Forest Science

Corresponding author:

Michael James Jenkins

Utah State University

[b]Department of Forest, Range, and Wildlife Science

5230 Old Main Hill

Logan, UT 84322-5230

Phone: 435-797-2531

Fax:

Email: mjenkins@cc.usu.edu

Mountain Pine Beetle Induced Changes to Selected Lodgepole Pine Fuel Complexes within the Intermountain Region

Wesley Green Page[a] and Michael James Jenkins[b]

[a]Department of Forest, Range, and Wildlife Science, Utah State University, 5230 Old Main Hill, Logan, UT 84322-5230 USA Email: wgpage@cc.usu.edu

Acknowledgments: Funding for this project was provided by the National Interagency Fire Center, Joint Fire Science Program through a participating agreement (02-PA-11046000-040) with Utah State University, and the USDA Forest Service, Forest Health Monitoring, Evaluation Monitoring through cooperative agreement (04-CA-11046000-055). We give special thanks to Elizabeth Hebertson, Dan Ott, Jason Neumann and the staff of the USDA Forest Service, Forest Health Protection, Ogden Field Office, Tim Garcia, Kamas Ranger District, Wasatch-Cache National Forest, and Patrick Kailey, Utah

State University for their help with logistics, data collection, and other technical support. For review and comment we thank Jesse Logan and Ted Evans. This research was supported by the Utah Agricultural Experiment Station, Utah State University, Logan, UT. Approved as journal paper no. xxxx

Abstract

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is a forest insect that infests lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) forests in the Intermountain West. The often widespread mortality caused by the mountain pine beetle has been suggested to cause significant changes to stand structure, composition, and fuel loading; however, little quantitative information is available that documents these changes. We examined mountain pine beetle induced changes to ground, surface, and aerial fuels in lodgepole pine stands during current epidemics and 20 years following an epidemic. Results indicated that there were statistically significant increases in the amounts of fine surface fuels in currently infested stands. In the previously infested stands, there were large increases in the amounts of dead woody fuels in all but the smallest size classes, with a 7.8-fold increase in the largest size class. Live shrubs and the amount of subalpine fir (*Abies lasiocarpa* Nutt.) regeneration were also significantly greater in the post-epidemic stands. The net result of epidemic mountain pine beetle activity was a substantial change in species composition and a highly altered fuels complex in which large dead woody fuels and live surface fuels dominate.

Keywords: disturbance ecology, fuels management

Introduction

The ecological role of the mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae)) in lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) forests in the Rocky Mountains has been well documented (Roe and Amman 1970, Amman 1977, Peterman 1978). During epidemics, MPB activity has been known to alter stand composition, structure, and successional patterns (Amman 1977, Gara et al. 1985, Safranyik 1989). Additionally, past research has suggested that increases in the amounts of dead woody fuels caused by MPB mortality can be significant, resulting in highly altered fuels complexes (Lotan et al. 1985, Romme et al. 1986, Amman 1991, Schmid and Amman 1992). However, few studies have attempted to quantify these changes with most work only documenting relative changes to broad fuel categories, i.e. large or small dead fuels. The potential alterations to these fuel complexes could also have important implications on both short and long term fire hazard (Knight 1987). Thus, with recent emphasis on fuels management in land management agencies and a lack of quantitative information on fuels in MPB infested forests more detailed information needs to be provided to fire, fuels, and forest health professionals so that they can make more informed decisions.

Extensive epidemics of the MPB have occurred in lodgepole pine forests throughout western North America both recently and historically. Widespread epidemics tend to occur when conditions such as drought (Mattson and Haack 1987) or pathogens (Goheen and Hansen 1993) weaken enough host trees for populations to build and

subsequently attack relatively healthy trees of suitable size (Berryman 1982). Generally, lodgepole pine stands with a large proportion of mature trees greater than 20 centimeters (cm) in diameter at breast height (dbh) are frequently considered the most susceptible to MPB epidemics (Safranyik 1989). When epidemics do occur they can be locally intense resulting in nearly complete mortality of trees greater than 10 to 13 cm in dbh (Furniss and Carolin 1977).

In lodgepole pine forests the amount, arrangement, and continuity of fuels can vary widely by location and through time with fuel loadings being strongly influenced by various mortality agents, such as the dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) and the MPB (Brown 1975, Alexander and Hawksworth 1976, Brown and See 1981). During early stand development total fuel loadings can be relatively high, due to remaining unburned fuel from the last high-intensity fire and suppression mortality in overly dense stands (Muraro 1971, Brown 1975). As stands develop and fuels decompose relatively sparse fuel conditions can dominate. It is not until stands mature and become susceptible to various mortality agents that fuel accumulations once again reach high levels (Lotan et al. 1985).

Changes in the amounts of dead and down woody fuels have been previously quantified in lodgepole pine stands affected by the MPB by Armour (1982) and Romme et al. (1986) in Montana and Wyoming, respectively. Romme et al. (1986) observed increases of only 3% to 6% in leaf litter for six years following an epidemic while Armour (1982) failed to find significant differences in fuel loading of fuels from 0 to 0.6 cm (1 hour) in diameter from 2 to 6 years following an epidemic. For larger size dead and down woody fuels both Romme et al. (1986) and Armour (1982) found substantial

increases in the total amounts of fuel but the rate and duration of the increase varied with habitat type being an important factor. What was missing from these studies was a more detailed evaluation of changes to the entire complex, including aerial fuels and live surface fuels.

In order to provide a more detailed description of the fuels complex in MPB infested lodgepole pine forests we conducted an intensive fuels inventory measuring ground, surface, and aerial fuels. Study sites were selected with current epidemics and 20 years following an epidemic. Within each study site similar uninfested endemic stands were identified and then paired with the current epidemic and post-epidemic stands. Statistical comparisons between the various fuels components were then made to determine if significant differences existed and the magnitude of the differences. While the data provided is considered specific to our selected sites it is hoped that fire, fuels, and forest health professionals will be able to apply our findings to other similar lodgepole pine stands within the Intermountain West by focusing on the general changes we observed. These professionals should then be able to make more informed decisions regarding MPB epidemics and their potential alterations to lodgepole pine fuel complexes.

Methods

Study Site Selection

Study sites were selected utilizing USDA Forest Service aerial detection surveys and assistance from USDA Forest Service personnel. Once sites were identified, aerial photographs and ground reconnaissance were used to verify beetle populations and make the final site selections. Three sites were chosen; two sites had current epidemics, northern Utah and central Idaho, and one site had a previous epidemic, northeastern Utah (Figure 1). Aerial photographs were then used to delineate a total of four stands within each study site; two treatment (current and post-epidemic) and two control (endemic), that were homogeneous in density and species composition. Current epidemics were identified as those stands with increasing MPB populations and significant recent mortality while endemic conditions were identified as those stands with low current beetle activity. Post-epidemic stands were identified as stands with greater than 80% mortality occurring more than five years ago with no current beetle activity. An attempt was made to select stands sharing similar characteristics, such that they represent a chronosequence or space-for-time substitution, to minimize potential confounding factors (Pickett 1989). In order to minimize these potential factors, stands were selected sharing similar size, slope steepness, aspect, age, density, and habitat type.

The site in northeastern Utah was located on the Ashley National Forest in the eastern Uinta Mountains. An extensive MPB epidemic occurred in this area beginning in the early 1980's and lasted through the decade (Binder 1995). Within the post-epidemic

stands that were delineated, increment cores from surviving trees were taken and growth releases were identified in order to determine the years of significant mortality. Most increment cores recorded a growth release around 1985 but mortality is assumed to have also occurred prior to and after this date. Elevations of both the post-epidemic and endemic stands ranged from 2800 to 2930 meters with gentle slopes and mainly southerly aspects. The post-epidemic stands were dominated by mature and immature subalpine fir (*Abies lasiocarpa* Nutt.) with only remnant patches of lodgepole pine. The endemic stands were dominated by mature lodgepole pine with understories of subalpine fir and Engelmann spruce (*Picea engelmannii* Parry ex Engel.). A prominent cover of grouse whortleberry (*Vaccinium scoparium* Leib. ex Coville) was present in all stands indicating that the habitat type was *Abies lasiocarpa* / *Vaccinium scoparium* (Mauk and Henderson 1984). The distance between the post-epidemic and endemic stands was about 9.5 kilometers while the distance between like stands was about 1.5 kilometers. The sizes of all stands sampled were uniform averaging approximately 40 hectares.

The site in central Idaho was located on the Sawtooth National Recreation Area near Stanley, Idaho. A current widespread epidemic is occurring in the area that began in the 1990's (Jorgensen and Mocettini 2005). Elevations of the selected stands were at approximately 2100 meters with gentle slopes and a variety of aspects. The sampled stands were dominated by mature lodgepole pine with an extensive cover of elk sedge (*Carex geyeri* Boott) in the understory with little evidence of replacement by fir or spruce. The habitat type selected for these stands was *Pinus contorta* / *Carex geyeri*; however, the two endemic stands did appear to have the potential to be replaced by subalpine fir, indicating an *Abies lasiocarpa* habitat type (Steele et al. 1981). Both

current epidemic stands were located within approximately 4.5 kilometers of each other but due to the widespread nature of the epidemic, suitable endemic stands were not located until a distance of about 8 kilometers from the epidemic stands. The sizes of the delineated stands averaged approximately 40 hectares.

The site in northern Utah was located on the Wasatch-Cache National Forest in the western Uinta Mountains. Elevations of the selected stands ranged from approximately 2700 to 2900 meters with flat to steep slopes occupying eastern to northwestern aspects. The stands were dominated by seral lodgepole pine with a developing understory of subalpine fir, Engelmann spruce, and a cover of grouse whortleberry, which was classified as the *Abies lasiocarpa* / *Vaccinium scoparium* habitat type (Mauk and Henderson 1984). All four sampled stands were located within the Upper Provo River watershed with a maximum distance between stands of about 3 kilometers. The sizes of the selected stands averaged approximately 30 hectares.

Quantifying the Fuels Complex

A systematic north-south or east-west grid of variable radius plots were laid out within the delineated stands on United States Geological Survey (USGS) 7.5 minute topographic maps. Where possible, 100.6 meter spacing between transects and 160.9 meter spacing between plots along the transects were used. The overall objective was to have at least 20 plots per stand (Avery and Burkhart 1994), but this varied between 14 to 25 plots per stand (Table 1). Once plot locations were determined, the latitude and longitude of the plot centers was calculated and input into a hand held global positioning system (GPS) to aid in field location of the plot centers.

At each plot center a general plot description including percent canopy cover, elevation, aspect, percent slope, and habitat type based on Mauk and Henderson's (1994) and Steele et al.'s (1981) keys to identifying habitat types, respectively, were determined. Ground and surface fuels were measured using the methods developed by Brown et al. (1982) and Anderson (1974). Specifically, using Brown's (1971) planar intersect method, between three and seven 19.8 meter long transects were laid out from each plot center (Figure 2). The total number of transects installed was based on the accumulation of at least 100 pieces in the total number of intersections of all dead fuel particles. Based on the suggestions by Brown et al. (1982) for sampling plane distances each 19.8 meter transect had the number of 0 to 0.64 cm (1 hour) and 0.64 to 2.54 cm (10 hour) diameter fuels tallied from 1.5 to 3.35 meters, the number of 2.54 cm to 7.62 cm (100 hour) diameter fuels tallied from 1.5 to 6.1 meters, and those fuels greater than 7.62 cm (1000 hour) in diameter tallied from 1.5 to 19.8 meters. In addition, dead woody fuels with diameters greater than 7.62 cm (1000 hour) had their respective diameters measured and a decay class assigned. These size classes correspond to the standard fuel size classes used in typical fuels inventories based on surface to area volume ratios, which are related to the rate at which fuel moisture changes in response to the environment (Brown 1970, Fosberg 1970, Brown et al. 1982). The distance from the beginning of the tape to 1.5 meters was used as a buffer zone so that the fuels were not disturbed while other measurements were taken.

At the 10.7 meter and 19.8 meter points along each transect, duff and litter depth, the high particle intercept depth, and shrub/herbaceous information were recorded. To measure the high particle intercept depth an imaginary plane perpendicular to the

main transect 0.31 meters long was used and the height of the highest dead fuel particle less than 7.62 cm in diameter that crossed the plane was measured from the bottom of the litter layer to the top of the fuel particle. The average high particle intercept depth was then used to calculate the fuel bed bulk depth by taking 63.8% of the average high particle intercept depth (Albini and Brown 1978). The shrub and herbaceous data were collected using fixed 1.83 meter diameter microplots, from which percent cover of live and dead shrubs, percent cover of live and dead herbaceous vegetation, and average height of both shrubs and herbaceous vegetation were collected. All cover estimates were by 10% categories. Also, within each microplot the numbers of shrub stems by diameter class were tallied by species. The diameter classes used for the shrub stem count corresponded to Brown's (1976) basal stem diameter classes: 0-0.5 cm, 0.5-1.0 cm, 1.0-1.5 cm, 1.5-2.0 cm, 2-3 cm, 3-5 cm, and 5-6 cm.

Aerial fuels and mortality were quantified at each plot using a 20 basal area factor measuring device. Each "in" tree's dbh was measured along with condition and crown dominance. Tree condition was classified as healthy, unhealthy, sick, or dead. Unhealthy trees were currently being affected by a mortality agent but were assumed to survive. Sick trees were those that were successfully killed by the MPB, not including strip attacks, within the past four years, since 2000, while dead trees were killed by any mortality agent. If the dead trees had evidence of MPB attack it was noted and the year of attack was assumed to be four or more years ago, prior to 2000. In addition, for each sick tree, a year of attack ranging from 0, for current attacks, to 4 was determined along with an estimation of the percent needles remaining on the tree, to the nearest 10%.

Crown dominance for each tree was classified as either dominant, co-dominant, intermediate, or suppressed.

During the summer of 2005 additional aerial fuel characteristics were measured that are important for modeling crown fire initiation and spread (Van Wagner 1977). At each plot a randomly selected live "in" tree had its total height and crown base height measured. Total crown length was then calculated, which with available canopy fuel load was used to calculate crown bulk density (Keane et al. 1998). For those stands sampled during the summer of 2004 crown bulk density was determined using equations developed by Cruz et al. (2003) based on average stand basal area and the number of trees per hectare. To estimate crown base height for the stands sampled during 2004 the average crown base height from the adjacent endemic stands sampled during 2005 were used.

Available live canopy fuel load was calculated using Brown's (1978) allometric equations for live crown weight based on tree species, crown dominance, and dbh. Note that available canopy fuel load was based not only on live foliage weight but also on a proportion of the amount of 0 to 0.64 cm diameter fuels (1 hour) within the crown. Call and Albini (1997) determined that 65% of canopy fuel 0 to 6 mm in diameter would be consumed at 100% moisture content during a crown fire. Therefore, based on Brown's (1978) allometric equations, 65% of the proportion of 1 hour fuels in each live tree crown was added to the live crown weight to determine the available canopy fuel load.

Percent mortality was determined in the current epidemic stands on the Wasatch-Cache N.F. and Sawtooth N.R.A. by taking the number of recently attacked trees (since 2000) and the number of older attacked trees (prior to 2000) divided by the total number

of lodgepole pine that were greater than 15.2 cm in dbh, considered susceptible to attack (Furniss and Carolin 1977). Percent mortality in the post-epidemic stands on the Ashley N.F. was calculated using 8.03 meter diameter fixed area plots installed at each plot center. Within each plot, the number of lodgepole pine that survived the epidemic, the number of dead standing, and the number of on the ground lodgepole pine were tallied. An on the ground lodgepole pine was tallied if its base was within the fixed area plot and the bole had evidence of MPB attack.

The amount of regeneration by species and height class were measured in a 2.1 meter diameter regeneration plot for trees less than 3.1 meters in height, by 0.04 meter size classes (Brown et al. 1982). Stand age was determined from the most dominant live "in" tree cored at stump height and counted in the field. The average of all tree ages within each stand was used to determine the age of the stand.

To obtain the oven dry weights of the dead and down woody fuels, duff, litter, and live surface vegetation, the fire effects monitoring and inventory protocol FIREMON, version 2.1.1 (Lutes, Keane, Key, Caratti, Gangi, and Couch http://www.fire.org/firemon. October 24, 2005) was used. FIREMON converted the number of dead fuel particle intersections, litter and duff depths, and percent cover and height of surface vegetation into oven dry weights based on the equations in Brown (1971), known bulk densities of duff and litter, and biomass equations, respectively. In order to calculate the oven dry weight of regeneration less than 3.1 meters high Brown et al.'s (1982) table was used based on species and height, expanded to a per hectare basis.

2.3 Data Analysis

Data were analyzed using the software program SAS® (version 9.1). Student's two tailed t-tests were used to compare the sample means for the treatments (current or post-epidemic stands) to the controls (endemic stands) for each fuel category within each study site using an α of 0.05 to determine significance. As reported by others, fuel loading data usually has rightly skewed distributions (Brown and See 1981, Brown and Bevins 1986). Therefore, transformations were applied to the data in order to meet the assumptions of the t-test. Square root and log transformations worked especially well but several of the variables still had unequal variances. In these cases the Satterthwaite method was used (Zar 1999). The averages, standard deviations, and 95% confidence intervals were also reported for each fuel category. Additionally, two tailed t-tests were used to evaluate homogeneity between like stands with the same beetle population level within each study site (i.e. between the two endemic, current epidemic, and post-epidemic stands).

Results

Ashley National Forest

Before statistical comparisons were made between the post-epidemic and endemic stands, the data were evaluated to determine if significant differences occurred between like stands (i.e. between the two post-epidemic and endemic stands). Analysis revealed that the two post-epidemic stands had similar densities of lodgepole pine ($t = 0.09$, $P = 0.93$) and subalpine fir ($t = 0.37$, $P = 0.71$). Likewise, the number of live lodgepole pine per hectare in the endemic stands was not significantly different ($t = 0.37$, $P = 0.71$). For the fuels data, the comparisons confirmed that all but the litter fuels ($t = 2.45$, $P = 0.02$) had similar loadings between the two post-epidemic stands. The fuels data for the two endemic stands showed that the 1 hour ($t = 4.25$, $P = 0.0001$), 1000 hour rotten ($t = 2.48$, $P = 0.02$), and duff ($t = 3.15$, $P = 0.004$) fuel loadings were statistically different between the stands.

The results of the statistical comparisons between the post-epidemic and endemic stands revealed that MPB activity has significantly altered the fuels complex (Figure 3). The cause of these changes is in part due to an average of 80% mortality, with 33% of the MPB killed trees still standing and 67% on the ground as of the year 2005 (Table 2). This high level of mortality has resulted in densities of live trees, greater than 3.1 meters

in height, of 161 and 1611 lodgepole pine per hectare (t = 22.79, P = 0.002) and 563 and 0 subalpine fir per hectare (t = 22.27, P = 0.002) for the post-epidemic and endemic stands, respectively. The high level of mortality has also resulted in significantly lower crown base heights, less available canopy fuels, and lower crown bulk densities in the post-epidemic stands than in the endemic stands (Table 2).

Detailed analysis of the surface fuels revealed significant differences between dead and down woody fuels and live surface vegetation. Table 3 shows statistically significant increases, in the post-epidemic stands, for dead fuels in the 10 hour, 100 hour, and 1000 hour sound sizes classes as well as for fuel bed depth. The average increases were 2.5 times, 2.1 times, and 7.8 times the loading of the endemic stands for the 10, 100, and 1000 hour sound fuels, respectively. There were also statistically significant increases in live shrub loading and average shrub height in the post-epidemic stands compared to the endemic stands (Table 4).

Differences in the amount of regeneration also existed between the post-epidemic and endemic stands on the Ashley N.F. (Table 5). The loading of subalpine fir was significantly more in the post-epidemic stands than in the endemic stands averaging 2.30 metric tons per hectare. However, total loading, the number for lodgepole pine, and the number for all species were not significantly different at the 0.05 level.

3.2 Sawtooth National Recreation Area

Before statistical comparisons were made between the current epidemic and endemic stands on the Sawtooth N.R.A. the data were evaluated to determine if significant differences occurred between like stands (i.e. between the two current epidemic and endemic stands). The analysis showed that the two current epidemic stands

had similar densities of both live (t = 0.47, P = 0.64) and successfully killed (t = 1.02, P = 0.31) lodgepole pine per hectare. The two endemic stands also had similar densities of live lodgepole pine per hectare (t = 0.44, P = 0.66). Analysis of the surface fuels data illustrated that the two current epidemic stands had similar fuel loadings for all categories except the 100 hour fuels (t = 4.06, P = 0.0003). The surface fuels data for both the endemic stands were similar for all categories except for the litter fuels (t = 2.06, P = 0.05).

The results of the statistical comparisons between the current epidemic and endemic stands sampled on the Sawtooth N.R.A. have shown that MPB activity has altered only a portion of the fuels complex. The number of live and healthy lodgepole pine, greater than 3.1 meters in height, was comparable (t = 2.36, P = 0.14) with an average of 1435 and 1075 live lodgepole pine per hectare occurring in the current epidemic and endemic stands, respectively. Mortality of the susceptible lodgepole pine in the current epidemic stands averaged 59% compared to 11% in the endemic stands with approximately 47% of the mortality in the current epidemic stands occurring since 2000 (Table 6). This high level of recent mortality in the current epidemic stands has produced significant amounts of dead foliage in the overstory, as of 2004, which was quantified for both the current epidemic and endemic stands (Figure 4). Approximately 30% of the total foliage in the current epidemic stands is dead as compared to 1% in the endemic stands.

Surface fuels data from the Sawtooth N.R.A. revealed few statistically significant differences between the current epidemic and endemic stands (Table 7). Fine fuel loadings of the litter and 1 hour fuels were the only fuel components that were

significantly greater in the current epidemic stands than in the endemic stands. The largest increase observed was for the loading of litter with an average of 6.82 metric tons per hectare in the current epidemic stands, which was about 2.2 times greater than the loading in the endemic stands. There were no other statistically significant differences in all other fuels including vegetation and regeneration between the current epidemic and endemic stands.

3.3 Wasatch-Cache National Forest

Before statistical comparisons were made between the current epidemic and endemic stands on the Wasatch-Cache N.F. the data were evaluated to determine if significant differences occurred between like stands (i.e. between the two current epidemic and endemic stands). The densities of live lodgepole pine between the two current epidemic stands was significantly different ($t = 2.47$, $P = 0.02$) but not between the number of successfully killed lodgepole pine ($t = 1.17$, $P = 0.25$). The densities of live lodgepole pine were similar between the two endemic stands ($t = 0.51$, $P = 0.62$). Comparisons of the fuels data revealed that none of the fuel categories between the two current epidemic stands were significantly different. The two endemic stands had significantly different loadings for the 1000 hour sound ($t = 2.22$, $P = 0.03$), 1000 hour rotten ($t = 3.90$, $P = 0.0003$), and duff ($t = 2.50$, $P = 0.02$) fuel categories.

The results of the statistical comparisons between the current epidemic and endemic stands showed that MPB activity has not significantly altered stand structure, live tree densities, or live canopy fuel characteristics (Table 8). Live tree densities, greater than 3.1 meters in height, averaged 872 and 631 live lodgepole pine per hectare ($t = 0.70$, $P = 0.56$) in the current epidemic and endemic stands, respectively. The level of

mortality was significantly different, with the current epidemic stands averaging 52% and the endemic stands averaging only 7% (Table 8). This increase in mortality is also reflected in the amount of dead foliage, as of 2004, in the overstory (Figure 5).

Dead and down woody fuels for the current epidemic stands are reported in Table 9. The only statistically significant differences that occurred were for the fine fuel loadings, litter and 1 hour, with nearly significant differences for the loading of 100 hour fuels. The largest increase was from the 1 hour fuels with an average of 1.10 metric tons per hectare in the current epidemic stands, which was approximately 2.1 times the loading in the endemic stands. All other fuel categories, including vegetation and regeneration failed to show any statistically significant differences.

Discussion

MPB activity in the selected post-epidemic and current epidemic lodgepole pine stands has resulted in significant alterations to the fuels complexes. In the post-epidemic stands, the high levels of mortality produced dramatic increases in dead and down woody fuels in all but the smallest size classes, with the largest increase occurring in the 1000 hour sound size class. These results are consistent with other studies, which have shown similar increases in the amounts of large woody fuels following MPB epidemics (Armour 1982, Romme et al. 1986). These heavy accumulations of large diameter fuels are important because they can promote long term smoldering and creeping of surface fires, allowing fires to sustain themselves until conditions are more favorable for active burning, and they can increase potential severity by raising total heat release and duration of burning (Davis et al. 1980, Smith and Fischer 1997). Additionally, large diameter fuels can provide a vector for fire movement when fuel moisture conditions prohibit the spread by fine fuels (Agee 1993). Responding to the increase in light reaching the forest floor, the live shrubs and total live understory fuels in the post-epidemic stands were also significantly greater. This agrees with previous work by Stone and Wolfe (1996) who also found increases in total understory biomass in post-epidemic MPB stands.

In the current epidemic stands, the surface fuels remained relatively unchanged. The only significant differences observed were for the loadings of the litter and 1 hour fuels. Across both study areas the litter fuels increased by an average of 101% while the

1 hour fuels increased by an average of 74%. These increases can be linked to the contribution of the dead needles and small branches from the recently killed lodgepole pine. However, results from the post-epidemic stands indicate that over time these small fuels decay enough so that the differences return to background levels at least after 20 years.

The amount and composition of aerial fuels in both the post-epidemic and current epidemic stands were significantly different than their associated endemic stands. In the post-epidemic stands, the high mortality and discontinuous overstory resulted in significantly lower available canopy fuels, crown base heights, and crown bulk densities. These decreases in aerial fuel continuity can increase the amount of solar radiation on surface fuels and alter the wind profile within stands, which in turn can alter surface fuel moistures and the relative speed of the wind reaching the forest floor (Albini and Baughman 1979, Knight 1987). In the current epidemic stands, the high mortality also resulted in large amounts of dead foliage in their overstories. Of the total foliage in the current epidemic stands approximately 30%, on the Sawtooth N.R.A., and 17%, on the Wasatch-Cache N.F., was dead. These dead fuels should have important implications for crown fire initiation due to lower fuel moistures and decreased times to ignition.

Regeneration was also another fuel component that showed statistically significant differences. In the post-epidemic stands, subalpine fir loading was extensive, making up approximately 95% of the total loading compared to just 11% in the endemic stands. This high level of subalpine fir regeneration in conjunction with the removal of the majority of the mature lodgepole pine component reinforces the concept of successional advancement caused by the MPB (Amman 1977). The post-epidemic stands

appear to be moving towards their predicted climax of subalpine fir and will continue to advance until the next stand replacing disturbance (Mauk and Henderson 1984, Bradley et al. 1992).

The analysis of homogeneity between like stands across all three study areas indicated that there were many potentially important differences between the stands, which could have impacted the results of our statistical comparisons. For example, the dissimilarities between many of the fuel categories probably indicates differences in past disturbance history, which would alter the amount and condition of fuel present. Although a good deal of effort was put forth to control these potential dissimilarities the variable nature of fuels in forested stands prevented us from totally eliminating all confounding factors.

Conclusion

During the course of a MPB epidemic the fuels complexes of lodgepole pine stands undergo significant and in some cases drastic changes. Initially in stands with significant recent mortality, buildup of the finer fuels occurs. Over time, fuels continue to build with the proportion of fuels in the largest size classes increasing until they dominate the fuels complex. During the period of dead and down woody fuel increase, live shrubs respond to the increases in light reaching the forest floor, allowing shrubs to become significant components in the post-epidemic stands. Along with these biological changes important physical changes take place within affected stands that alter the amount of solar radiation on surface fuels and the relative amount of wind reaching the forest floor. These changes to the fuels complex will have important implications on potential fire hazard. Although the changes presented here reaffirm long held beliefs of MPB mortality and fuel buildup it should be recognized that these changes may not be outside of their historical range of variability. Large scale and intense MPB epidemics have been documented in lodgepole pine forests prior to extensive manipulation of these forests by man (Hopkins 1909), thus, the resulting buildup of dead fuels from these epidemics has also happened for an equally long period of time. Therefore, the changes observed in this study should not represent abnormal fuel conditions for lodgepole pine forests.

Literature Cited

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington, DC. 493 p.

Albini, F.A., and R.G. Baughman. 1979. Estimating windspeeds for predicting wildland fire behavior. USDA For. Serv. Res. Pap. INT-221. 12 p.

Albini, F.A., and J.K. Brown. 1978. Predicting slash depth for fuel modeling. USDA For. Serv. Gen. Tech. Rep. INT-GTR-45. 21 p.

Alexander, M.E., and F.G. Hawksworth. 1976. Fire and dwarf mistletoes in North American coniferous forests. J. For. 74:446-449.

Amman, G.D. 1977. The role of the mountain pine beetle in lodgepole pine ecosystems: Impact on succession. P. 3-18 *in* The role of arthropods in forest ecosystems, Mattson, W.J. (ed.). Springer-Verlag, New York.

Amman, G.D. 1991. Bark beetle-fire associations in the greater Yellowstone area. P. 313-320 *in* Fire and the environment: Ecological and cultural perspectives Proc., Nodvin, S.C., and T.A. Waldrop (eds.). USDA For. Serv. Gen. Tech. Rep. SE-GTR-69.

Anderson, H.E. 1974. Appraising forest fuels: A concept. USDA For. Serv. Res. Note INT-187. 10 p.

Armour, C.D. 1982. Fuel and vegetation succession in response to mountain pine beetle epidemics in northwestern Montana. M.Sc. thesis, Univ. of Idaho, Moscow, ID. 47 p.

Avery, T.E. and H.E. Burkhart. 1994. Forest Measurements. 4th Ed., McGraw Hill, Boston, MA. 408 p.

Berryman, A.A. 1982. Mountain pine beetle outbreaks in Rocky Mountain lodgepole pine forests. J. For. 80:410-413.

Binder, J.C. 1995. Spatial characteristics of a mountain pine beetle outbreak in the Uinta Mountains. M.Sc. thesis, Utah State Univ, Logan, UT.

Bradley, A.F., N.V. Noste, and W.C. Fischer. 1992. Fire ecology of forests and woodlands in Utah. USDA For. Serv. Gen. Tech. Rep. INT-GTR-287. 128 p.

Brown, J.K. 1970. Ratios of surface area to volume for common fine fuels. For. Sci. 16:101-105.

Brown, J.K. 1971. A planar intersect method for sampling fuel volume and surface area. For. Sci. 17:96-102.

Brown, J.K. 1975. Fire cycles and community dynamics in lodgepole pine forests. P. 429-456 *in* Management of lodgepole pine ecosystems, Baumgartner, D.M. (ed.). Washington State Univ. Press, Corvallis, OR.

Brown, J.K. 1976. Estimating shrub biomass from basal stem diameters. Can J. For. Res. 6:153-158.

Brown, J.K. 1978. Weight and density of crowns of Rocky Mountain conifers. USDA For. Serv. Res. Pap. INT-197. 56 p.

Brown, J.K., and C.D. Bevins. 1986. Surface fuel loadings and predicted fire behavior for vegetation types in the northern Rocky Mountains. USDA For. Serv. Res. Note INT-358. 9 p.

Brown, J.K., R.D. Overheu, and C.M. Johnston. 1982. Handbook for inventorying surface fuels and biomass in the interior West. USDA For. Serv. Gen. Tech. Rep. INT-GTR-129. 48 p.

Brown, J.K., and T.E. See. 1981. Downed dead woody fuel and biomass in the Northern Rocky Mountains. USDA For. Serv. Gen. Tech. Rep. INT-GTR-117. 48 p.

Call, P.T., and F.A. Albini. 1997. Aerial and surface fuel consumption in crown fires. Int. J. Wild. Fire 7:259-264.

Cruz, M.G., M.E. Alexander, and R.H. Wakimoto. 2003. Assessing canopy fuel stratum characteristics in crown fire prone fuel types of western North America. Int. J. Wild. Fire 12:39-50.

Davis, K.M., B.D. Clayton, and W.C. Fischer. 1980. Fire ecology of Lolo National Forest habitat types. USDA For. Serv. Gen. Tech. Rep. INT-GTR-79. 77 p.

Fosberg, M.A. 1970. Drying rates of heartwood below fiber saturation. For. Sci. 16:57-63.

Furniss, R.L., and V.M. Carolin. 1977. Western forest insects. USDA For. Serv. Misc. Publ. No. 1339. Washington, DC. 654 p.

Gara, R.I., W.R. Littke, J.K. Agee, D.R. Geiszler, J.D. Stuart, and C.H. Driver. 1985. Influence of fires, fungi, and mountain pine beetles on development of a lodgepole pine forest in south-central Oregon. P. 153-162 *in* Lodgepole pine: The species and its management, Baumgartner D., R. Krebill, J. Arnott, and G. Weetman, (eds.). Washington State Univ. Office of Conf. and Inst., Pullman, WA.

Goheen, D.J., and E.M. Hansen. 1993. Effects of pathogens and bark beetles on forests. P. 175-196 *in* Beetle-pathogen interactions in conifer forests, Schowalter, T.D. and G.M. Filip, (eds.). Academic Press, San Diego, CA.

Hopkins, A.D. 1909. Practical information on the Scolytid beetles of North American forests I. bark beetles of the genus *Dendroctonus*. USDA Bureau of Entomol. Bull. 83, U.S. Gov. Printing Office, Washington, D.C.

Jorgensen, C., and P.M. Mocettini. 2005. Monitoring mountain pine beetle-caused mortality of lodgepole pine in the Sawtooth and Bear Valleys of south central Idaho, 2004. USDA For. Serv. For. Health Prot. Rep. BFO-PR-05-01. 8 p.

Keane, R.E., J.L. Garner, K.M. Schmidt, D.G. Long, J.P. Menakis, and M.A. Finney. 1998. Development of input data layers for the FARSITE fire growth model for the

Selway-Bitterroot Wilderness complex. USDA For. Serv. Gen. Tech. Rep. RMRS-GTR-3. 66 p.

Knight, D.H. 1987. Parasites, lightning, and the vegetation mosaic in wilderness landscapes. P. 59-83 *in* Landscape heterogeneity and disturbance, Turner, M.G. (ed.). Springer-Verlag, New York.

Lotan, J.E., J.K. Brown, and L.F. Neuenschwander. 1985. Role of fire in lodgepole pine ecosystems. P. 133-152 *in* Lodgepole pine: The species and its management, Baumgartner D., R. Krebill, J. Arnott, and G. Weetman, (eds.). Washington State Univ. Office of Conf. and Inst., Pullman, WA.

Mattson, W.J., and R.A. Haack. 1987. The role of drought in outbreaks of plane-eating insects. Biosci. 37:110-118.

Mauk, R.L., and J.A. Henderson. 1984. Coniferous forest habitat types of northern Utah. USDA For. Serv. Gen. Tech. Rep. INT-GTR-170. 89 p.

Muraro, S.J. 1971. The lodgepole pine fuel complex. Can. For. Serv. Inf. Rep. BC-S-53, For. Res. Lab., Victoria, B.C., Canada. 35 p.

Peterman, R.M. 1978. The ecological role of mountain pine beetle in lodgepole pine forests. P. 16-26 *in* Theory and practice of mountain pine beetle management in lodgepole pine forests, Berryman, A.A., G.D. Amman, and R.W. Stark (eds.). Univ. of Idaho, For., Wildlife, and Range Exp. Stn., Moscow, ID.

Pickett, S.T.A. 1989. Space-for-time substitution as an alternative to long-term studies. P. 110-135 *in* Long-term studies in ecology: Approaches and alternatives, Likens, G.E. (ed.). Springer-Verlag, New York.

Roe, A.L., and G.D. Amman. 1970. The mountain pine beetle in lodgepole pine forests. USDA For. Serv. Res. Pap. INT-71. 23 p.

Romme, W.H., D.H. Knight, and J. Fedders. 1986. Mountain pine beetle outbreaks in the Rocky Mountains: Effects on fuels and fire in lodgepole pine forests (abstract) *in* Program of the annual meeting of the Ecol. Soc. Am., Syracuse Univ., New York.

Safranyik, L. 1989. Mountain pine beetle: Biology overview. P. 9-12 *in* Proc. – symp. on the management of lodgepole pine to minimize losses to the mountain pine beetle. USDA For. Serv. Gen. Tech. Rep. INT-GTR-262.

SAS Institute Inc. Version 9.1. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA.

Schmid, J.M., and G.D. Amman. 1992. *Dendroctonus* beetles and old-growth forests in the Rockies. P. 51-59 *in* Old-growth forests in the Southwest and Rocky Mountain Regions, Proc. of a Workshop, Kaufmann, M.R., W.H. Moir, and R.L. Bassett (tech. coord.). USDA For. Serv. Gen. Tech. Rep. RM-GTR-213.

Smith, J.K., and W.C. Fischer. 1997. Fire ecology of the forest habitat types of northern Idaho. USDA For. Serv. Gen. Tech. Rep. INT-GTR-363. 142 p.

Steele, R., R.D. Pfister, R.A. Ryker, and J.A. Kittams. 1981. Forest habitat types of central Idaho. USDA For. Serv. Gen. Tech. Rep. INT-GTR-114. 138 p.

Stone, W.E. and M.L. Wolfe. 1996. Response of understory vegetation to variable tree mortality following a mountain pine beetle epidemic in lodgepole pine stands in northern Utah. Vegetatio 122:1-12.

Van Wagner, C.E. 1977. Conditions for the start and spread of crown fire. Can. J. For. Res. 7:23-34.

Zar, J.H. 1999. Biostatistical analysis. 4th Ed., Prentice Hall, Upper Saddle River, NJ. 663 p.

Table 1. The year and the number of plots sampled for all stands across all three study sites.

	Stand	Year Sampled	Number of Plots
Ashley National Forest	PE[a] #1	2005	25
	PE[a] #2	2005	24
	EN[b] #1	2005	24
	EN[b] #2	2005	24
Sawtooth National Recreation Area	EP[c] #1	2004	15
	EP[c] #2	2004	22
	EN[b] #1	2005	16
	EN[b] #2	2005	22
Wasatch-Cache National Forest	EP[c] #1	2004	23
	EP[c] #2	2004	14
	EN[b] #1	2005	24
	EN[b] #2	2005	22
	Total		255

[a]PE, post-epidemic; [b]EN, endemic; [c]EP, current epidemic

Table 2. The average ages, quadratic mean diameters, percent mortalities, available canopy fuel loads, crown base heights, and crown bulk densities for all sampled stands on the Ashley National Forest.

	Age (yr)		**QMD[d] (cm)**					
	AVG[c]	**95% CI**	**Live[e] PICO**	**PA[f]**	**Mortality (%)**	**ACFL[g] (tonne/ha)**	**CBH[h] (m)**	**CBD[i] (kg/m^3)**
PE[a] #1	85	± 14	19.3	22.4	71	10.02*	3.1**	0.1378***
PE[a] #2	106	± 14	18.5	22.1	89	8.97*	4.2**	0.1185***
EN[b] #1	128	± 18	17.5	24.1	4	17.57*	6.2**	0.1794***
EN[b] #2	143	± 23	17.3	27.9	11	22.06*	4.8**	0.1970***

[a]PE, post-epidemic; [b]EN, endemic; [c]AVG, average; [d]QMD, quadratic mean diameter; [e]PICO, lodgepole pine; [f]PA, past attack; [g]ACFL, available canopy fuel load; [h]CBH, crown base height; [i]CBD, crown bulk density;
*T-test: t-vlaue= 5.13, P= 0.04
**T-test: t-value= 4.95, P= 0.04
***T-test: t-value= 4.60, P= 0.04

Table 3. The averages, standard deviations, 95% confidence intervals, and significance tests for down woody debris in various size classes for the sampled stands on the Ashley National Forest.

		AVG[c]	STDEV[d]	95% CI	df	t-value	P > t
1 Hour	PE[a]	1.19	0.37	± 0.15	2	3.00	0.10
	EN[b]	0.72	0.24	± 0.10			
10 Hour	PE[a]	4.47	2.26	± 0.90	2	6.09	0.03*
	EN[b]	1.81	0.97	± 0.39			
100 Hour	PE[a]	8.75	4.70	± 1.87	2	4.58	0.05*
	EN[b]	4.13	2.41	± 0.97			
1000 Hour Sound	PE[a]	83.65	40.18	± 15.89	2	12.36	0.01*
	EN[b]	10.74	9.59	± 3.84			
1000 Hour Rotten	PE[a]	18.18	11.14	± 4.41	2	3.66	0.07
	EN[b]	43.33	23.72	± 9.48			
Duff	PE[a]	28.25	10.45	± 4.14	2	0.62	0.60
	EN[b]	30.77	9.18	± 3.67			
Litter	PE[a]	3.68	1.14	± 0.45	2	0.28	0.80
	EN[b]	3.77	1.09	± 0.44			
Fuel Bed Depth[e] (cm)	PE[a]	12.16	8.35	± 3.30	2	21.60	0.002*
	EN[b]	3.49	2.66	± 1.06			

[a]PE, post-epidemic; [b]EN, endemic; [c]AVG, average; [d]STDEV, standard deviation; [e]fuel bed depth is only the depth of the dead and down woody fuels;
*, significant at the 0.05 level
All numbers except fuel bed depth reported as metric tons per hectare

Table 4. The average percent cover, height, and loading for both live and dead shrubs and herbaceous (forbs + grass) material for stands sampled on the Ashley National Forest.

	Shrubs			
	Live			**Dead**
	Cover (%)	**Height (m)**	**Loading (tonne/ha)**	**Loading (tonne/ha)**
PE[a]	18	0.10	1.24	0.09
EN[b]	9	0.07	0.58	0.01
T-Test[c]	2/3.54/0.07	2/4.55/0.05*	2/28.72/0.001*	1.04/0.57/0.67[d]
	Herbaceous			
	Live			**Dead**
	Cover (%)	**Height (m)**	**Loading (tonne/ha)**	**Loading (tonne/ha)**
PE[a]	7	0.09	0.47	0.14
EN[b]	13	0.09	0.63	0.14
T-Test[c]	2/2.79/0.11	2/0.02/0.98	2/2.92/0.10	2/0.05/0.97

[a]PE, post-epidemic; [b]EN, endemic; [c]T-Tests are of the form: degrees of freedom / t-value / P > t; [d]The Satterthwaite method was used due to unequal variances; *****, significant at the 0.05 level; Loading is in metric tons per hectare

Table 5. The average regeneration (trees less than 3.1 meters tall) by number, oven dry weight, and species with associated tests for significance between post-epidemic and endemic stands on the Ashley National Forest.

				df	t-value		P > t	
	Species	**# per ha**	**Loading[f]**		**#**	**Loading**	**#**	**Loading**
PE[a]	ABLA[c]	7129	2.30	2	2.52	100.05	0.13	<0.001*
EN[b]		334	0.07					
PE[a]	PICO[d]	854	0.11	2	0.30	0.85	0.79	0.49
EN[b]		597	0.33					
PE[a]	Total[e]	8309	2.41	2	2.66	3.19	0.12	0.09
EN[b]		1122	0.63					

[a]PE, post-epidemic; [b]EN, endemic; [c]ABLA, subalpine fir; [d]PICO, lodgepole pine; [e]Total, total regeneration for all species; [f]Loading, loading in metric tons per hectare; *****, significant at the 0.05 level

Table 6. The average ages, quadratic mean diameters, percent mortalities, available canopy fuel loads, crown base heights, and crown bulk densities for the stands sampled on the Sawtooth National Recreation Area. Crown data are only for live fuels.

	Age (yr)		**QMD[d] (cm)**			**Mortality (%)**				
	AVG[c]	**95% CI**	**Live PICO[e]**	**RA[f]**	**PA[g]**	**RA[f]**	**PA[g]**	**ACFL[h] (tonne/ha)**	**CBH[i] (m)**	**CBD[j] (kg/m^3)**
EP[a] #1	110	± 16	12.2	22.9	23.1	48	7	9.42	8.0[k]	0.2090[l]
EP[a] #2	129	± 18	12.4	23.6	22.4	46	17	8.77	8.0[k]	0.1898[l]
EN[b] #1	110	± 15	16.5	27.7	24.6	8	5	10.94	6.9	0.1073
EN[b] #2	95	± 7	18.5	37.6	24.4	8	1	13.90	9.1	0.1442

[a]EP, current epidemic; [b]EN, endemic; [c]AVG, average; [d]QMD, quadratic mean diameter; [e]PICO, lodgepole pine; [f]RA, recent attack (since 2000); [g]PA, past attack (prior to 2000); [h]ACFL, available canopy fuel load (live fuel); [i]CBH, crown base height; [j]CBD, canopy bulk density (live fuel); [k]Average from the two endemic stands; [l]These data were calculated from Cruz et al. (2003)

Table 7. The averages, standard deviations, 95% confidence intervals, and significance tests for down woody debris in various size classes for stands sampled on the Sawtooth National Recreation Area.

		AVG[c]	STDEV[d]	95% CI	df	t-value	P > t
1 Hour	EP[a]	1.16	0.27	± 0.12	2	7.90	0.02*
	EN[b]	0.85	0.27	± 0.13			
10 Hour	EP[a]	2.22	1.14	± 0.51	2	1.19	0.36
	EN[b]	2.45	1.13	± 0.51			
100 Hour	EP[a]	3.73	1.94	± 0.91	2	1.47	0.28
	EN[b]	6.76	5.44	± 2.41			
1000 Hour Sound	EP[a]	11.80	10.17	± 4.63	2	0.58	0.62
	EN[b]	11.16	9.97	± 4.49			
1000 Hour Rotten	EP[a]	23.93	15.62	± 7.12	2	1.70	0.23
	EN[b]	17.90	25.17	± 11.68			
Duff	EP[a]	31.22	13.23	± 6.04	2	0.63	0.59
	EN[b]	28.24	12.16	± 5.44			
Litter	EP[a]	6.82	1.61	± 0.73	2	7.11	0.02*
	EN[b]	3.06	0.61	± 0.28			
Fuel Bed Depth[e] (cm)	EP[a]	3.26	2.08	± 1.00	2	0.90	0.46
	EN[b]	3.47	1.85	± 0.84			

[a]EP, current epidemic; [b]EN, endemic; [c]AVG, average; [d]STDEV, standard deviation; [e]fuel bed depth is only the depth of dead and down woody fuels;
*, significant at the 0.05 level
All numbers except fuel bed depth reported as metric tons per hectare

Table 8. The average ages, quadratic mean diameters, percent mortalities, available canopy fuel loads, crown base heights, and crown bulk densities for the stands sampled on the Wasatch-Cache National Forest. Crown data are only for live fuels.

	Age (yr)		**QMD[d] (cm)**			**Mortality (%)**				
	AVG[c]	**95% CI**	**Live PICO[e]**	**RA[f]**	**PA[g]**	**RA[f]**	**PA[g]**	**ACFL[h] (tonne/ha)**	**CBH[i] (m)**	**CBD[j] (kg/m^3)**
EP[a] #1	92	± 8	16.3	23.4	14.2	40	8	14.44	3.9[k]	0.2206[l]
EP[a] #2	80	± 8	15.7	23.1	18.8	42	13	13.05	3.9[k]	0.1528[l]
EN[b] #1	106	± 19	18.5	27.7	17.8	6	3	15.47	3.6	0.1426
EN[b] #2	90	± 9	20.6	24.4	26.9	3	2	14.37	4.2	0.1410

[a]EP, current epidemic; [b]EN, endemic; [c]AVG, average; [d]QMD, quadratic mean diameter; [e]PICO, lodgepole pine; [f]RA, recent attack (since 2000); [g]PA, past attack (prior to 2000); [h]ACFL, available canopy fuel load (live fuel); [i]CBH, crown base height; [j]CBD, crown bulk density (live fuel); [k] Average from the two endemic stands; [l] These data were calculated from Cruz et al. (2003)

Table 9. The averages, standard deviations, 95% confidence intervals, and significance tests for down woody debris in various size classes for stands sampled on the Wasatch-Cache National Forest.

		AVG[c]	STDEV[d]	95% CI	df	t-value	P > t
1 Hour	EP[a]	1.10	0.41	± 0.39	2	7.00	0.02*
	EN[b]	0.52	0.27	± 0.11			
10 Hour	EP[a]	2.89	1.81	± 0.86	2	0.82	0.50
	EN[b]	3.06	1.65	± 0.67			
100 Hour	EP[a]	2.90	2.45	± 1.14	2	3.77	0.06
	EN[b]	3.91	2.32	± 0.95			
1000 Hour Sound	EP[a]	11.63	10.27	± 4.62	2	2.01	0.18
	EN[b]	5.60	5.50	± 2.24			
1000 Hour Rotten	EP[a]	17.74	19.36	± 8.99	2	0.91	0.46
	EN[b]	25.77	17.58	± 7.13			
Duff	EP[a]	32.20	15.77	± 7.41	2	0.62	0.60
	EN[b]	28.08	12.03	± 4.90			
Litter	EP[a]	5.18	1.54	± 0.69	2	6.71	0.02*
	EN[b]	2.90	0.69	± 0.28			
Fuel Bed Depth[e] (cm)	EP[a]	1.48	1.42	± 0.64	2	1.99	0.19
	EN[b]	2.25	1.40	± 0.57			

[a]EP, current epidemic; [c]AVG, average; [b]EN, endemic; [d]STDEV, standard deviation; [e]fuel bed depth is only the depth of the dead and down woody fuels;
*, significant at the 0.05 level
All numbers except fuel bed depth reported as metric tons per hectare

Figure Captions

Figure 1. The approximate locations and the number and type of stands sampled for the three study areas selected.

Figure 2. View of the transect layout for each plot. The first three transects were laid out along 90°, 180°, and 270° azimuths with additional transects installed at 0°, 115°, 225°, and 315° until the total number of dead fuel intersections was 100 pieces or more.

Figure 3. Post-epidemic versus endemic stand conditions on the Ashley National Forest.

Figure 4. Average amount of live versus dead foliage, in metric tons per hectare, for the current epidemic and endemic stands on the Sawtooth National Recreation Area.

Figure 5. Average amount of live versus dead foliage, in metric tons per hectare, for the current epidemic and endemic stands on the Wasatch-Cache National Forest.

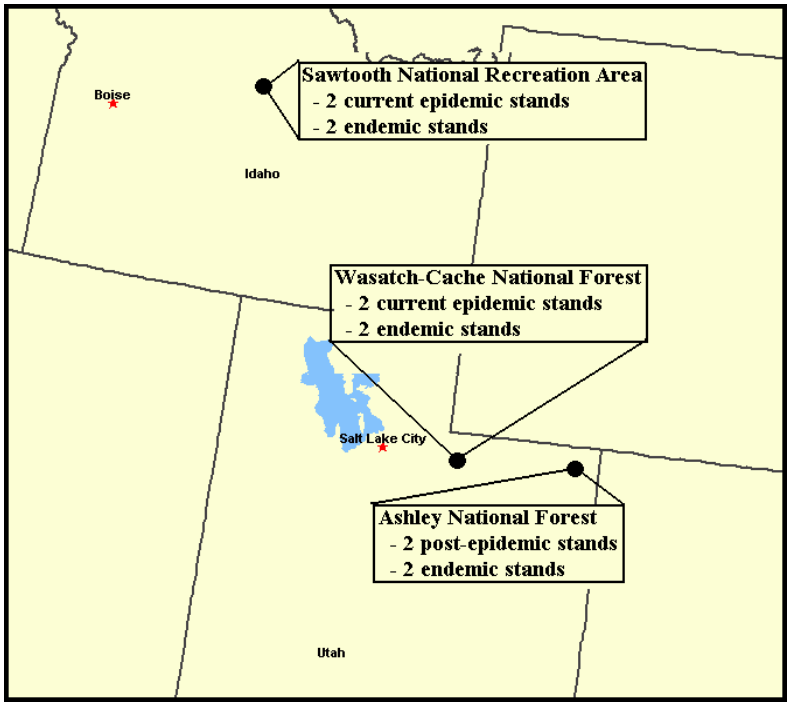
Sawtooth National Recreation Area
- 2 current epidemic stands
- 2 endemic stands
Boise
Idaho
Wasatch-Cache National Forest
- 2 current epidemic stands
- 2 endemic stands
Salt Lake City
Ashley National Forest
- 2 post-epidemic stands
- 2 endemic stands
Utah

Figure 1.

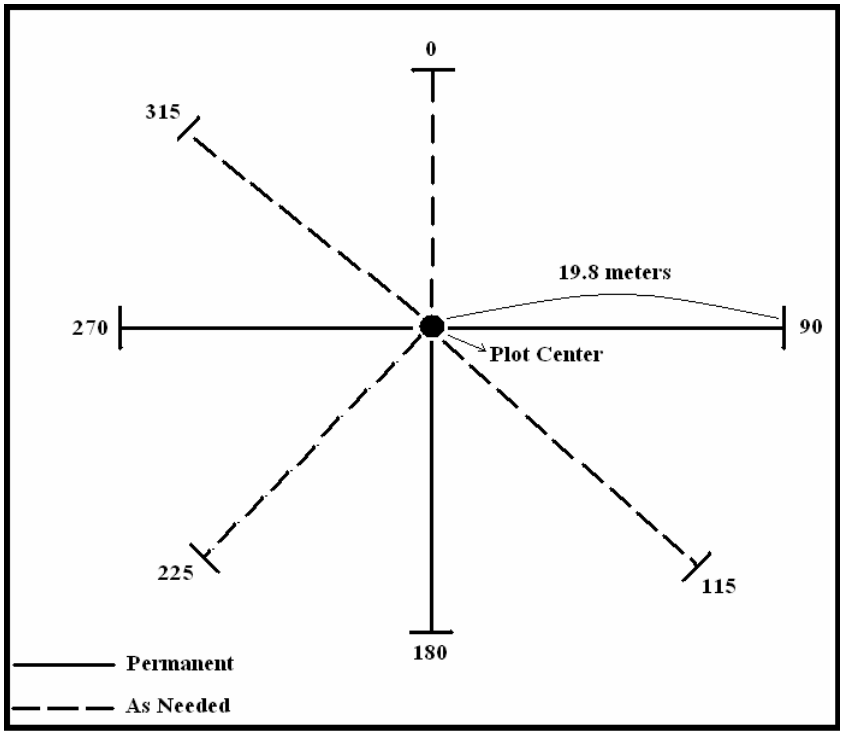
0
315
19.8 meters
270
90
Plot Center
225
115
180
Permanent
As Needed

Figure 2.

Post-Epidemic Endemic

Figure 3.

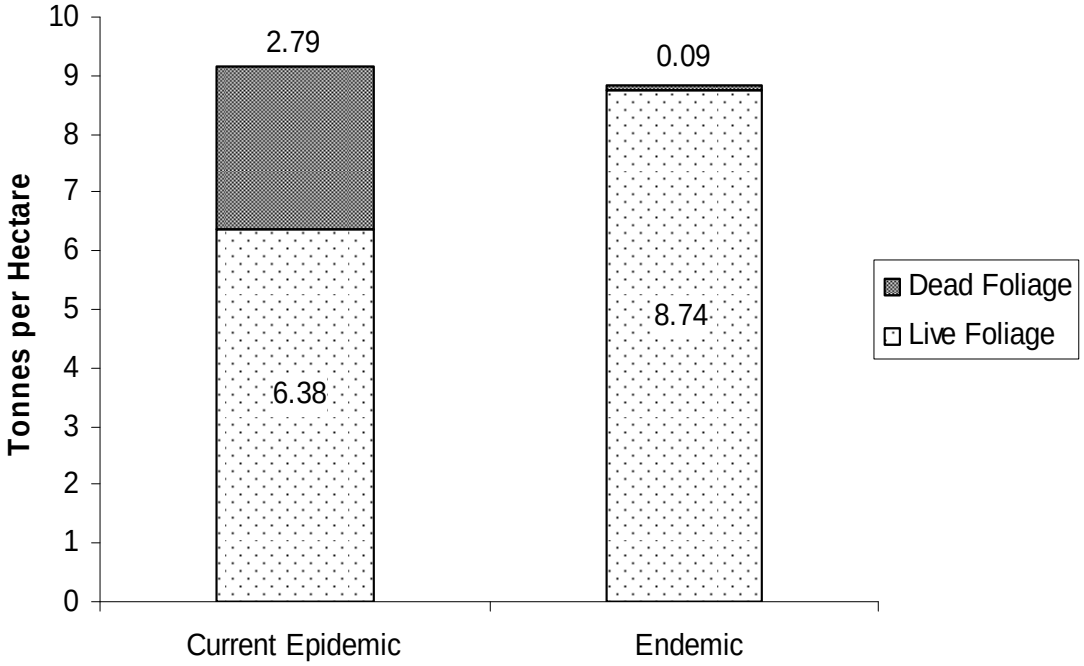
10
9
8
7
6
5
4
3
2
1
0
Tonnes per Hectare
2.79
6.38
0.09
8.74
Dead Foliage
Live Foliage
Current Epidemic
Endemic

Figure 4.

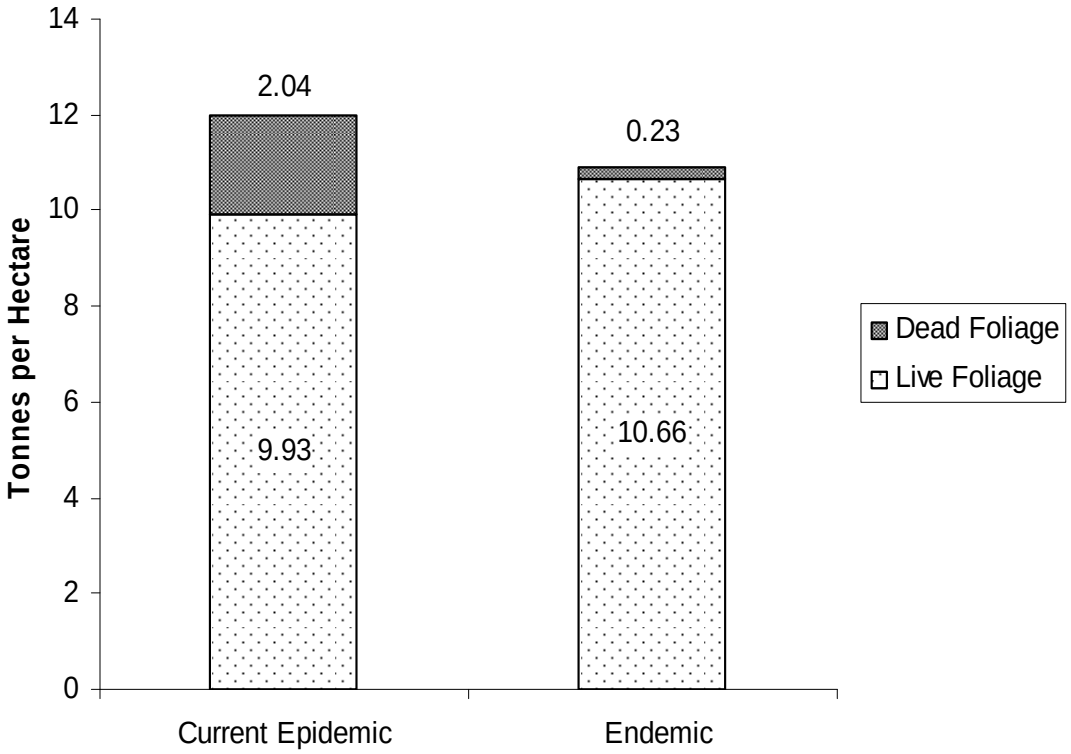
14
12
10
8
6
4
2
0
Tonnes per Hectare
2.04
0.23
9.93
10.66
Current Epidemic
Endemic
Dead Foliage
Live Foliage

Figure 5.