- inch classes were significantly less than in the 16-inch class.

Average diameter growth in specific diameter classes in partially cut plots varied with respect to average diameter growth in the control. For the 10- to 14-inch diameter classes, diameter growth in the partially cut plots was generally significantly greater than in the control. For the 15- and 16-inch diameter classes, average diameter growth was not significantly different than in the control.

CRK Plots

Average diameter growth in partially cut plots for the 20 years was generally ≥2 inches in all diameter classes (table 5). Diameter growth in the GSL 80 was ≥2.7 inches in all diameter classes except for the 2.4-inch growth of the lone 7-inch tree. Average diameter growth in the control was ≤1.8 inches.

In partially cut plots, average diameter growth was not significantly different among diameter classes in each GSL. Average diameter growth among diameter classes in the control was significantly less in the 4- and 5-inch classes versus the 12- and 15-inch classes.

Comparisons of average diameter growth within specific diameter classes in partially cut plots to diameter growth in corresponding diameter classes in the control produced mixed results. In the 7- and 8-inch classes, average diameter growth in GSL 100 was greater than in the control. In the 10- to 17-inch classes, average diameter growth in the GSL 80 was greater than in the control. In the 18- and 19-inch classes, no significant difference existed between diameter growth rates in the partially cut plots and the control.

Basal Area

BA changed variously among locations and among GSLs within locations for the 20-year period (table 6). BA increased at all locations during the first decade with increases ranging from 9 to 18 ft^2/acre in partially cut plots and from 9 to 19 ft^2/acre in the controls. BA in the BM1 control increased more than its respective partially cut plots. This greater increase was probably due to the greater number of trees existing on that plot—almost twice as many as on the respective GSL 80/90.

During the second decade, BAs generally increased in plots at the BOR, BRN, CRK, and C-C plot locations, but decreased in three BM1 plots. BA increases in the partially cut plots ranged from 10 to 26 ft^2, while BAs in the respective controls increased ≤10 ft^2/acre or decreased (table 6). In the BM1 plots, the GSL 60/70 increased 10 ft^2/acre, but the GSL 80/90, 100/110, and control all decreased below installation levels because of MPB-caused mortality.

Table 5. Diameter growth by 1-inch diameter class for the Crook Mountain plots for the 20 years following installation. Under each GSL, N equals the number of trees used in calculating the average diameter for each diameter class.

	GSL 80		GSL 100		GSL 120		Control	
Diameter	N	X±S.D.	N	X±S.D.	N	X±S.D.	N	X±S.D.
4							6	0.3±0.2
5							6	0.3±0.4
6			1	1.3			7	0.8±1.0
7	1	2.4	7	2.1±0.6			4	0.6±1.0
8			8	2.7±0.4	1	0.0		
9			11	2.0±0.8	1	2.4	1	0.8
10	2	3.2±1.3	12	2.1±1.1	4	2.0±1.1	3	0.3±0.4
11	3	3.4±0.2	21	2.0±1.0	5	1.9±0.8	11	1.2±0.7
12	10	3.0±1.1	19	2.0±0.9	7	2.9±0.5	26	1.5±0.9
13	14	2.9±0.7	23	2.1±0.7	24	2.6±0.8	31	1.5±0.6
14	17	2.9±0.8	15	2.0±0.6	30	2.5±0.9	34	1.5±0.7
15	17	3.1±1.0	9	2.6±0.8	13	2.4±0.9	30	1.6±0.6
16	8	3.4±1.1	5	2.3±0.6	20	2.5±1.0	9	1.5±0.4
17	4	3.0±1.0	1	2.1	2	1.8±0.7	8	1.5±0.6
18	1	2.7	1	3.2	1	1.7	4	1.8±0.3
19			1	2.2	1	3.3	3	1.6±0.6

Table 6. Basal Areas by GSL for the Bear Mountain 1, Border, Brownsville, Crook Mountain, and C-C plots at installation and 10 years and 20 years after installation.

Location	Installation	10 years	20 years
Bear Mountain 1			
GSL 60/70	60.7	76.8	80.7
GSL 80/90	80.8	98.4	48.9
GSL 100/110	101.5	117.3	58.0
Control	154.7	174.0	34.0
Border			
GSL 60/70	60.1	76.9	88.1
GSL 80/90	80.1	97.7	113.2
GSL 100/110	98.3	108.2	124.1
Control	199.1	210.9	220.4
Brownsville			
GSL 60/70	60.5	73.6	81.3
GSL 80/90	80.8	93.4	104.8
GSL 100/110	100.7	113.4	126.4
Control	146.1	155.3	150.1
Crook Mountain			
GSL 80	84.1	100.2	99.3
GSL 100	104.0	116.4	119.2
GSL 120	119.1	136.8	131.2
Control	158.1	172.1	173.8
C-C Plot			
GSL 80	83.6	92.9	102.6

The reader should realize that BAs in the partially cut plots at the BM1, BOR, BRN, and CRK locations increased/decreased more in the second decade than can be calculated from table 6 because the partially cut plots at those locations were cut back to lesser levels after the first remeasurement (see methods). Thus, for example, reduction of the BM1 GSL 60 from 76.8 to about 70 ft^2/acre would indicate that this plot increased about 10 ft^2/acre (80.7 to 70 ft^2/acre) during the second decade rather than the 3.9 ft^2/acre as calculated from table 6.

Over the 20 years since installation, BAs in the partially cut plots increased about 20 to 40 ft^2/acre, except in the BM1 GSL 80/90 and 100/110 where MPB-caused mortality decreased the BAs to below the designated levels (table 6). Simultaneously, BA increases in the BOR, BRN, and CRK control plots ranged from 5 to 21 ft^2/acre while the BM1 control decreased to 34 ft^2/acre.

Increases in basal area resulted from growth of the residual trees and not from ingrowth. Ingrowth was not a contributing factor for BA increases because trees ≤6 inches were usually cut, saplings were generally absent on the plots except for the BRN GSL 60/70 and the CRK GSL 80 after 20 years, and we did not measure trees ≤3 inches.

The BM1 plots showed the most dramatic change in BAs from the first 10 years compared to the second 10 years. During the first decade, increases in BAs were as good or better than at the other locations. During the second decade, the MPB epidemic caused BAs to decrease more than in plots at other locations with BAs in the BM1 GSL 80/90, 100/110, and control decreasing 40, 59, and 140 ft^2/acre, respectively. As noted in the previous paragraph, decreases were probably greater than can be computed from table 6.

The substantial decrease in BA in the BM1 GSL 80/90 and 100/110 can be misleading from the MPB susceptibility standpoint. As noted in Schmid and Mata (2005), the MPB-caused mortality was not uniformly distributed throughout the CIPs. Because some parts of the stand were unaffected, BAs in those areas exceeded 110 ft^2/acre. Left to grow without subsequent management, the areas could reach the high susceptibility threshold (GSL 120) relatively soon and thus become potential sites for MPB infestations.

BAs in the BRN partially cut plots increased during the second decade while the BA in the control decreased. The decrease in the BRN control was caused by an incipient MPB epidemic beginning in 1998.

During the second decade, BAs in the CRK plots were affected by weather events. Trees with trunks broken below the crowns were observed in all CRK plots, but most notably in the GSL 100 and control. This condition was attributed to snow/wind storms in 1998, 2001, and 2002. The northern Hills commonly receive wet snowstorms in the spring and early fall. The wet snow tends to accumulate on the crowns and when accompanied by strong winds, causes breakage of the trunk below the bottom of the crown. While the loss of the storm-damaged trees reduced the existing BAs and the potential increases in BA from annual growth on the damaged trees, BAs in the CRK plots were not impacted to the point where BAs decreased below their respective GSL at the beginning of the decade. However, the BA in the control was significantly impacted such that BA increased only 1.7 ft^2/acre during the second decade as compared to the 14 ft^2/acre increase during the first decade (table 6).

BA in the C-C plot increased similarly to that for the BOR and BRN GSL 80s except BA increases were less than at those locations (table 6). More importantly from a MPB perspective, BAs within the subplots of the C-C plot ranged from 65 to 100 ft^2/acre in 1985 and from 80 to 126 ft^2/acre in 2006 (table 7). If BA 120 is accepted as the threshold for high susceptibility to MPB infestation (Schmid and others 1994), then a small part of the C-C stand, which presumably was uniformly cut to BA 80, has become highly susceptible in <20 years. What

Table 7. Basal area per acre per 0.25 acre subplots within the 2.47-acre C-C plot.

Subplot	1985	1996	2006
		ft^2/acre	
1	94.2	99.1	108.7
2	84.2	90.5	90.9
3	90.7	104.9	108.6
4	79.6	91.6	101.2
5	65.7	76.8	89.8
6	78.8	90.3	106.8
7	67.4	73.5	80.1
8	100.4	112.5	125.8
9	74.6	86.5	101.6
10	90.8	103.0	112.0
C-C Plot	83.6	92.9	102.6

this means in terms of actual MPB infestation remains to be determined. However, this situation appears to be a smaller version of the BM1 plots wherein MPBs initially infested the most susceptible plot (for example, control) and then spread to adjacent partially cut plots that might otherwise have not incurred mortality. Because Olsen and others (1996) found MPB infestations were predominantly found where stand densities were higher, MPBs would most likely infest parts of the C-C stand with higher densities and then could cause considerable tree mortality in adjacent, less dense parts of the stand if the infestation persisted.

MPB-caused Tree Mortality

MPB-caused tree mortality ranged from 0 to 77 percent per plot for the plots from the five locations (table 8). Mortality on the control plots ranged from 1 to 77 percent (table 8) and the percent mortality in the BM1 control exceeded what McCambridge and others (1982) found for areas of heavy loss in Colorado's Front Range. Mortality on the partially cut plots ranged from 0 to 51 percent, but the range in mortality for partially cut plots was greatly influenced by what occurred in the BM1 plots. If percent mortality for BM1 partially cut plots is excluded, then percent mortality for other partially cut plots ranges from 0 to 8 percent (table 8).

By location, percent mortality was greater in the control than in the partially cut plots at BM1, BOR, and

Table 8. Percent MPB-caused tree mortality by location/GSL for five locations. The data for the C-C plot is derived from a 2.47-acre plot, while data for all other locations/GSLs is derived from the CIP (1.25 acre) within each plot. Numbers of trees represent the number of live trees present after partial cutting was completed. Percent mortality in the Bear Mtn. 1 GSL 60/70 and 80/90 differs slightly from that presented in Schmid and Mata (2005) because a few trees thought to be successfully attacked in the 2004 survey were later determined to be pitchouts.

Location/GSL	Number of trees	Number of MPB-killed trees	Percent mortality
Bear Mtn. 1			
GSL 60/70	114	9	8%
GSL 80/90	180	91	51%
GSL 100/110	210	100	48%
Control	351	269	77%
Border			
GSL 60/70	115	1	1%
GSL 80/90	155	4	3%
GSL 100/110	195	7	4%
Control	571	32	6%
Brownsville			
GSL 60/70	89	2	2%
GSL 80/90	138	2	1%
GSL 100/110	140	0	0%
Control	206	28	14%
Crook Mtn.			
GSL 80	101	5	5%
GSL 100	165	7	4%
GSL 120	143	5	3%
Control	224	2	1%
C-C Plot			
GSL 80	231	11	5%

Table 9. Number of MPB-attacked trees by GSL by year for the Bear Mtn. 1 plots.

Year	GSL 60/70	GSL 80/90	GSL 100/110	Control
1986				
1987			1	
1988		1		
1989				
1990				
1991				
1992				
1993				
1994				
1995	1	1		
1996				
1997				
1998				5
1999				7
2000				15
2001		1	2	15
2002		29	29	4
2003	8	2	65	215
2004		62	7	14
2005				21

BRN locations but slightly less in the CRK control than in partially cut CRK plots (table 8). Mortality in the CRK control was slightly less because the MPB population was subsiding at that location when the plots were installed and only endemic MPB populations were present for the 20 years following cutting. Thus, mortality was limited to single tree infestations.

Table 10. Number of MPB-attacked trees by GSL by year for the Border plots.

Year	GSL 60/70	GSL 80/90	GSL 100/110	Control
1986		2		
1987				
1988		1		17
1989				
1990				1
1991				
1992				
1993				
1994				
1995				
1996				
1997				
1998				2
1999			2	1
2000				
2001		1	1	
2002				
2003			1	1
2004		1	4	
2005		1		3
2006	1			8

The BM1, BOR, and BRN locations were subjected to incipient epidemic and/or epidemic infestations in addition to endemic levels of tree mortality. The BM1, BOR, and BRN locations developed incipient epidemic/epidemic MPB populations during the second decade (tables 9, 10, 11), while an incipient epidemic population appeared to be developing in the C-C plot. Epidemic MPB populations existed at BOR and CRK locations when the plots were installed, but apparently were collapsing in the general area because high numbers of MPB-attacked trees were not evident 3 to 4 years after installation (tables 10, 12).

MPB-caused tree mortality at the BM1 location provides insight into the development of epidemics and the relative susceptibility of various stocking levels in 2.47-acre partial cuts. As the epidemic arose in the Bear Mountain area, infestations first developed in the control (table 9) and in adjacent unmanaged stands. As the population increased, it spread from the control and adjacent unmanaged stands into the buffer strips of the partially cut plots even though those areas had reduced stocking levels. Two years later, MPB populations moved into the CIPs of the partially cut plots (table 9), especially in the GSL 80/90 and 100/110 where BAs approached or exceeded 120 ft^2/acre. Thus, partial cuts of 2.47 acres may not prevent substantial MPB-caused mortality if the cuts are conducted in an otherwise unmanaged forest and/or are cut to GSLs $\geq$100.

Number of MPB-attacked Trees by Year

From 1991 through 1996, MPB-attacked trees were not present on 13 of 17 plots or were limited to 1 to 2 trees/plot/year on the remaining four plots at the five locations (tables 9 through 13). The lack of MPB-attacked trees could primarily result from chance, as the 1.25-acre CIPs may be too small to detect endemic MPB populations. However, air temperatures dropped to $\leq$-5°F on October 30 and 31, and November 2 and 3, 1991, in Hill City, SD (Schmid and others 1993). The temperatures were not confined to Hill City but were present throughout the Black Hills. Thus, cold temperatures likely caused a decrease in MPB populations throughout the Hills as evidenced by the general absence of MPB-attacked trees in the five locations.

The number of MPB-attacked trees (successful + pitchouts) per plot varied by location and year within each location. Numbers varied as MPB populations subsided or increased. During the first decade following cutting, the BOR and CRK locations had $\geq$3 MPB-attacked trees in at least one plot 1 or more years, while the number of MPB-attacked trees in the other 3 locations (BM1, BRN, and C-C plot) was 0 to 1 tree per year for all plots at each location (tables 9 through 13). Most of the BM1 and BRN plots had single or no MPB-attacked trees and MPB-attacked trees were rarely observed in consecutive years (tables 9 and 11). During the second decade for the BM1, BOR, and BRN plots, the number of MPB-attacked trees increased, especially in the controls where three or more trees per plot were evident in 2 or more consecutive years. Numbers increased in the C-C plot only during the last 2 years.

MPB Population Level Definitions

The number of MPB-attacked trees by year at the five locations provides data for further defining endemic and epidemic MPB population levels. MPB population levels are usually classified as endemic or epidemic. Endemic populations are low, relatively static numbers of an insect that cause essentially unnoticed or insignificant amounts of defoliation or tree killing (Graham and Knight 1965). Endemic MPB populations could be visualized as almost undetectable on a landscape basis. In contrast, epidemic populations, as evidenced by their damage rather than their actual numbers, cause readily noticed or significant amounts of tree damage on a landscape scale. Landscape vistas of a MPB epidemic are dotted with small and large groups of beetle-killed trees.

With respect to MPB populations, Sartwell and Stevens (1975) defined the lower limits of MPB outbreaks (= epidemics) as the group killing of three to five or more adjacent trees in a single year. Lessard (1982) further defined MPB population levels as:

Endemic: <1 infested tree per acre per year,

Increasing or Decreasing: >1 infested tree per acre per year or <10 percent of a stand infested over 3 years,

Epidemic: >10 percent of a stand infested over 10 years.

The Sartwell and Stevens definition has contradictory and biological complications. The dictionary defines “outbreak” as a sudden increase in the numbers of a harmful organism. After defining the lower limits of MPB outbreaks, Sartwell and Stevens subsequently indicate that MPB outbreaks rarely develop suddenly. If the term is to be applied correctly, then either MPB populations must increase rapidly or a more suitable term should be used. Although outbreak and epidemic are used interchangeably, and epidemic has the same contradiction with respect to MPB population increases, epidemic seems the preferable term because it contrasts with endemic. More important biologically, their definition is stated in terms of MPB-killed trees for a single year. Our observations indicate that a single group of three MPB-killed trees may indicate the start of a MPB

Table 11. Number of MPB-attacked trees by GSL by year in the Brownsville plots.

Year	GSL60/70	GSL 80/90	GSL100/110	Control
1985				
1986				
1987				1
1988				
1989				
1990				1
1991				
1992				
1993				
1994				
1995				
1996				
1997	1	1		1
1998	1	1		6
1999				
2000				
2001				12
2002				4
2003			1	7
2004				2
2005				

Table 12. Number of MPB-attacked trees by GSL by year for the Crook Mountain plots.

Year	GSL 80	GSL 100	GSL 120	Control
1985	3	1	1	
1986		4		
1987				
1988		3	1	
1989		2		1
1990				
1991				
1992				
1993				
1994				
1995				
1996				2
1997			1	
1998			1	
1999		1		
2000				
2001		2		1
2002				
2003			1	
2004	1		2	
2005				
2006	1			1

Table 13. Number of MPB-attacked trees in the C-C plot by year.

Year	MPB-attacked trees
1985	2
1986	
1987	
1988	
1989	
1990	
1991	
1992	
1993	
1994	1
1995	1
1996	
1997	2
1998	1
1999	1
2000	1
2001	
2002	1
2003	2
2004	5

epidemic if other such groups are simultaneously evident in surrounding and nearby stands. Alternatively, it may indicate a 1-year anomaly in the endemic condition if similar and/or larger groups are not evident either in surrounding and nearby stands or in succeeding years.

Lessard's definitions are more suitable because they incorporate the time factor. However, defining endemic as <1 tree per acre per year may be unsuitable when large tracts are considered. Since endemic/epidemic populations are commonly judged on a landscape basis, Lessard's definition may be met on a per acre basis, but the population level might be otherwise. For example, if five groups of five to seven trees per group are present on a tract of 40 acres, then the average number of MPB-infested trees would be <1 per acre. However, the presence of the five groups with five to seven trees per group would not be considered as endemic.

Lessard defines epidemic as the infestation of >10 percent of the stand over 10 years. Three of the BM1 plots had more than 10 percent of its trees infested in 4 years (tables 8 and 9). While the CIP of a plot is only 1.235 acres and may thusly represent only a small portion of the landscape, the level of mortality would nevertheless be classified as epidemic. In addition, MPB populations might cause significant tree mortality for a few years before suddenly decreasing. Should that situation be classified as endemic just because the infestation did not last 10 years?

Proposed MPB Population Level Definitions

While MPB population level definitions are usually generalizations because precise knowledge of population numbers is difficult to obtain, some improvements in the definitions can be made. Drawing from the previous definitions and using the frequency of MPB-attacked trees per year from our five locations, the following definitions are proposed:

Endemic: usually ≤1 but occasionally two MPB-attacked trees per 5 or more acres per year. Most of the time, the number of MPB-attacked trees will be <1 tree per 10 or more acres. However, an endemic MPB population may attack two adjacent, narrowly spaced trees so two trees per 5 acres is recognized as being endemic. In endemic situations, one of the two trees will probably be a pitchout and pitchouts may be found more frequently than successfully attacked trees.

Incipient Epidemic: two or more groups of three to four MPB-attacked trees per group on 40 to 320 acres for 2 to 3 consecutive years. The appearance of a single group of three or four infested trees in any particular year (for example, Sartwell and Stevens [1975] definition) may signal an incipient epidemic, but when considered over a landscape of 20 to 50 acres, it might be a 1-year anomaly. The incipient level represents the transition from endemic to epidemic but recognizes that at the beginning of an epidemic, MPB populations do not usually increase rapidly because the number of trees per group increases slowly and infested groups have not coalesced.

Epidemic: several groups of four or more MPB-attacked trees per group on 20 to 320 acres over 2 to 3 consecutive years, especially if the number of trees per group is increasing and groups are coalescing. As for the incipient epidemic definition, the appearance of two to three groups on 50 acres for 1 year may be an anomaly, but their continued presence in succeeding years indicates otherwise. In contrast to the incipient epidemic condition where numbers of infested trees are increasing relatively slowly, the number of infested trees per group in specific stands in the epidemic condition may increase tenfold (as evidenced by increases in plots at the BM1 location).

Endemic MPB populations may be easily distinguished from epidemic MPB populations most of the time, but the transition from endemic to epidemic, which we call incipient epidemic, is difficult to ascertain and may be considered moot from a management perspective. However, epidemic MPB populations rarely develop rapidly (Sartwell and Stevens 1975), so the transition from endemic to epidemic is important to recognize because it provides managers with a grace period during which control activities could be initiated before substantial tree mortality occurs. The incipient epidemic stage represents a last chance for managers to minimize MPB-caused mortality.

Similarly, the transition from incipient epidemic to epidemic is also difficult to ascertain. However, the epidemic condition might be signified by the appearance of infested spots with greater than seven trees per spot, or when infested groups appear to be coalescing within a stand.

Tree Diameters Attacked by the MPB

MPBs attacked a range of diameter classes in partially cut and unmanaged stands (control plots). Diameters of MPB-attacked trees ranged from 8 to 18 inches in partially cut stands and from 7 to 19 inches in unmanaged stands (tables 14 through 18). No trees <8 inches were attacked in the partially cut stands and no trees <7 inches were attacked in the unmanaged stands. No trees <7 inches were attacked in the partially cut plots because trees <7 inches were generally cut during the initial cut.

During the first decade following plot establishment, diameters of all MPB-attacked trees in the partially cut plots were ≤15 inches except for two trees in the CRK GSL 100/110 that were ≥16 inches. Thus, 93 percent of all attacked trees were ≤15 inches.

During the second decade, the number of trees per diameter class shifted to higher diameter classes as trees grew (tables 14 through 18) and slightly greater numbers of trees ≥16 inches were attacked. The percent of MPB-attacked trees per diameter class varied by location. BM1 and BOR plots had ≥96 percent of the trees in diameter classes ≤15 inches. Some plots at BRN and CRK, and the C-C plot, had 25 to 100 percent trees ≤15 inches. The differences in the percentage of trees attacked in the ≤15- versus ≥16-inch diameter classes in the first versus the second decade for BRN, CRK, and the C-C plot resulted because the number of attacked trees per plot in both diameter categories was relatively small and the number of trees in the larger diameter classes increased as trees grew. The differences were not attributed to a change in MPB tree selection behavior.

The partially cut and control BM1 plots had 97 percent or more of the MPB-attacked trees in the ≤15-inch diameter classes through 2006. This diameter class distribution of MPB-attacked trees matches that for the area of heavy MPB-caused tree mortality in Colorado's Front Range as determined by McCambridge and others (1982). The diameter class distribution for the Bear Mtn. 1 plots is similar to that of Lessard (1982) for epidemic conditions in the Black Hills, but not quite comparable because Lessard's diameter range was 7 to 13 inches.

Table 14. Number of trees by 1-inch diameter class for the Bear Mtn. 1 plots. Numbers in parentheses represent the number of MPB-attacked trees (successful and pitchouts) in the decade following the year of inventory. The number of MPB-attacked trees in some diameter classes may exceed the number of trees in the year of inventory because trees in lesser diameter classes grew into those classes before being attacked.

	GSL 60/70			GSL 80/90			GSL 100/110			Control		
Diameter	**1987**	**1997**	**2006**	**1987**	**1997**	**2006**	**1987**	**1997**	**2006**	**1987**	**1997**	**2006**
5										1		
6										1	1	1
7	5			4			4	1		21	12 (4)	5
8	9 (1)	2		30	2		30	5		67	39 (21)	8
9	19	6	1	44 (1)	22		34 (1)	29 (4)	2	82	74 (50)	14
10	26	15	1	44	46 (20)	3	49	30 (8)	15	68	73 (62)	18
11	23	17	5	30 (1)	47 (26)	10	49	48 (19)	15	53	64 (49)	12
12	20	26 (1)	15	18	22 (18)	22	22	43 (26)	13	28	37 (50)	8
13	3	18 (1)	15	5	20 (13)	11	16	21 (18)	19	20	26 (31)	1
14	4	15 (4)	22	4	10 (10)	10	4	19 (22)	11	3	11 (14)	2
15	2	4 (2)	15	1	4 (4)	5	2	5 (4)	4	6	5 (9)	2
16	1	2	8		2 (2)	3		1 (2)	4		5 (2)	1
17	1	3	3		(1)	2			1	1	(3)	
18	1	1	2									
19			2								1 (1)	
20	1	2										
21			2									

Table 15. Number of trees by 1-inch diameter class for the Border plots. Numbers in parentheses represent the number of MPB-attacked trees (successful and pitchouts) in the decade following the year of inventory.

	GSL 60/70			GSL 80/90			GSL 100/110			Control		
Diameter	**1986**	**1997**	**2006**	**1986**	**1997**	**2006**	**1986**	**1997**	**2006**	**1986**	**1997**	**2006**
3										2	1	1
4										19	8	6
5										30	21	14
6							1			59 (3)	28	21
7				1			6			74 (3)	51 (1)	39 (1)
8	8			13			20	1		99 (4)	71 (2)	48
9	20			29 (1)			41	10		104 (6)	73	56
10	26	9		32	9		38	20	6	77 (1)	90 (1)	60 (2)
11	25	6		30 (1)	20	4	35	33 (1)	12	48 (1)	62 (1)	64 (2)
12	21	27	6	28 (1)	32	3 (1)	22	37 (3)	32	35	44 (1)	62 (2)
13	13	27	10	18	27	23 (1)	18	24 (1)	27	15	26	38 (1)
14	1	20	20	4	25	23 (1)	12	21 (2)	33	5	15	20
15	1	10	26		13	31	1	9 (1)	18	4	6 (1)	14
16		3	15		5	24		6	9		3	6
17		1	9		1	5		1	10		1	2
18			4 (1)			5			3			2
19							1					

In the MPB literature, MPBs generally attack trees ≥7- to 8-inch DBH in PP and LPP stands. Trees of lesser diameters may be attacked, especially when they are intermixed with trees of larger diameter. MPBs killed 3-inch diameter trees during an epidemic in the Front Range of Colorado (McCambridge and others 1982). In LPP stands, MPBs usually attack the largest diameter trees in a stand and then, if the infestation persists, attack progressively smaller diameter trees (Cole and Amman 1969). This habit prompted researchers to investigate the potential of diameter-limit cutting—the cutting of all host trees with diameters greater than a specified diameter (for example, 10 inches)—as a means of minimizing MPB-caused tree mortality in LPP stands. While diameter-limit cutting reduced MPB-caused tree mortality in LPP (McGregor and others 1987), the residual LPP stands may be composed of mostly undesirable leave trees. In some quarters, this silvicultural treatment also raised speculation that the treatment was simply a justification for providing large diameter trees for the timber industry.

Diameter-limit cutting has not been a standard treatment in PP stands on the BHNF, and cutting large diameter PP to control MPB populations has been questioned with regard to some BHNF timber sales. In susceptible PP stands in this study, endemic and incipient epidemic MPB populations attacked a range of diameter classes and did not concentrate solely on the largest diameter classes (tables 14 through 18). Our results agree with Olsen and others (1996) who found MPBs did not exclusively attack large diameter trees in susceptible stands. However, as incipient epidemic MPB populations transition into epidemic populations, the percent of MPB-attacked becomes greater in the largest diameter classes (table 14) even though the general distribution of MPB-attacked trees is predominantly less than 15 inches. Based on this information, silvicultural treatments for unmanaged PP stands with endemic or incipient epidemic MPB populations need not be designed to remove only the largest trees nor predicated on reasoning that MPBs exclusively attack only the largest trees.

MPB Susceptibility Thresholds

When the GSL thresholds for rating the susceptibility of PP stands to MPB infestation were established in 1994, the lower and upper limits of the moderate hazard level were derived primarily by default (Schmid and others 1994). The lack of MPB-caused mortality in GSLs between 80 and 120 restricted the definitiveness of the limits until future results from plots in GSLs ranging from 80 to 120 would validate or nullify the limits.

Upon first inspection, the number of MPB-attacked trees per year for each GSL at the four locations with multiple stocking levels (tables 9 through 12) suggests the upper limit for the moderately susceptible level (GSL 120) might warrant changing. The number of MPB-attacked trees in GSLs between 80 and 120 at the BOR and BM1 locations was similar to the numbers in GSLs <80 and even GSLs >120 in most years

Table 16. Number of trees by 1-inch diameter class for the Brownsville plots. Numbers in parentheses are the numbers of MPB-attacked trees (successful and pitchouts) in the decade following the year of inventory.

	GSL 60/70			GSL 80/90			GSL 100/110			Control		
Diameter	**1985**	**1995**	**2005**	**1985**	**1995**	**2005**	**1985**	**1995**	**2005**	**1985**	**1995**	**2005**
5										2		
6										4	4	4
7										1	1	0
8				4						3	3	1
9	1			13	3					4 (1)	3	5
10	3	1		24	16 (1)	3	6	1		16 (1)	10 (1)	3
11	15	1		36	25	15	24	14		30	16 (2)	10
12	33	12		30	33	24	39	23	9	41 (1)	42 (3)	16
13	24	24	6	21	29	29	34	35	26	42 (1)	33 (7)	36
14	11	32 (2)	18	6	16	25	23	34	29	29	35 (6)	27
15	2	13	23	2	9	17	11	22 (1)	34	18	25 (6)	27
16		4	19	1	4 (1)	9	3	9	21	14	14 (3)	20
17		1	12	1		5		2	11	1	10 (1)	8
18			2		1	1			2		1 (2)	8
19									1	1	1 (1)	3
20						1						1

when MPB populations were endemic. As MPB populations increased, the number of MPB-attacked trees in the BOR GSL 100/110 increased just prior to the increase in the control, which suggests this GSL may be incorrectly rated as moderately susceptible. Similarly, the BM1 GSL 100/110 plot had rates of infestation similar to adjacent plots during the first 13 years, but the number of MPB-attacked trees increased beginning in 2001. In both plots, however, the BA was ≥120 ft^2/acre when MPB-attacked trees increased. Thus, each plot fell in the

Table 17. Number of trees by 1-inch diameter class for the Crook Mountain plots. Numbers in parentheses represent the number of MPB-attacked trees (successful and pitchouts) in the decade following the year of inventory.

	GSL 80			GSL 100			GSL 120			Control		
Diameter	**1985**	**1996**	**2006**	**1985**	**1996**	**2006**	**1985**	**1996**	**2006**	**1985**	**1996**	**2006**
3										2	1	1
4										14	13	9
5										10	7	5
6	1			2			2	1		10	10	6
7	1	1		9	4		2	1		7	8	5
8	1			11	6	3	3	2		2	3	1
9		1	1	17	14	2	1	1		3	1	2
10	3			17	16	8	5	2		3	6 (1)	3
11	6 (1)	2		24 (2)	19	16	8	5	2	15	6 (1)	2
12	15 (1)	6 (1)		21 (3)	17	12	11	9	4	30	24	11 (1)
13	22 (1)	10	1	27	23 (1)	17	29	7	1	33	21	14
14	20	16	8	18 (2)	28	17	38 (2)	29 (1)	6	37	41	24
15	18	21	8	8 (1)	14	20	18	37	22	31	33 (1)	32
16	8	16	11 (1)	6	9	22	21	21 (3)	16	12 (1)	25	29
17	4	13	17	2 (1)	7 (1)	3	3	17	28	8	10	24
18	1	6	11	2 (1)	1 (1)	8	1	7 (1)	12	4	8	9
19	1	4	13	1	1	4	1		13	3	2	6
20		1	4		1				3		2	4
21			3			2		1				2
22									1			

Table 18. Number of trees by 1-inch diameter class for the C-C plot (2.47 acres). Numbers in parentheses represent the number of MPB-attacked trees (successful and pitchouts) in the decade following the year of inventory.

Diameter	1985	1996	2006
5	2		
6		1	1
7			
8			
9	2	2	1
10	8	2	
11	39	11 (1)	5
12	61 (1)	41	11
13	58 (2)	49 (3)	27
14	37 (1)	60 (3)	57
15	15	35 (4)	45
16	5	14 (1)	39
17	3	7 (2)	14
18		1	7
19	1	2	3
20			3

high susceptibility category even though it was originally designated as GSL 100. The original GSL designation no longer described stand density so a lowering of the upper limit of the moderate rating does not seem warranted.

Based on the amount of mortality in the BM1 GSL 80/90 and GSL 100/110, these GSL levels could be considered just as susceptible as unmanaged stands. However, the susceptibility rating system is based on crude probabilities of potential for infestation, not total mortality. In the BM1 plots, the probabilities were modified because of the epidemic MPB population in surrounding stands (unmanaged and control). In addition, the control plot was infested 2 years before infestations arose in either the BM1 GSL 80/90 or GSL 100/110. Whether the two plots would have been attacked and/or exhibited the same level of percent mortality if the plots were larger or the MPB population was not in such close proximity remains debatable.

The MPB mortality in the two BM1 plots provides insight into the crude probabilities of beetle infestation relative to the size of the partial cut. For both plots, MPB-attacked trees first showed up in their buffer strips where they bordered adjacent unmanaged stands and the control. In succeeding years, beetles moved into the CIPs of the plots as the MPB infestation persisted. The MPB population, being the magnitude that it was, overwhelmed trees in the partial cuts. Under these circumstances, partial cutting did not prevent substantial mortality.

Modifications in MPB Susceptibility Ratings

Even though the number of MPB-attacked trees in the various plots may have resulted from circumstances confounding susceptibility so changes in the rating system do not seem warranted, we think modifications are in order. Schmid and others (1994) suggested that two methods might eventually evolve—one for unmanaged stands and one for managed stands. Two methods are proposed in hopes of more precisely identifying susceptibility for unmanaged and managed stands.

The method for unmanaged even-aged stands would be similar to the Schmid and others (1994) method with three susceptibility categories. The limit separating the high and moderate susceptibility categories would be lowered to GSL 110 while the limit between the low and moderate categories would remain the same. In addition, the rating given each stand would correspond to the highest GSL found in that stand rather than an average of all points sampled. Even though stands are relatively even-aged and appear homogeneous, a high degree of variability may exist (Olsen and others 1996) and that variability in stocking complicates susceptibility ratings when ratings are based on some measure of mean stand density. This variation is not a problem if GSLs for the various sampling points are within the range for the susceptibility category. However, if the overall GSL is below the demarcation value between two categories, but one sampling point is above the same demarcation value, then the stand may be underrated. Under the current method of Schmid and others (1994), if overall GSL is 105, but a small portion of the stand is at 125, then the stand would be rated moderately susceptible because the overall value was below GSL 120, the minimum value for high susceptibility. Under the proposed method, the stand would be rated high because part of the stand was in the high category. This change in the way stands are rated seems justified in light of the work of Olsen and others (1996), who found MPB infestations associated with high BA but not necessarily the highest BA in the stand. Thus, it seems logical to expect MPBs to infest parts of a stand where the GSL (BA) is greater than the overall average.

The method for managed stands would consist of two susceptibility categories—high and low categories separated at GSL 110. GSL 110 is used in this method for the same reasons cited for the unmanaged stand method. The same concern regarding heterogeneity of stand density is present for managed stands because one subplot in the C-C plot exceeded BA 120 while overall BA was 103 (table 7, 2006 data). Although minimal heterogeneity of stand density would be expected in managed stands as compared to unmanaged stands, the BHNF's marking procedures may contribute to variation in stand densities. If the acceptable range of leave tree densities is ±10 ft^2 of the desired density level, then the variation in stand density as evidenced in the C-C plot is easily understood. As with unmanaged stands, managed stands with one or more sampling point exceeding GSL 110 would be classified as highly susceptible even though the overall GSL was below 110.

Management Implications

Partial Cutting

The immediate implication of these results is that partial cutting unmanaged PP stands can minimize MPB-caused tree mortality. While MPB-caused tree mortality will not be eliminated in partially cut stands (tables 9 through 13), tree mortality can be limited to a relatively low level (for example, single trees or pairs of trees). Mortality such as that in the partially cut BM1 GSL 80/90 and GSL 100/110 need not be evident in PP stands if stands are regularly managed silviculturally.

MPB-caused mortality in the partially cut plots at the various locations indicates that the effectiveness of various levels of partial cutting in preventing high levels of tree mortality over the long-term is not influenced solely by stand stocking level (residual GSL). The interactive effects of the size (acreage) of the cutting, number of years since the stand was cut, and proximity of incipient epidemic or epidemic MPB populations to the cut stand(s) are also important.

In general, the lower the residual GSL, the greater the reduction in subsequent MPB-caused tree mortality over the long-term, especially if the area to be cut is relatively large and the stand(s) are not silviculturally managed after the initial cut. Based on the results at the BM1 plots, unmanaged stands cut to GSLs ≤75 will sustain significantly less MPB-caused mortality than stands partially cut to GSLs ≥100. The difference in tree mortality for GSLs ≤75 compared to GSLs ≥100 results from the interrelationships among greater spacing between residual trees, less inter-tree competition, and different microclimates. The lower densities also increase the greater amount of time required for low density stands (GSL ≤75) versus high density stands (GSL ≥100) to grow to the critical susceptibility threshold.

The greater the size of the partial cut, the lower the percentage of subsequent total mortality in the cut stand. MPB-caused mortality was about 50 percent in the BM1 GSL 80/90 and GSL 100/110 over a 20-year period primarily because the two stands were surrounded by unmanaged stands and MPBs from those stands moved into the partially cut stands. Thus, 2.5-acre partial cuts can suffer considerable mortality when surrounded by unmanaged stands. GSL 80 to 100 stands may not initially incur substantial tree mortality if the cut area is considerably larger than 2.5 acres (for example, >10 acres). Mortality would probably be confined to the boundaries between the cut stand and adjacent unmanaged stands. However, the low potential for MPB-caused mortality in GSLs of 80 to 100 in larger cutting areas may be lost as years since the initial partial cutting increase. GSLs of 80/90 can grow to exceed BAs of 120 in 20 to 30 years (Obedzinski and others 1999) or, as the C-C plot shows, more than BA 120 in parts of the stand if spacing is not properly addressed (table 7). GSLs of 100/110 can exceed BA 120 in 10 to 20 years (table 6, Obedzinski and others 1999). Both GSL levels thus reach the GSL 120 threshold for MPB infestation relatively quickly. If GSL 110, as proposed in this report, is accepted as the new threshold for high susceptibility, then GSL 100/110 stands would be near or at that level after their initial cutting.

If stands are partially cut to GSLs ≥100, the stands may sustain a low level of MPB-caused tree mortality (percent) as long as epidemic MPB populations are not present in the immediate vicinity. If epidemic populations are present, such stands could lose more than 50 percent of their trees, especially if the acreage of the partially cut stand(s) is <3 acres and it is surrounded by unmanaged stands. Moreover, stands partially cut to GSL ≥100 are just below the current susceptibility threshold of 120 and can grow to that level in 10 to 20 years (see Obedzinski and others 1999) so MPB-caused mortality in such areas should be expected within 15 years.

General statements regarding partial cutting are useful, but forest managers need more specific recommendations. When this study began in the Black Hills, Floyd Fowler, Timber Management Officer, Nemo district, BHNF, stated, "We know we can reduce MPB-caused tree mortality to a negligible level if we greatly reduce the stocking level of unmanaged stands. What we need to know is the greatest level of stocking we can carry without sustaining substantial MPB-caused mortality." His question is not simply answered, because specific recommendations for maintaining minimal MPB-caused mortality in a particular stand(s) for ≥20 years encompass a multitude of considerations, including:

1) Management objectives,
2) Stand reentry period,
3) Reaction time of management (time period between the appearance of incipient epidemic MPB

populations and when control efforts are initiated in the stand[s]), and

4) Factors influencing the effectiveness of partial cutting previously discussed.

Assuming a relatively large contiguous tract of forest is to be partially cut and stand(s) within are to be managed to maintain high stocking levels of mature trees, then partial cutting to GSL 90 to 100 could be recommended as long as incipient epidemic MPB populations are absent. If incipient epidemic MPB populations are present in surrounding stands and management cannot initiate future control efforts within a year, then GSLs ≤80 would be a better recommendation. Despite the threat of MPB populations in adjacent tracts, forest managers may still opt to cut to GSL 90 to 100 if they can initiate control operations within a year or reentry is scheduled within a few years.

If the tract to be cut is relatively small (for example, 2 to 5 acres) and surrounded by unmanaged forest, then partial cutting to GSL 90 to 100 would not be generally recommended as a long-term solution. This is especially pertinent for private landowners whose holdings consist of a few acres bordered by unmanaged forest. It is highly probable that their tract could be decimated by MPB populations from adjacent stands (as in the BM1 plots) before control efforts could be initiated on surrounding lands. In this case, partial cutting to a GSL ≤75 would be more advisable.

The former, long-standing BHNF policy of partial cutting stands to BA 80 will probably keep such stands free of epidemic MPB populations for 10 to 15 years following cutting. However, as evidenced by results from the C-C plot (table 13), stands of BA 80 (GSL 80) may begin to sustain more than endemic MPB mortality 15 to 20 years after the initial cutting. Such stands should be closely monitored after 15 years, especially if additional cutting is not initiated or planned during that time. Further, uniform spacing is not always achieved during the leave tree selection/marking process. Uneven spacing leads to microcosm stands of 110 to 120 BA within the overall stand (table 7) that become more susceptible to MPB infestation and may lead to more extensive MPB-caused tree mortality. This may explain why stands cut to GSL 80 are exhibiting MPB infestations before their normally scheduled reentry.

Leave Tree Selection

The distribution of MPB-killed trees by diameter class within the partially cut and associated unmanaged stands (tables 14 through 18) has implications regarding leave tree selection for proposed silvicultural treatments in unmanaged stands. In unmanaged susceptible PP stands on the BHNF, endemic and incipient epidemic MPB populations attacked a range of diameter classes and did not concentrate exclusively on the largest diameter classes (tables 14 through 18). Thus, harvesting the three to four largest diameter classes within an unmanaged stand (for example, trees in diameter classes ≥16 inches) during an initial partial cut does not necessarily reduce stand susceptibility if the stocking level after cutting is GSL ≥100, as a substantial number of susceptible-sized trees (10 to 15 inches) would still exist in most stands. Further, susceptibility of partially cut stands will not automatically increase even though some trees ≥16 inches are left because large diameter trees in such stands would not be expected to be attacked more readily than trees with 10 to 15 inch diameters. However, if susceptible stands are partially cut to a GSL ≥100, and an epidemic MPB population is present, then most trees in the large diameter classes may be killed because MPB-caused mortality (percentage-wise) would be highest in the largest diameter classes if the epidemic persists in the stands. Obviously, removal of trees in the largest diameter classes before a MPB epidemic occurs will ensure that such trees will be harvested when their value is greatest and will eliminate such trees from being major contributors to future MPB generations. Nevertheless, if the largest trees are the most desirable for regeneration production or other management objectives, then leaving some of them is warranted as long as the trees are in apparent good health.

Management of Ponderosa Pine Stands

The greater implication of these results is the management of PP stands to minimize MPB-caused mortality in relation to the BHNF Management Plan. Graham and Knight (1965) succinctly state that forest insect management is an integral part of forest management. The most important aspect of managing mature PP stands on the BHNF is minimizing MPB-caused mortality. If forest managers are to achieve long-term multiple objectives, managers need to assume that minimization of MPB-caused mortality is the primary objective in stands where incipient epidemic MPB populations arise and should temporarily relegate other objectives to secondary status until the immediate threat from epidemic MPB populations has been eliminated. While this approach may be contrary to the principle of multiple use and many objectives within the BHNF Plan, it is essential to achieving many of the Plan's long-term multiple objectives. Allowing MPB populations to expand beyond the incipient stage will prevent achievement of most other management objectives.

To illustrate how reticent MPB management causes objective achievement failure, consider the recent MPB epidemic in the Beaver Park area of the Sturgis watershed. In 1996, MPB populations began increasing in Beaver Park SW of Sturgis, SD (Allen and others 2002). In subsequent years, MPB populations continued to increase with more than 100,000 trees attacked in 2000 (Allen and others 2002). Due to legal restraints, the BHNF was unable to conduct silvicultural treatments in the area. MPB-caused tree mortality became so extensive that "entire hillsides are now completely devoid of large trees" (Allen and others 2002). Areas exhibiting this degree of mortality "may take 80 to 100 years before a mature forest is present again" (Allen and others 2002). When this level of stand mortality occurs, achievement of other objectives is extremely unlikely. For example, loss of the overstory will eliminate the "thermal cover" for wild ungulates. Death of mature trees will eliminate the habitat for red squirrels and roosting sites for wild turkeys. MPB-killed trees increase dry fuel loads and thereby increase the potential for severe fires if fires start. Increased runoff and the possibility of flooding may temporarily occur on hillsides devoid of trees. Thus, failure to address incipient epidemic MPB populations can substantially affect the achievement of other objectives well beyond the immediate objective of dealing with MPB populations.

Once PP stands reach the susceptible condition for MPB attack, maintaining minimal MPB-caused mortality must become of primary concern and the concern must extend well beyond an initial single partial cut. A single partial cut to GSL 80 in susceptible stands may suffice for a number of years, but waiting another 20 to 30 years to make the regeneration cut may not be prudent. As shown in Obedzinski and others (1999) and in this report, PP stands may again become susceptible in 10 to 20 years just through natural growth. Further, microcosm stands with densities greater than the overall average stand density may be inadvertently created within large tracts during the marking process for the initial partial cut (table 7). These microcosm stands may become highly susceptible well before overall stand susceptibility exceeds the high susceptible threshold or the stand is silviculturally revisited. Constant silvicultural action is a must if the BHNF is to ever extricate itself from the periodic appearances of MPB epidemics in its timber managed areas.

Literature Cited

Allen, K.K.; Schaupp, W.C., Jr.; Long, D.F. 2002. Evaluation of mountain pine beetle activity in the Beaver Park area of the Black Hills National Forest. Biological Evaluation R2-03-03. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Renewable Resources. 14 p.

Blackman, M.W. 1931. The Black Hills beetle (*Dendroctonus ponderosae* Hopk.) New York State College of Forestry Tech. Bull. 36. 97 p.

Cole, W.E.; Amman, G.D. 1969. Mountain pine beetle infestations in relation to lodgepole pine diameters. Res. Note INT-95. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 7 p.

Furniss, R.L.; Carolin, V.M. 1977. Western forest insects. Miscellaneous Publication No. 1339. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 654 p.

Graham, S.A.; Knight, F.B. 1965. Principles of forest entomology. 4th Edition. McGraw-Hill Inc. xii + 417 p.

Johnson, E.; Schaupp, W.E., Jr.; Long, D.F. 2001. [Letter to Forest Supervisor]. October 12. 3 p. On file at: U.S. Department of Agriculture, Forest Service, Black Hills National Forest, Custer, SD.

Johnson, E.; Long, D.F. 2003. [Letter to Forest Supervisor]. January 7. 3 p. On file at: U.S. Department of Agriculture, Black Hills National Forest, Custer, SD.

Lessard, G. 1982. Factors affecting ponderosa pine stand susceptibility to mountain pine beetle in the Black Hills 1981. Technical Report R2-26. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Timber, Forest Pest, and Cooperative Forestry Management. 16 p.

McCambridge, W.F.; Hawksworth, F.G.; Edminster, C.B.; Laut, J.G. 1982. Ponderosa pine mortality resulting from a mountain pine beetle outbreak. Res. Pap. RM-235. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 7 p.

McGregor, M.D.; Amman, G.D.; Schmitz, R.F.; Oakes, R.D. 1987. Partial cutting lodgepole pine stands to reduce losses to the mountain pine beetle. Can. J. For. Res. 17: 1234-1239.

Obedzinski, R.A.; Schmid, J.M.; Mata, S.A.; Olsen, W.K.; Kessler, R.R. 1999. Growth of ponderosa pine stands in relation to mountain pine beetle susceptibility. Gen. Tech. Rep. RMRS-GTR-28. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 13 p.

Olsen, W.K.; Schmid, J.M.; Mata, S.A. 1996. Stand characteristics associated with mountain pine beetle infestations in ponderosa pine. Forest Science 42: 310-327.

Sartwell, C.; Stevens, R.E. 1975. Mountain pine beetle in ponderosa pine: prospects for silvicultural control in second-growth stands. Journal of Forestry 73: 136-140.

Schaupp, B.; Johnson, E.; McConnell, T. 2004. [Letter to Forest Supervisor]. April 26. 3 p. On file at: U.S. Department of Agriculture, Forest Service, Black Hills National Forest, Custer, SD.

Schmid, J.M.; Mata, S.A. 2005. Mountain pine beetle-caused tree mortality in partially cut plots surrounded by unmanaged stands. Res. Pap. RMRS-RP-54. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 11 p.

Schmid, J.M.; Mata, S.A.; Obedzinski, R.A. 1994. Hazard rating ponderosa pine stands for mountain pine beetles in the Black Hills. Res. Note RM-529. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p.

Schmid, J.M.; Mata, S.A.; Olsen, W.K.; Vigil, D.D. 1993. Phloem temperatures in mountain pine beetle-infested ponderosa pine. Res. Note RM-521. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 10 p.

Thompson, R.G. 1975. Review of mountain pine beetle and other forest insects active in the Black Hills: 1895 to 1974. Forest Pest Management Special Report R2-75-1. Lakewood CO: U.S. Department of Agriculture, Forest Service, Forest Pest Management. 35 p.

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