

INTRODUCTION

Mountain pine beetle (*Dendroctonus ponderosae* Hopkins) has infested over 2 million acres of lodgepole pine (*Pinus contorta* Dougl. ex Loud.) forest since an outbreak began approximately in 2000 in north central Colorado. The tree mortality from mountain pine beetle outbreaks has the potential to alter stand composition and stand characteristics, along with fuel complexes. In general, it is assumed that these changes in stand structure from mountain pine beetle outbreaks in lodgepole pine forests increase fire hazard (Arno 1980, Jenkins and others 2008), though lodgepole pine fire regimes are characterized as having stand replacing high-severity fires, with nonlethal surface fires generally playing a lesser role in lodgepole pine ecosystems (Arno 1980, Kipfmüller and Baker 2000). To quantify the amount of mortality in infested lodgepole pine stands, along with identifying differences in stand characteristics and tree species composition before and after infestation, a study was conducted in Colorado lodgepole pine 7 years after mountain pine beetle outbreak initiation. Furthermore, litter, duff, and fuel bed depth along with downed woody debris loads and vegetation characteristics were examined in infested and uninfested stands. We also compared potential fire behavior and first order effects modeled with the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS) in uninfested stands, stands 7 years after mountain pine beetle outbreak initiation, and infested stands with projected fuel and stand characteristics that represent 10-percent and 80-percent tree fall.

METHODS

The study was conducted in the Sulphur Ranger District, Arapaho National Forest, in Colorado (40° 4' N, 106° 0' W). During 2006 and 2007, a geographic information system was used to randomly select potential plot locations within the lodgepole pine forest type from Forest Service, U.S. Department of Agriculture, vegetation cover maps. We established a total of 221 0.05-acre (26.3-foot radius) plots that were in uninfested areas (51 plots) and infested areas (170 plots). Plots in areas with infested lodgepole pine were either initially infested between 2000 and 2003 (68 plots), hereafter referred to as plots 4 to 7 years after infestation, or between 2004 and 2007 (102 plots), hereafter referred to as plots 0 to 3 years after infestation (0 represents current infestation in 2007). In a plot, the tree with the earliest year of infestation by mountain pine beetle determined the time since infestation category for the plot. The year a tree was infested by mountain pine beetle was estimated by degradation status of the crown. For plots 4 to 7 years after infestation, all needles had been shed from the earliest infested lodgepole pine, whereas for the plots 0 to 3 years after infestation, most needles remained on the infested lodgepole pines.

In each plot, diameter at breast height (d.b.h.) (4.5 feet above ground), tree species, condition (live, infested or killed by mountain pine beetle, or dead from other causes), and year of mountain pine beetle infestation were recorded. Downed woody fuel loads and fuel depth were recorded on modified Brown's fuel transects (Brown 1974) and vegetation cover was visually estimated in

CHAPTER 11.

Mountain Pine Beetle in Lodgepole Pine: Mortality and Fire Implications (Project INT-F-07-03)

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each plot. Fuel loads and stand characteristics were used as input into a fire behavior model to evaluate potential fire behavior, fire type, tree mortality, and smoke production. The Central Rockies variant (Suppose 2.02) (Edminster and others 1991, Reinhardt and Crookston 2003) of FFE-FVS was used to model potential fire behavior and effects for uninfested plots and for infested plots under high fire weather conditions at three points: 7 years after outbreak initiation, at projected 10-percent infested tree fall, and at projected 80-percent infested tree fall. Mitchell and Preisler (1998) indicated that about 10 percent of mountain pine beetle-killed lodgepole pine in Oregon had fallen 6 years after infestation and 80 percent after 12 years. For infested plots in this study, 10-percent mountain pine beetle-killed tree fall was chosen to represent about 6 years after infestation and 80 percent to represent about 12 years. Surface fuel loads under projected 10-percent and 80-percent tree fall were calculated from infested trees using allometric equations (Brown 1978, Pearson and others 1984).

RESULTS

Stand Conditions

We found that stand characteristics and surface fuel loads have been significantly altered due to this recent mountain pine beetle outbreak (Klutsch and others 2009). Lodgepole pine density was subsequently reduced by 42 percent in stands infested with mountain pine beetle, resulting in an average density of 240 live

lodgepole pine per acre (standard error of the mean [SEM] = 18). The distribution of trees per diameter class killed by mountain pine beetle was significantly different than the distribution of live trees (chi-square = 291.5, $p < 0.0001$) in infested plots (fig. 11.1—live and infested lodgepole pine bars). Mountain pine beetle selectively infested larger lodgepole pine resulting in a reduction of live quadratic mean diameter of 34 percent in affected areas. There was still a component of other tree species, such as Engelmann spruce, subalpine fir, and quaking aspen, in infested plots, though lodgepole pine was the most abundant live tree species in the d.b.h. classes of 1 to 12 inches (fig. 11.1).

Logistic regression modeling identified lodgepole pine basal area (plot level) as a predictor of the probability of attack. Other variables modeled included, lodgepole pine/ha but did not demonstrate a strong relationship to probability of attack. There was a positive coefficient of lodgepole pine basal area which indicates an increase in the likelihood of attack as lodgepole pine basal area increases. The estimated probability of infestation for a plot was 0.64 with a lodgepole pine basal area of 9 square feet per acre, the lowest observed in our study.

Downed fine and coarse woody debris loads were not different between infested plots and uninfested plots 7 years after outbreak initiation. However, the median litter depth was significantly greater in plots 4 to 7 years after initial infestation compared to plots in 0 to 3 years after initial infestation and uninfested plots. The average amount of downed woody

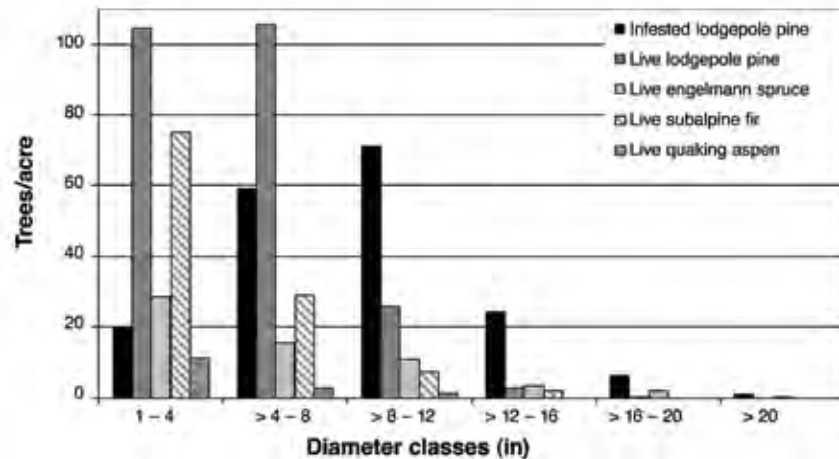


Figure 11.1—Diameter distribution of mountain pine beetle-killed lodgepole pine, live lodgepole pine, live Engelmann spruce, live subalpine fir, and live quaking aspen in stands with mountain pine beetle-caused mortality, Arapaho National Forest, Colorado, 2006–07.

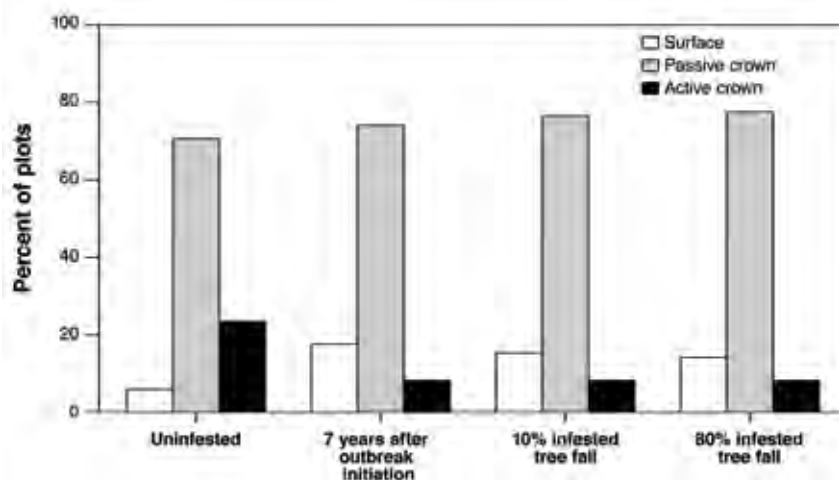


Figure 11.2—Percent of plots within infestation class with surface, passive, conditional or active fire type with 90th percentile fire weather. Significantly different distribution (p -value < 0.0001) tested with a Pearson's chi-square test (test statistic = 79.5, df = 9).

debris in infested stands was not different from uninfested stands, with total surface fuel loads of 8.7 tons per acre (SEM = 8.0) and 9.8 tons per acre (SEM = 8.3), respectively. Simulations in which 80 percent of affected trees were converted to surface fuels showed that projected downed woody fuel loads (total, fine, and coarse) were significantly greater than with no tree fall, resulting in an estimated 22.8 tons per acre increase in total fuel load.

Fire Behavior

There were significant differences in potential fire behavior between uninfested and infested plots under high fire weather conditions. Infested plots had a greater potential for fire to move from the surface to the crown as a passive fire but had less potential for fire to move between crowns as an active crown fire as compared to uninfested plots (fig. 11.2). The potential smoke production from a fire was modeled to be greater with 80-percent infested tree fall than in uninfested plots and plots with less tree fall. Tree mortality from a fire was predicted to be almost 100 percent in both uninfested and infested plots.

DISCUSSION

Stand Conditions

Mountain pine beetle populations in our study sites have initially shown a preference for densely stocked lodgepole pine stands. Mountain pine beetle has been more active in stands with higher lodgepole pine basal area, and lower tree density and basal area of non-host species. This is consistent with literature that indicates mountain pine beetle prefer densely stocked stands dominated by suitable host tree species (Fettig and others 2007). Within infested stands, mountain pine beetle exhibited preference for larger diameter trees, as killed trees were significantly larger than the residual live trees. This could be due to beetles preferring trees with thicker phloem for brood development and/or larger trees being older, less vigorous, and less able to defend themselves than younger trees. In addition, the distribution of live lodgepole pine and mountain pine beetle-killed trees by diameter classes in infested plots indicates preference for large diameter trees, which is also consistent with the literature (Amman 1977, Cole and Amman 1969).

The depth of litter increased in plots 3 to 7 years after infestation compared to plots 0 to 3 years after infestation and uninfested plots, as enough time had elapsed for most of the needles and some of the twigs to drop from these trees. Mortality that had occurred within 3 years after infestation includes trees that still had a large component of needles attached at the time of measurement. This is consistent with studies on mountain pine beetle epidemics in lodgepole

pine forests in Utah and Idaho, where Page and Jenkins (2007) showed a greater amount of litter in current epidemic stands compared to stands with endemic levels of mountain pine beetle.

Quantification of downed woody debris showed no change in mountain pine beetle-affected stands within 7 years after outbreak initiation, which was unexpected as we anticipated the initiation of tree fall. The lack of tree fall in our plots suggests that tree fall rates will be slower in north-central Colorado than those reported by Mitchell and Preisler (1998) for Oregon. Nevertheless, when 10 percent of killed trees fall, the amount of downed woody debris in infested plots was projected to not be different from that of uninfested plots. With 80 percent of infested trees down, we anticipate a significant increase in surface fuel loads. The median amount of coarse woody debris > 3 inches that is expected to be on the ground is 29 tons per acre [the median and median absolute deviation (MAD) = 13]. Coarse woody debris amounts are highly variable (Brown and others 2003); therefore, the amount of downed woody debris projected to accumulate after tree fall in our study sites is not likely to be different from that reported for historical and disturbed stands (Brown and See 1981, Tinker and Knight 2000). Coarse woody debris accumulation from the mountain pine beetle outbreak will persist for many decades due to slow degradation rates. Brown and others (1998) found that windthrown lodgepole pine logs in north-central Colorado took more than 150 years to completely decompose, though degradation rates may be more rapid due to bark beetle infestation (Busse 1994).

Fire Behavior

The different fire types and potential fire behavior predicted for infested and uninfested plots is due to a combination of the surface fuel loads and stand characteristics. The extensive mortality in infested stands reduced the canopy fuel continuity. The greater potential for passive fire to occur in infested plots is due to less fuel in the crown with the passive fire occurring in the lodgepole pine and other tree species remaining. Similarly, in Engelmann spruce forests, DeRose and Long (2009) modeled potential fire behavior 10 to 29 years after an outbreak of spruce beetle (*Dendroctonus rufipennis* Kirby) and found active crown fires to occur in areas unaffected and areas with low densities of spruce beetle-killed trees but not in areas with high densities of mortality.

Mountain pine beetle-caused mortality after an outbreak in lodgepole pine-dominated forest will affect fire behavior through accumulations of surface fuels and changes in stand characteristics. Plots without mountain pine beetle-caused mortality with intact and continuous canopy fuel components were expected to have greater potential for active crown fire than infested plots, though potential mortality from a fire was extremely high for both uninfested and infested plots. Although bark beetle-caused mortality changes fuel complexes, the occurrence of a wildfire is also dependent on the timing of fire conducive weather with a sustainable ignition event.

IMPLICATIONS

Effects of the current mountain pine beetle outbreak on ecological processes such as downed wood accumulation and decomposition, hydrology, windthrow events, fire, and others in lodgepole pine forests of north-central Colorado will be long lasting. Native bark beetles are important disturbance agents in forest ecosystems and have co-evolved with their hosts for millennia. Under a climate change scenario it is expected that disturbance processes may change in frequency and become more intense (Dale and others 2001) with eruptive forest insects having the potential to create large-scale ecological changes (Logan and others 2003). The distribution, range, and abundance of different conifer species will depend on their response to increasing temperatures (Nielson and others 2005). The high intensity, large-scale, and infrequent fires of lodgepole pine forests have been associated with region-wide and multi-year drought conditions (Bessie and Johnson 1995, Kipfmüller and Baker 2000). The occurrence of a fire during high fire weather could be stand replacing in areas affected and not affected by mountain pine beetle. As demonstrated, the speed at which the fire moves may be different, with passive fires in mountain pine beetle-affected areas potentially moving slower than active crown fires in areas not affected. It will be imperative to continue long-term monitoring of ecological processes after these extensive bark beetle outbreaks as lessons may be of benefit to understanding these novel interactions and to mitigate, as appropriate, future bark beetle outbreaks if they continue to be exacerbated under a changing climate scenario.

LITERATURE CITED

- Amman, G.D. 1977. The role of mountain pine beetle in lodgepole pine ecosystems: impact on succession. In: Mattson, W.J., ed. *The Role of Arthropods in Forest Ecosystems*. New York: Springer-Verlag: 3-18.
- Arno, S.F. 1980. Forest fire history in the northern Rockies. *Journal of Forestry*. 78: 460-465.
- Bessie, W.C.; Johnson, E.A. 1995. The relative importance of fuels and weather on fire behavior in subalpine forests. *Ecology*. 76(3): 747-762.
- Brown, J.K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. Ogden, UT: U.S. Department of Agriculture Forest Service, Intermountain Forest and Range Experiment Station. 24 p.
- Brown, J.K. 1978. Weight and density of crowns of Rocky Mountain conifers. Res. Pap. INT-197. Ogden, UT: U.S. Department of Agriculture Forest Service, Intermountain Forest and Range Experiment Station. 56 p.
- Brown, J.K.; See, T.E. 1981. Downed woody fuel and biomass in the Northern Rocky Mountains. Gen. Tech. Rep. INT-117. Ogden, UT: U.S. Department of Agriculture Forest Service, Intermountain Forest and Range Experiment Station. 48 p.
- Brown, J.K.; Reinhardt, E.D.; Kramer, K.A. 2003. Coarse woody debris: managing benefits and fire hazard in the recovering forest. Gen. Tech. Rep. GTR-RMRS-105. Ogden, UT: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 20 p.
- Brown, P.M.; Shepperd, W.D.; Mata, S.A.; McClain, D.L. 1998. Longevity of windthrown logs in a subalpine forest of central Colorado. *Canadian Journal of Forest Research*. 28: 932-936.
- Busse, M.D. 1994. Downed bole-wood decomposition in lodgepole pine forests of central Oregon. *Soil Science Society of America Journal*. 58: 221-227.
- Cole, W.E.; Amman, G.D. 1969. Mountain pine beetle infestation in relation to lodgepole pine diameters. Res. Note 95. Ogden, UT: U.S. Department of Agriculture Forest Service, Intermountain Forest and Range Experiment Station. 7 p.
- Dale, V.H.; Joyce, J.A.; McNulty, S. [and others]. 2001. Climate change and forest disturbances. *BioScience*. 51: 723-734.
- DeRose, R.J.; Long, J.N. 2009. Wildfire and spruce beetle outbreak: simulation of interacting disturbances in the central Rocky Mountains. *Ecoscience*. 16(1): 28-38.
- Edminster, C.; Mowrer, H.T.; Mathiasen, R.L. [and others]. 1991. GENGYM: A variable density stand table projection system calibrated for mixed conifer and ponderosa pine stands in the Southwest. Res. Pap. RM-297. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station. 32 p.
- Fettig, C.J.; Klepzig, K.D.; Billings, R.F. [and others]. 2007. The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States. *Forest Ecology and Management*. 238: 24-53.
- Jenkins, M.J.; Hebertson, E.; Page, W.; Jorgensen, C.A. 2008. Bark beetles, fuels, fires and implications for forest management in the Intermountain West. *Forest Ecology and Management*. 254: 16-34.
- Kipfmüller, K.F.; Baker, W.L. 2000. A fire history of a subalpine forest in south-eastern Wyoming, USA. *Journal of Biogeography*. 27: 71-85.
- Klutsch, J.G.; Negrón, J.F.; Costello, S.L. [and others]. 2009. Stand characteristics and downed woody debris accumulations associated with a mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreak in Colorado. *Forest Ecology and Management*. 258: 641-649.
- Logan, J.A.; Regniere, J.; Powell, J.A. 2003. Assessing the impact of global warming on forest pest dynamics. *Frontiers in Ecology and the Environment*. 1: 130-137.
- Mitchell, R.G.; Preisler, H.K. 1998. Fall rate of lodgepole pine killed by the mountain pine beetle in central Oregon. *Western Journal of Applied Forestry*. 13: 23-26.
- Nielson, R.P.; Pitelka, L.F.; Solomon, A.M. [and others]. 2005. Forecasting regional to global plant migration in response to climate change. *BioScience*. 55: 749-759.
- Page, W.; Jenkins, M.J. 2007. Mountain pine beetle-induced changes to selected lodgepole pine fuel complexes within the Intermountain region. *Forest Science*. 53: 507-518.
- Pearson, J.A.; Fahey, T.J.; Knight, D.H. 1984. Biomass and leaf area in contrasting lodgepole pine forests. *Canadian Journal of Forest Research*. 14: 259-265.
- Reinhardt, E.D.; Crookston, N.L., tech. eds. 2003. The fire and fuels extension to the forest vegetation simulator. Gen. Tech. Rep. RMRS-GTR-116. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 209 p.
- Tinker, D.B.; Knight, D.H. 2000. Coarse woody debris following fire and logging in Wyoming lodgepole pine forests. *Ecosystems*. 3: 472-483.