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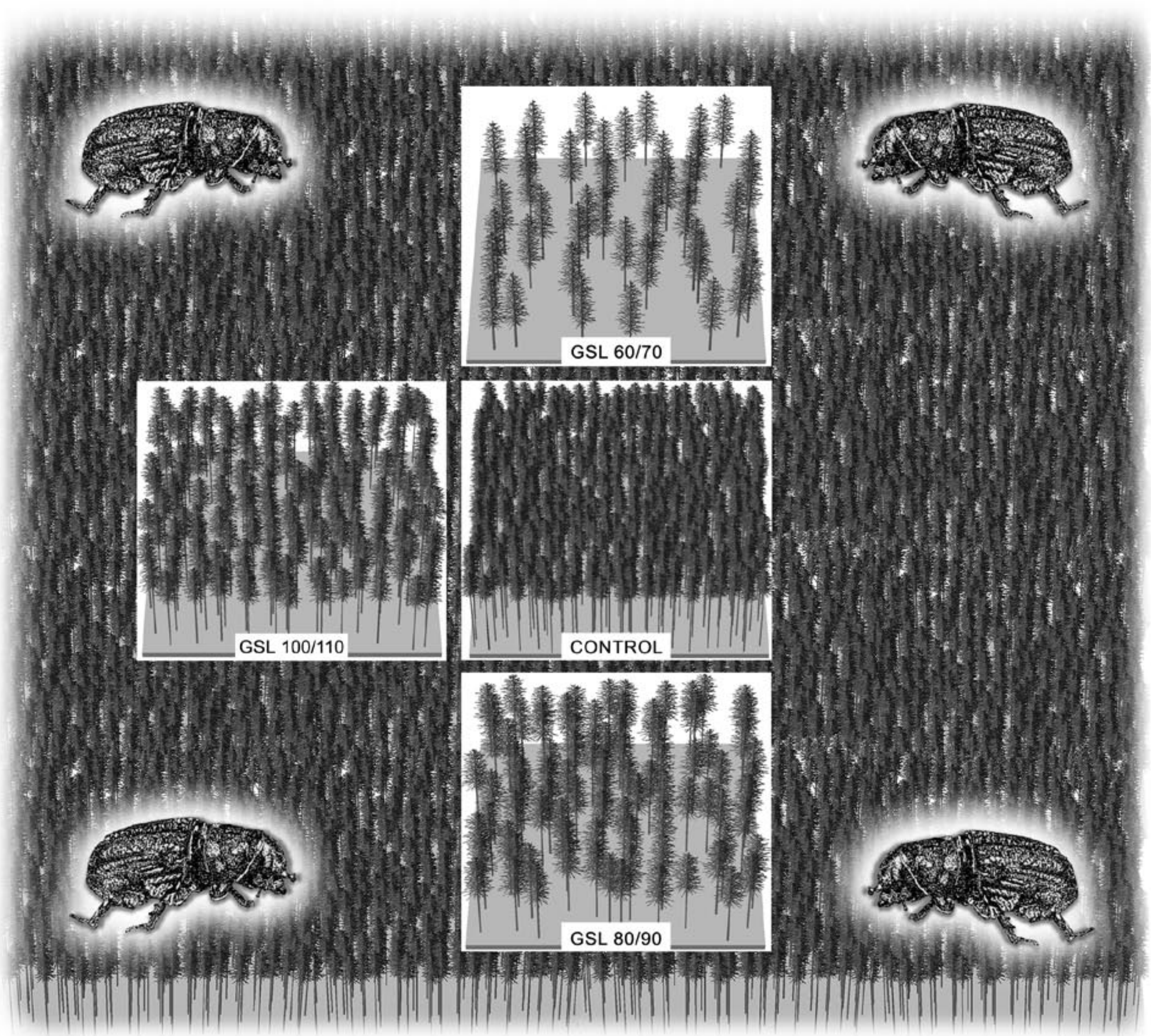
J.M. Schmid and S.A. Mata



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Abstract—Mountain pine beetle activity was monitored in one set of 2.5 acre plots in the southern portion of the Black Hills National Forest over a 17-year period. Beetles attacked 77 percent of the trees in the uncut control, 48 percent of the trees in the growing stock level (GSL) 100/110, 53 percent of the trees in the GSL 80/90, and 9 percent of the trees in the GSL 60/70. The percentages of MPB-attacked trees in each 1 in diameter class were lowest in the GSL 60/70, intermediate in the GSL 80/90 and GSL 100/110, and highest in the uncut control. Live basal area was significantly reduced in the GSL 80/90, GSL 100/110, and control but not in the GSL 60/70. Partial cutting to reduce beetle-caused mortality may be ineffective for partially cut parcels of <10 acres if the partially cut stands are surrounded by unmanaged susceptible stands. To increase the effectiveness of partial cutting, stands should be managed on a landscape basis. A 100-ft-wide strip with stand density of ≤GSL 70 between unmanaged and managed stands may be sufficient to limit the spread of beetle-caused mortality from unmanaged stands to adjacent partially cut stands.

Keywords: Mountain pine beetle, ponderosa pine, stand management

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Mountain Pine Beetle-Caused Tree Mortality in Partially Cut Plots Surrounded by Unmanaged Stands

J.M. Schmid[1] and S.A. Mata

Introduction

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) causes high levels of tree mortality in ponderosa pine (*Pinus ponderosa* Lawson) and lodgepole pine (*Pinus contorta* Douglas) stands. Epidemics of the mountain pine beetle (MPB) have caused extensive ponderosa pine (PP) mortality in the Black Hills during most decades in the last century (see Thompson 1975; Pasek and Schaupp 1992; Allen and McMillin 2001; and Johnson and Long 2003). Since 1996, forest-wide MPB-caused tree mortality increased from about 1500 trees in 1996 to an excess of 300,000 trees per year in 2001 (Johnson and others 2001).

In 1984, the Rocky Mountain Forest & Range Experiment Station of the U.S. Forest Service began a study to determine the relationship between stand density and MPB-caused tree mortality in both PP and lodgepole pine (LP) stands. From 1985 to 1992, 10 sets of 2.5 acre plots were established in PP stands at various locations on the Black Hills National Forest (BHNF) in South Dakota. Each set of plots was usually composed of four 2.5 acre plots, although one location had only three plots and one location had five plots. In the four plot set, three of the plots were partially cut to various growing stock levels (GSL) while the fourth plot was left uncut to serve as the control.

At the time sets of plots were being installed on the BHNF, MPB populations were epidemic in 1987 in Bear Basin just north of Bear Mountain in the southern Black Hills. Two sets of plots were installed in the northern and eastern portions of the infested area; one set in 1989 and one set in 1991. As MPB populations and, thus, the infested area increased in subsequent years, trees in the plots were increasingly exposed to MPB attack. Unfortunately, silvicultural activities by the BHNF in 1992 and unusually cold temperatures in October/November 1991 (see Schmid and others 1993) drastically reduced MPB populations, and thereby reduced potential information yield. However, preliminary results from the set of plots established in 1989 suggested the critical threshold for MPB infestation of unmanaged stands should be lowered from basal area 150 ft^2/acre to basal area 120 ft^2/acre (see Schmid and Mata 1992).

In 1997, MPB populations began to increase throughout the Black Hills and particularly in the vicinity of Bear Mountain in the southern Black Hills (McMillin and Allen 1999). Simultaneously, the number of MPB-infested trees began to increase on a set of plots located southwest of Bear Mountain (hereafter called the Bear Mountain I plots) that were surrounded by unmanaged stands. These plots were not exposed to the MPB populations associated with the previous MPB epidemic in Bear Basin north of Bear Mountain. This report summarizes the MPB activity to date on that set of plots in the southern Black Hills and discusses the results in relation to PP management.

Methods

In June 1986, a set of four 2.5 acre growing stock level (GSL) plots were installed on the west side of the Bear Mountain Lookout road about 0.5 mile southwest of the Lookout. The Bear Mountain Lookout is on the BHNF about 12 miles northwest of Custer, SD. Three of the plots were partially cut to GSLs of 60, 80, and 100 in June-July 1987 while the fourth plot was left uncut to serve as the control. Each of the partially cut plots bordered on the control; the GSL 80 on the south side of the control, the GSL 100 on the west side, and the GSL 60 on the north side. The plots were generally surrounded by unmanaged PP stands with tree densities and diameter classes the same as within the plots when the plots were being installed. In 2004, the BHNF conducted a sanitation/salvage timber sale in the area surrounding the plots.

Each 2.5 acre plot was subdivided into two parts: a central inventory plot (CIP) equal to 1.25 acres and the buffer strips surrounding it which also equaled

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1.25 acres. When the appropriate plot size for this study was being discussed, a 2.5 acre plot was considered as possibly too small to evaluate the effect of partial cutting because epidemic MPB populations might inundate a plot and prevent detection of treatment effect. While this disadvantage was recognized, a 2.5 acre plot size was chosen because it was more conducive for plot installation and long-term record keeping. To address the potential problem of overwhelming MPB populations, the central one-half of the plot (CIP) was designated for record keeping. The CIP was thus surrounded by strips that would "buffer" the influence of MPB infestation from adjacent plots of different stocking levels or uncut stands that bordered the plots.

After the plot boundaries were delineated, the diameter at breast height (DBH) of each tree within the CIP was measured and recorded. Other characteristics such as forked boles, presence of diseases, and scars were also recorded. Using the tree diameters, the GSL of each plot was computed. Following computation of GSLs within all of the CIPs, the CIPs within the three plots chosen for cutting were marked to GSLs of 60, 80, or 100. We tried to hold the GSL of each partially cut plot within ± 1 of the designated level (i.e., a GSL 80 stand would be between 79 and 81).

Leave trees were selected on the basis of DBH, spacing, tree form, crown development, and visually apparent good health. Tree selection emphasized leaving the best and largest PP as evenly spaced as possible. Although tree selection tended to favor trees with larger diameters and discriminate against trees with smaller diameters, not all of the largest trees were retained nor were all of the smallest trees marked to be cut. Metal tags were placed at DBH on all leave trees to facilitate record keeping with regard to MPB activity and the determination of diameter growth in subsequent years.

The buffer strips for each plot were marked to the same GSL as their CIP but tree diameters were not permanently recorded nor did the leave trees receive metal tags.

The plots were reinventoried in August 1997, at which time all live trees within the CIPs were remeasured. Using those tree diameters, the current GSLs of each plot were computed. Using this information, each plot was marked for cutting in May 2000 and then cut in November and December 2000. Because the susceptibility of GSLs between 80 and 120 was still questionable (Schmid and others 1994), and additional information regarding susceptibility of such stands was desirable, we increased the GSL in each of the partially cut stands during marking in 2000. The GSL 60 plot was raised to GSL 70, the GSL 80 to GSL 90, and the GSL 100 to GSL 110. The increased levels were attained through the diameter growth on the existing trees and not by the addition of more leave trees.

The plots were surveyed at one or two year intervals from 1988 to 1997 to assess MPB activity. From 1997 to 2004, surveys were at two to three year intervals. During each survey, each tree was examined for the presence or absence of MPB attacks as well as other possible mortality factors such as *Ips* spp., *Armillaria*, and physical damage. Examinations for insect activity were confined to the lower 7 ft of the bole. If insect activity as evidenced by woodpecker-caused debarking was observed on the bole above 7 ft, it was noted but the bole was not examined. Records were maintained for each tree in the CIP as to its health or cause of death during each survey.

MPB-attacked trees were classified as successfully attacked (tree likely to die) or as a pitchout (tree unlikely to die because MPB attacks appeared insufficient to kill it). Some trees were pitchouts one year but were successfully attacked in subsequent years. Other pitchouts were not as yet attacked one or two years later. Because some pitchouts survived one or more years after attack, they could not be considered as MPB-caused mortality. Thus, the question arose as to whether pitchouts should be considered together with successfully attacked trees or ignored as MPB-attacked trees. We chose to combine pitchouts with successfully attacked trees because the combined number of MPB-attacked trees is more indicative of the level of beetle activity. In addition, because some pitchouts were attacked and killed by another generation of MPBs in subsequent years, such trees could be considered as two MPB-attacked trees. However, that accounting procedure would represent double counting in such instances. Therefore, pitchouts that were attacked again at a later date were counted as MPB-attacked trees only once, but the incidence of reattacks in a plot is discussed.

Sources of tree mortality other than MPB were not always accurately assessed because they often act in concert with each other. For example, a tree may have had *Ips* galleries present as well as *Armillaria.* Whether the *Ips* killed the tree and the *Armillaria* developed after *Ips* attack or the *Armillaria* essentially killed the tree and the *Ips* attacked as the tree was dying could not be determined. Similarly, wind damaged the crowns of some trees but whether the wind-damage killed the tree or only predisposed it to some other mortality factor was not determined. A few MPB-attacked trees were predisposed by lightning, *Armillaria*, or wind damage. Thus, two or more sources of mortality should be recognized as possibly acting in concert.

Numbers of MPB-attacked trees are based on the CIP records from 1987 to 2004. Data from the buffer strips is used to supplement the CIP information but is not incorporated in the CIP records. Percentages of trees attributed to the various mortality factors are based on the total number of trees existing in the CIPs after the 1987 cutting.

To determine the distribution of MPB-attacked trees by diameter class, the diameters recorded in 1986 were used for trees attacked from 1987 through 1997 because we did not measure tree diameters the year each tree was killed. From 1998 through 2004, diameters recorded in 1997 were used for the MPB-attacked trees.

Basal area (BA) in ft^2/acre was computed for the CIP of each GSL from the diameters of the live trees on the plots in 1986 and 1997. Because diameters were not remeasured after 1997, BAs for 2004 were computed by determining the average annual growth rate from 1986 to 1997 for those trees still alive in 2004. The average annual growth rate for each tree was then multiplied by seven and the result added to the 1997 diameter to derive the 2004 diameter. The estimated 2004 diameters were then used to compute the 2004 BAs.

Results and Discussion

Control

Seventy-seven percent (272 trees) of the trees in the CIP were MPB-attacked (table 1). If pitchouts that were attacked a second time are counted as two MPB-attacked trees, then the percentage of MPB-attacked trees would increase. For example, seven pitchouts in 2003 were attacked again in 2004.

No MPB-attacked trees were found in the CIP between 1987 and 1997. MPB-attacked trees were first observed in the CIP in 1998 (figure 1). The number of MPB-attacked trees in the CIP increased in 1999 and again in 2000. The numbers in the CIP in 2001 were the same as in 2000. MPB-attacked trees decreased in 2002 but increased 50-fold in 2003 as compared to 2002 (figure 1).

Within the buffer strips, six MPB-attacked trees were present in the south buffer in 1991. Fifteen trees were attacked in buffer strips in the southwest corner of the plot in 2000. Sixteen trees were attacked in the north buffer in 2001. Fifty trees were also attacked in 2003 in the north, east, and west buffer strips.

Ips, *Armillaria*, wind, and unknown caused 3 percent of the tree mortality in the CIP since 1987 (table 1). One tree had both *Ips* and *Armillaria* present while another tree had a wind-broken top and *Ips* present. *Ips* may have attacked the trees after the *Armillaria* and wind had affected tree health.

GSL 60/70

Nine percent (10 trees) of the trees in the CIP were MPB-attacked from 1987 to 2004 (table 1). No pitchouts were observed. From 1987 to 1997, MPBs attacked one tree (figure 2). After 1997, no new MPB-attacked trees were evident in the CIP until nine trees were attacked in 2003.

Within the north buffer, one MPB-attacked tree was found in 1990, one in 1991, six in 2001, and 17 in 2003. Just outside the north buffer, one MPB-attacked tree was found in 2000 and 21 in 2001. Outside the

Table 1—Tree conditions on the Bear Mountain I growing stock level plots after 17 years. Under each GSL, the percent of the total number of trees in the CIP is listed for each condition category and is followed by the total number of trees (in parentheses) in each category.

	Growing stock level (GSL)			
Tree condition	**GSL 60/70**	**GSL 80/90**	**GSL 100/110**	**Control**
Live	78% (90)	34% (61)	41% (86)	20% (71)
MPB-attacked	9% (10)	53% (96)	48% (100)	77% (272)
Cut	10% (12)	11% (20)	9% (18)	
Ips	1% (1)			1% (2)
Scolytid	1% (1)			
Armillaria		1% (2)	<1% (1)	1% (2)
Unknown/Wind	1% (1)	1% (1)	2% (5)	1% (4)
Total	100 (115)	100 (180)	100 (210)	100 (351)

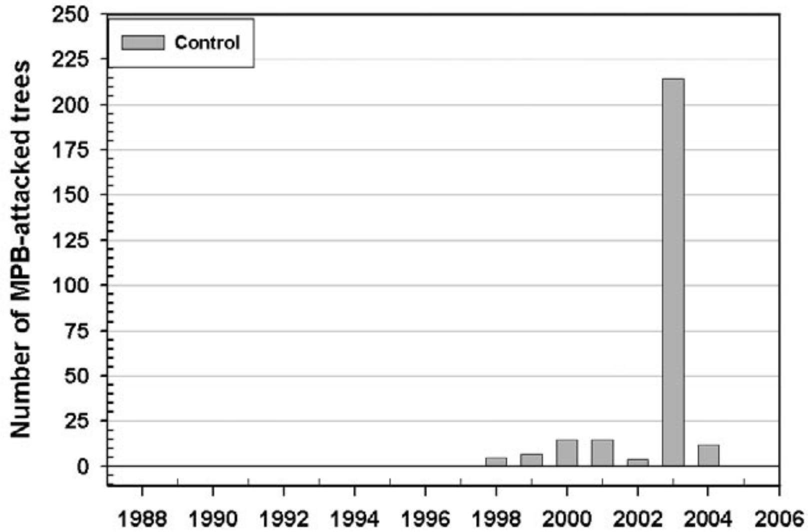

Figure 1—Number of MPB-attacked trees per year in the CIP of the control plot from 1987 through 2004.

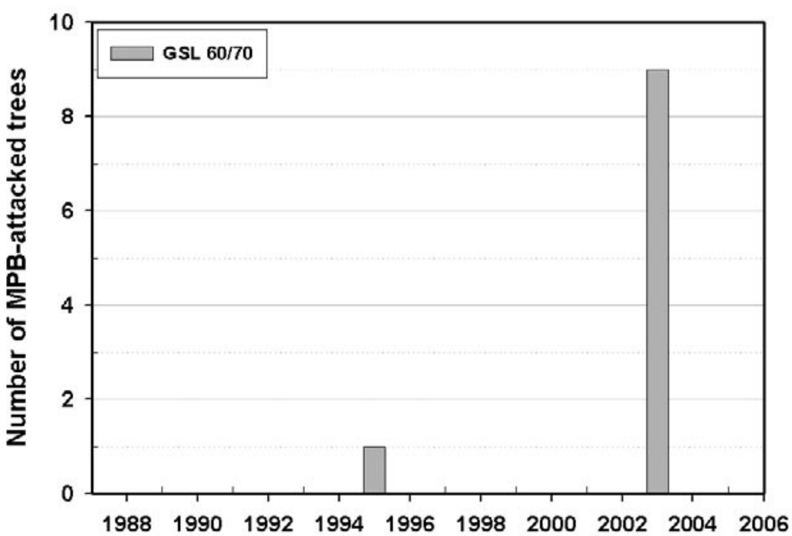

Figure 2—Number of MPB-attacked trees per year in the CIP of the GSL 60/70 plot from 1987 through 2004.

west buffer, one MPB-attacked tree was found in 1999, three in 2000, and one in 2001.

Ips, other scolytids, and unknown factors caused a 3 percent loss in the total number of trees (table 1).

GSL 80/90

Fifty-three percent (96 trees) of the trees in the CIP were MPB-attacked since 1987 (table 1). From 1987 to 1997, one tree was attacked in 1988 and one in 1995 (figure 3). From 1996 through 2000, no MPB-attacked trees were found in the CIP. MPB-attacked trees in the CIP numbered one in 2001, 29 in 2002, one in 2003, and 63 in 2004 (figure 3). Three pitchouts were present among the trees attacked in 2002 and five pitchouts among the 2004 trees. One 2002 pitchout was attacked again in 2004.

In the buffer strips, four trees were MPB-attacked in the north strip in 2001. Trees attacked in the south buffer strip numbered two in 2000, three in 2002, and 10 in 2003. In the west buffer, two trees were attacked in 2002 and eight trees in 2003.

Armillaria and unknown factors accounted for 2 percent of tree loss in the CIP from 1987 to 2004 (table 1). One of the MPB-attacked trees had evidence of *Armillaria* resinosis and another had a broken top in addition to the MPB attacks.

GSL 100/110

Forty-eight percent (100 trees) of the trees in the CIP were MPB-attacked since the plot was established (table 1). During the first 10 years, one tree was attacked in 1991 (figure 4). Additional attacked trees were not

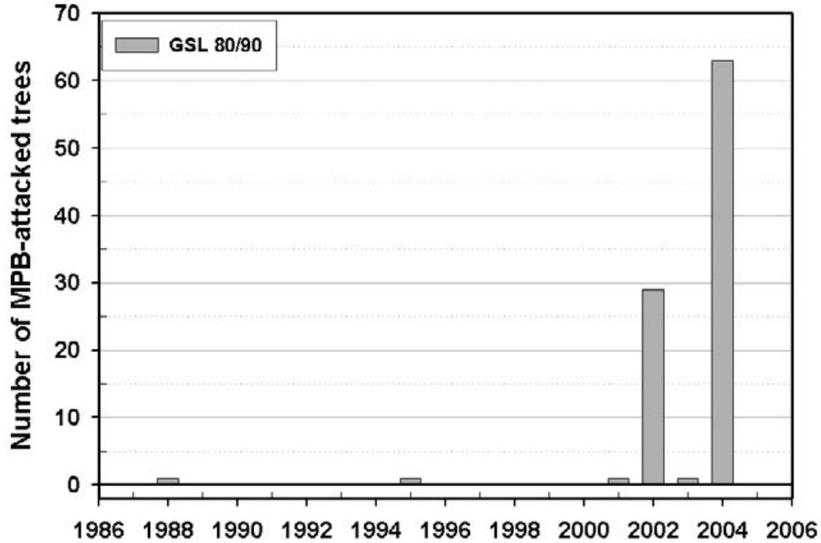

Figure 3—Number of MPB-attacked trees per year in the CIP of the GSL 80/90 plot from 1987 through 2004.

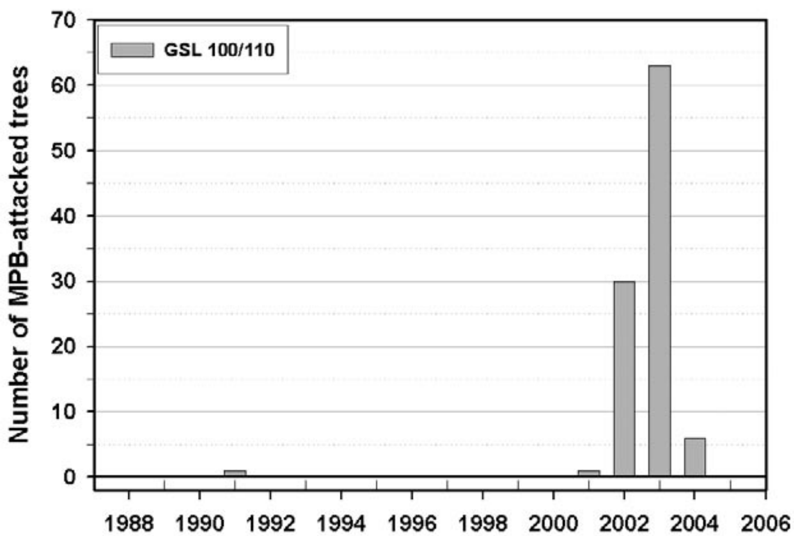

Figure 4—Number of MPB-attacked trees per year in the CIP of the GSL 100/110 plot from 1987 through 2004.

found until one tree was attacked in 2001. The numbers of MPB-attacked trees increased to 30 in 2002, more than doubled to 63 in 2003, and then decreased to six in 2004 (figure 4). Of the 63 MPB-attacked trees in 2003, 12 were considered pitchouts and two of the 2003 pitchouts were attacked a second time in 2004.

In the buffer strips, four trees were attacked in the west buffer in 1997. One of the four trees had a broken top that may have caused it to become a primary focus tree. Eight trees were attacked in the west buffer in 2000. Two trees were attacked in the west buffer and 22 trees were attacked in an unmanaged stand just outside the west buffer in 2001.

About 3 percent of the trees were lost to Armillaria or unknown causes (table 1). Several of the trees had broken tops that may have killed them or caused them to succumb to *Armillaria.*

Sequence of Infestation History

During the first 10 years (1987-1996) the Bear Mountain I plots existed, the number of MPB-attacked trees in each of the four CIPs was either zero or limited to a single tree for one or two years. In the partially cut plots, one tree was found in the GSL 60/70 and GSL 100/110 and two trees were found in the GSL 80/90 during the period. No MPB-attacked trees were found in the control CIP. While MPB-attacked trees were relatively scarce in the CIPs during the first 10 years, small groups of trees (four to six trees per group) were evident in the buffers of the GSL 100/110 and control as well as outside the plots.

As MPB populations began to increase in the vicinity of Bear Mountain in 1997 (McMillin and Allen 1999), MPB-attacked trees also increased in and around the Bear Mountain I plots. The initial increases of MPB-attacked trees in the CIPs occurred in the control in 1998 (figure 1). Increasing numbers of MPB-attacked trees became evident in the CIPs of the partially cut plots in 2001 (figures 3 and 4). Some of the initial MPB-infested spots were created by primary focus factors—factors that predispose trees to attack by the MPB (see Eckberg and others 1994). For example, a lightning-struck tree in the control CIP centered a group of five MPB-attacked trees in 1998 and one of four MPB-attacked trees in the west buffer of the GSL 100/110 had a recently broken top.

As MPB populations further enlarged in the control CIP (figure 1) and in surrounding stands, more extensive infestations appeared in the partially cut plots. In the GSL 80/90, attacked trees appeared in the north buffer that was adjacent to the south boundary of the control and in the west buffer that was adjacent to an unmanaged stand. In the GSL 100/110, attacked trees appeared in the northern part of the CIP and in the west buffer; both areas were near infestations in adjacent unmanaged stands to the north and west. In the GSL 60/70, attacked trees were first evident in the north buffer that was adjacent to an unmanaged stand. Eventually, the MPB populations residing within the plots plus those from surrounding stands concentrated within the plots to create the substantial numbers of MPB-attacked trees evident in 2003.

Distribution of MPB-attacked Trees by 1 inch Diameter Class

MPB-attacked trees in the CIPs of the four plots were only present in diameter classes ≤10 in from 1987 to 1997 even though each CIP had substantial numbers of trees in diameter classes ≥11 in (tables 2-5). From 1998 to 2004, MPB-attacked trees were present in nearly all diameter classes in the GSL 80/90, 100/110, and control except for the two lowest diameter classes (tables 3, 4, and 5). In contrast, the GSL 60/70 had no MPB-attacked trees in the ≤9 and ≥15 in diameter classes (table 2).

Percentage-wise, MPB-attacked trees in respective diameter classes were generally lowest in the GSL 60/70, intermediate in the GSL 80/90 and GSL 100/110, and highest in the control (tables 2, 3, 4, and 5). However, percentages in the GSL 80/90 and GSL 100/110 were variable such that percentages in the 9, 10, and 15 in classes of the GSL 80/90 were greater than the same classes in the GSL 100/110 but the situation was reversed for the 12, 13, 14, and 16 in classes (tables 3 and 4). The highest percentage loss in the GSL 60/70 was 22 percent in the 13 in class (table 2) while losses ≥95 percent were present in the 13, 15, 16, and 19 in classes in the control (table 5, figure 5).

Table 2—Number and percent of MPB-attacked trees by 1 inch diameter class in the CIP of the GSL 60/70. Numbers in parentheses are the 1998 leave trees that were cut in 2000.

Diameter class (inches)	Number of leave-trees 1986	Number of MPB-attacked 1987-1997	Percent of trees-attacked 1987-1997	Number of leave-trees 1998	Number of MPB-attacked 1998-2004	Percent of trees-attacked 1998-2004
7	5	1	20	0	0	0
8	9	0	0	2 (2)	0	0
9	19	0	0	6 (3)	0	0
10	26	0	0	15 (3)	1	7
11	23	0	0	17 (1)	1	6
12	20	0	0	26 (1)	1	4
13	3	0	0	18	4	22
14	4	0	0	15 (1)	2	13
15	2	0	0	4	0	0
16	1	0	0	2	0	0
17	1	0	0	3 (1)	0	0
18	1	0	0	1	0	0
19	0	0	0	0	0	0
20	1	0	0	2	0	0
Total	115	1		111	9	

Table 3—Number and percent of MPB-attacked trees by 1 inch diameter class in the CIP of the GSL 80/90.

Diameter class (inches)	Number of leave-trees 1986	Number of MPB-attacked 1987-1997	Percent of trees-attacked 1987-1997	Number of leave-trees 1998	Number of MPB-attacked 1998-2004	Percent of trees-attacked 1998-2004
7	4	0	0	0	0	0
8	30	0	0	2	0	0
9	44	1	2	22	11	50
10	44	1	2	46	30	65
11	29	0	0	47	23	49
12	18	0	0	22	11	50
13	5	0	0	20	12	60
14	4	0	0	10	4	40
15	1	0	0	4	2	50
16	0	0	0	2	1	50
17	0	0	0	0	0	0
Total	180	2		175	94	

Table 4—Number and percent of MPB-attacked trees by 1 inch diameter class in the CIP of the GSL 100/110. Numbers in parentheses are the 1998 leave trees that were cut in 2000.

Diameter class (inches)	Number of leave-trees 1986	Number of MPB-attacked 1987-1997	Percent of trees-attacked 1987-1997	Number of leave-trees 1998	Number of MPB-attacked 1998-2004	Percent of trees-attacked 1998-2004
7	4	0	0	1	0	0
8	30	0	0	5 (3)	0	0
9	35	1	3	29 (6)	9	31
10	49	0	0	30 (1)	11	37
11	48	0	0	48 (4)	24	50
12	22	0	0	43 (1)	25	58
13	16	0	0	21 (1)	14	67
14	4	0	0	19	13	68
15	2	0	0	5	2	40
16	0	0	0	1	1	100
17	0	0	0	0	0	0
Total	210	1		202	99	

On first thought, the decrease in the number of MPB-attacked trees in the GSL 60/70, GSL 100/110, and control in 2004 (figures 1, 2, and 4) may have resulted because previous MPB-caused mortality reduced the number of larger diameter trees available for MPB attack. While this may be true for the control where 80 percent or more of the trees were lost in several diameter classes (table 5), it is not the case for the GSL 60/70 and 100/110 (tables 2 and 4). Moreover, the number of MPB-attacked trees increased in the GSL 80/90 in 2004 and substantial numbers of 2003 pitchouts were reattacked in 2004. Thus, while the number of MPB-attacked trees in those three plots decreased in 2004, the decrease was probably not due to a lack of available larger diameter trees but to the shifting of the population from the three plots to the GSL 80/90, reattack of pitchouts, and sanitation/salvage efforts by the BHNF.

The distribution of MPB-attacked trees by diameter class indicates that MPBs do not always attack the largest diameter trees in PP stands. During the first 10 years, no trees ≥11 in were attacked even though substantial numbers of trees ≥11 in existed. When the MPB epidemic commenced in 1997, only three trees ≥14 in were attacked from 1997 to 2001. Thus, while the MPB in LP usually selects the largest trees to infest during the few years preceding and during a major epidemic (Amman and Cole 1983), that is not necessarily the case in PP stands. As suggested by Olsen and others (1996), large trees are not always the first trees to be attacked in PP stands.

Table 5—Number and percent of MPB-attacked trees by 1-inch diameter class in the CIP of the control.

Diameter class (inches)	Number of leave-trees 1986	Number of MPB-attacked 1987-1997	Percent of trees-attacked 1987-1997	Number of leave-trees 1998	Number of MPB-attacked 1998-2004	Percent of trees-attacked 1998-2004
5	1	0	0	0	0	0
6	1	0	0	1	0	0
7	21	0	0	12	3	25
8	67	0	0	39	22	56
9	82	0	0	74	57	77
10	68	0	0	73	62	85
11	53	0	0	64	53	83
12	28	0	0	37	32	86
13	20	0	0	26	25	96
14	3	0	0	11	7	64
15	6	0	0	5	5	100
16	0	0	0	5	5	100
17	1	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	1	1	100
Total	351	0		349	272	

Changes in Basal Areas and Mean Diameters

BAs in all plots increased from 1986 to 1997 (table 6). The control increased about 20 ft^2 while the GSLs 60/70, 80/90, and 100/110 increased 17 to 18 ft^2. MPB-caused tree mortality was insignificant during this period so BAs were not significantly altered.

BAs decreased on all plots from 1998 to 2004. The decrease in the GSL 60/70 was only 2.3 ft^2 but the GSLs 80/90, 100/110, and control lost at least 53, 60.4, and 139.9 ft^2, respectively (table 6). Percentage-wise, the GSL 80/90 and GSL 100/110 lost 53 percent and 51 percent of their respective BAs while the control lost 80 percent. The actual and percentage losses in BAs are greater than reported above because most trees in each plot grew for several years before the MPB population reached epidemic status. The substantial loss in BAs during the 1998 to 2004 period coincides with the onset and increase in the MPB population.

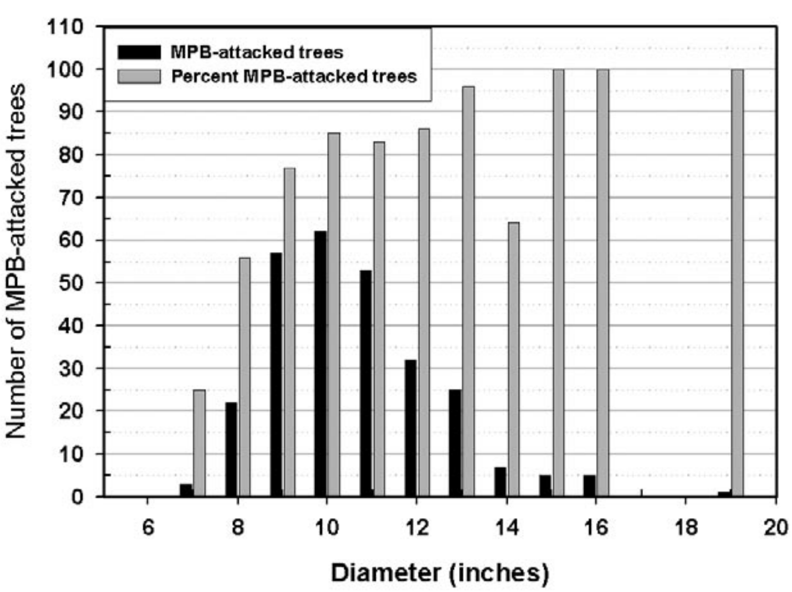

Figure 5—Number and percent of MPB-attacked trees in each diameter class in the CIP of the control

Table 6—Basal areas (BA) and mean diameters (DBH) in the CIPs of the partially cut plots and control in 1986, 1997, and 2004. Basal areas and mean diameters are estimated for 2004.

	GSL 60/70		GSL 80/90		GSL 100/110		Control	
Year	BA	DBH	BA	DBH	BA	DBH	BA	DBH
1986	61.1	11.0	80.8	10.1	101.5	10.5	154.7	10.0
1997	77.3	12.6	98.4	11.3	117.3	11.5	174.0	10.6
2004	75.0	13.7	46.0	12.4	56.9	11.9	34.1	10.0

The 2004 BAs are, however, somewhat misleading because MPB-caused tree mortality was not uniformly distributed throughout the CIPs. Trees were attacked in groups or portions of the plots such that BAs in the attacked areas were zero while BAs in the unattacked portions were considerably greater than the 1997 BAs. The unattacked portions of the stands are similar to the microcosm stands of Olsen and others (1996) and, therefore, of concern to forest managers. Left to grow without subsequent management, the unattacked portions of the GSL 100/110 and GSL 80/90 in the Bear Mountain I plots could reach the susceptibility threshold of GSL 120 within five and 15 years, respectively. The stands then become potential sites for future MPB infestations.

Mean diameters increased about 1 inch in the GSL 60/70, 80/90, and 100/110 from 1986 to 1997 while the mean diameter in the control increased about 0.5 inches (table 6). From 1998 to 2004, mean diameters increased 1.1 inches in the GSL 60/70 and 80/90; increased 0.4 inches in the GSL 100/110; and decreased 0.6 inches in the control. The increases in mean diameters in the GSL 60/70, 80/90, and 100/110 indicate that the MPB was not always attacking the trees of largest diameter further supporting the hypothesis that the largest trees are not always attacked first during MPB epidemics in PP stands.

Management Implications

The effectiveness of partial cutting unmanaged PP stands to GSLs from 80 to 120 seems questionable in light of the MPB-caused tree mortality in the GSL 80/90 and 100/110. With mortality averaging about 50 percent, forest managers will question whether stands with GSLs ranging from 80 to 120 are really moderately susceptible and whether partial cutting is really reducing susceptibility. However, the presence of unmanaged stands surrounding the Bear Mountain I plots may mitigate these detrimental conclusions regarding the effectiveness of partial cutting to GSLs of 80 to 120. As noted in the methods, the partially cut plots were surrounded by unmanaged stands and MPB populations were evident in those stands before MPB-caused tree mortality substantially increased in the partially cut plots. MPB populations also began causing substantial mortality in the control plot before such mortality was evident in the partially cut plots. Eventually, MPB populations in the control and the unmanaged adjacent stands increased to the point where their numbers began to overwhelm the partially cut stands. Had the unmanaged stands not existed adjacent to the partially cut stands, MPB-caused tree mortality in the cut stands may have been different.

The development of MPB infestations in partially cut stands surrounded by unmanaged stands supports the need to manage susceptible stands on a landscape basis. As primary focus trees are attacked in unmanaged stands at or near the boundaries of partially cut stands, MPB pheromones released from these trees attract additional MPBs to the general area. When epidemic MPB populations are present, such as existed in and around the Bear Mountain I plots, in the immediate vicinity of the initially attacked tree(s), thousands of beetles could be attracted to the vicinity of the primary focus tree. MPBs will then attack trees adjacent to the focus tree within the unmanaged stand but may eventually attack trees within the partially cut stands. This occurs because the pheromone's influence may extend beyond the boundary of the unmanaged stand and into the adjacent partially cut stand. The influence of the pheromones may override the positive benefits of increased spacing and improved tree growth derived from partial cutting. As former research entomologist William McCambridge stated in past years, "Given sufficient MPBs, any tree no matter what its condition can be successfully attacked." Thus, while partial cutting can eliminate substantial MPB-caused mortality, zero mortality should not be expected in partially cut stands adjacent to unmanaged stands, especially in the vicinity of their common boundaries. Further, as evidenced by the MPB-caused tree mortality in this set of plots, management of a single stand or a few stands within an unmanaged landscape may not provide long-term reduction in MPB-caused tree mortality in the cut stands. Reduced long-term tree mortality will be accomplished when sufficient area is managed so that partially cut stands are separated from unmanaged stands by natural buffers and/or buffers of low GSLs.

While it is not desirable to manage only one or a few susceptible stands in a landscape of susceptible stands, it is equally undesirable from a MPB management standpoint to leave one or a number of unmanaged MPB-susceptible stands scattered throughout a managed landscape. Cover plots, presumably cover for wildlife, are commonly left among managed stands on the BHNF (R.R. Kessler, 2005, personal communication). These cover plots are high density stands with DBHs generally >8 in. As such, the cover plots function as focal points for MPB infestations (R.R. Kessler, 2005, personal communication) in a manner similar to the "microcosm stands" in unmanaged stands (see Olsen and others 1996). Leaving these "cover plots" among a managed landscape may mean that forest managers will have to return to the plots to manage MPB populations before the usual time for reentry.

If susceptible stands are partially cut in and adjacent to other susceptible stands, what GSL levels can be expected to have the least amount of MPB-caused mortality? The GSL 60/70 plot was the only GSL level sustaining <10 percent mortality (table 1). The GSL 80/90 and 100/110 sustained about 50 percent tree mortality (table 1). Thus, GSLs <80 would be more appropriate for situations where partially cut stands are to exist next to unmanaged stands.

While GSLs <80 are best for reducing MPB-caused mortality in the long-term, such stands usually become heavily stocked with seedlings and saplings in the Black Hills. Eventually, two-storied susceptible stands evolve and managers are faced with stand conditions highly conducive for MPB infestations. If management objectives prefer GSLs >80 in partially cut stands adjacent to unmanaged stands, then a combination of a GSL ≤70 in a buffer strip adjacent to the unmanaged stand and GSLs ≥80 in the remainder of the stand might provide a desirable solution to minimizing the infestation of the partially cut stand adjacent to the unmanaged stand while carrying a higher GSL in the rest of the stand.

The threshold for highly susceptible stands was lowered from GSL 150 to GSL 120 as the result of the work of Schmid and Mata (1992). Stands with GSLs <120 but >80 are considered moderately susceptible stands (Schmid and others 1994). The data from this study also suggest that the threshold for highly susceptible stands may need further lowering to GSL 100 or lower. However, before that action is taken, additional evidence should be gathered. Mortality in the GSL 80/90 and 100/110 Bear Mountain I plots may represent an anomaly because of the epidemic MPB populations and unmanaged susceptible stands surrounding the partially cut stands. Other sets of plots in the Black Hills may confirm or deny reducing the high susceptibility threshold because they are generally not surrounded by unmanaged stands.

The number of MPB-attacked trees within the CIP and buffer strips of the GSL 60/70 has implications regarding what width of buffer should be provided along the edge of unmanaged stands to minimize mortality in adjacent managed stands. In unmanaged stands, 84 percent of the new MPB-infested spots were found on average within 330 ft of the previous year's infested spot (Knight and Yasinski 1956). Thus, a logical buffer would be 330 ft or <.1 mile. However, the lack of MPB-attacked trees in the CIP of the GSL 60/70 suggests that a narrower buffer could be used. The buffer on the GSL 60/70 was about 50 ft so a buffer of 100 ft would provide an additional measure of reduced risk.

References Cited

Allen, K.K.; McMillin, J.D. 2001. Evaluation of mountain pine beetle activity on the Black Hills National Forest. Biological Evaluation R2- 01-01. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Renewable Resources, Forest Health Management. 27 p.

Amman, G. D.; Cole, W.E. 1983. Mountain pine beetle dynamics in lodgepole pine forests Part II: Population dynamics. Gen. Tech. Rept. INT-145. Ogden, UT: Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 59 p.

Eckberg, T.B.; Schmid, J.M.; Mata, S.A.; Lundquist, J.E. 1994. Primary focus trees for the mountain pine beetle in the Black Hills. Res. Note RM-531. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 10 p.

Johnson, E.; Schaupp, W.E.,Jr.; Long, D.F. 2001. [Letter to the 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 the Forest Supervisor]. January 7. 3 p. On file at: U.S. Department of Agriculture, Forest Service, Black Hills National Forest, Custer, SD.

Knight, F.B.; Yasinski, F.M. 1956. Incidence of trees infested by the Black Hills Beetle. USDA Forest Service Res. Note RM-21. Fort Collins, CO: U.S. Department of

Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p.

McMillin, J.D.; Allen, K.K. 1999. Evaluation of mountain pine beetle activity in the Black Hills National Forest. Biological Evaluation R2-00-03. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Renewable Resources, Forest Health Management. 18 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.

Pasek, J.E.; Schaupp, W.C., Jr. 1992. Status and trends of mountain pine beetle populations in the Bear Mountain and White House Gulch areas on the Harney Ranger District, Black Hills National Forest, South Dakota. Biological Evaluation R2-92-04. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Renewable Resources, Forest Health Management. 17 p.

Schmid, J.M.; Mata, S.A. 1992. Stand density and mountain pine beetle-caused tree mortality in ponderosa pine stands. Res. Note RM-515. Fort Collins, CO: U.S. Department of Ariculture, 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. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. Res. Note RM-521. 10 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.

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

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