Effects of Salvage Logging on Fire Risks After Bark Beetle Outbreaks in Colorado Lodgepole Pine Forests

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Most mature lodgepole pine (*Pinus contorta var. latifolia* Engelm. ex Wats.) forests in the central and southern Rocky Mountains originated after stand-replacing wildfires or logging (Brown 1975, Lotan and Perry 1983, Romme 1982). In recent years, mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreaks have created a widespread, synchronous disturbance (i.e., greater than 1.4 million hectares of pine forests in Colorado and southeastern Wyoming since 1996) (USDA 2010) that will shape forest dynamics for the coming century. Compared with the ample knowledge of how lodgepole forests recover after fire and harvesting (Lotan and Perry 1983), the trajectory of stand development and forest disturbance set in motion by bark beetle outbreaks is poorly understood.

Concern about wildfire and threats to infrastructure and human safety from falling beetle-killed trees has prompted harvesting of infested stands (Collins et al. 2010, 2011; Fettig et al. 2007). Logging within these forests reduces surface and canopy fuels and disrupts the fuels' horizontal and vertical continuity in an attempt to minimize crown fire hazard (Agee and Skinner 2005, USDA 2005). By removing large woody fuels (i.e., tree boles), these operations diminish fire-line intensity, aid wildfire suppression, and minimize soil-heating effects caused by prolonged smoldering (Monsanto and Agee 2008, USDA 2005). Removal of standing, dead pine restricts potential wildfire activity to surface fuels in the years immediately following treatment, yet, as new stands develop, the implications of harvesting for fire behavior and fire effects will be less certain.

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Tree mortality that results from mountain pine beetle and associated harvesting will influence forest dynamics, fuel loads, and fire behavior for many decades following the current outbreak. We need to understand whether post-beetle salvage logging will have major effects on stand development and fire risks, or if the effects would be small compared with the other factors that change with forest development after beetle outbreaks. To address this need, our objectives were to answer the following questions:

1. Does salvage logging in beetle-killed forests change the species composition or density of trees compared with untreated stands?
2. What is the effect of salvage logging on surface and canopy fuel loads compared with untreated forests?
3. How will potential differences in species composition and fuel loads brought about by salvage logging affect potential fire behavior in harvested and untreated stands during the coming century?

Current Forest Conditions

Lodgepole pine forests of the Medicine Bow-Routt and Arapaho-Roosevelt National Forests and the Colorado State Forest have lost 79 to 91 percent of their overstory basal area (equivalent to 77 percent of the stand total) to bark beetles since 2003. The understory of these pine-dominated forests contains subalpine fir, Engelmann spruce, and quaking aspen. Management projects responding to the insect outbreak in the region remove the dead overstory to reduce the risk of crown fire and to interrupt the horizontal and vertical fuel continuity. In spite of an extensive management response, salvage logging is likely to treat less than 15 percent of the affected landscape (Collins et al. 2010).

Key Findings

Stand Development in Harvested and Untreated Beetle-Killed Stands

Seedling colonization in both untreated and salvage-logged, beetle-killed stands is abundant. Three-fourths of all new seedlings colonizing harvested areas were lodgepole pine; 10 times more new pine seedlings were in the cut areas compared with untreated stands. Aspen sprouts were seven-fold more abundant in harvest units compared with untreated stands. In untreated areas, subalpine fir accounted for 70 percent of all new seedlings.

Stand development projections based on these field measurements suggest abundant sprouting in the first four decades after beetle infestation will increase the presence of aspen in untreated and harvested stands (fig. 1). In harvested areas, lodgepole pine will once again become the dominant species as aspen declines. In untreated stands,

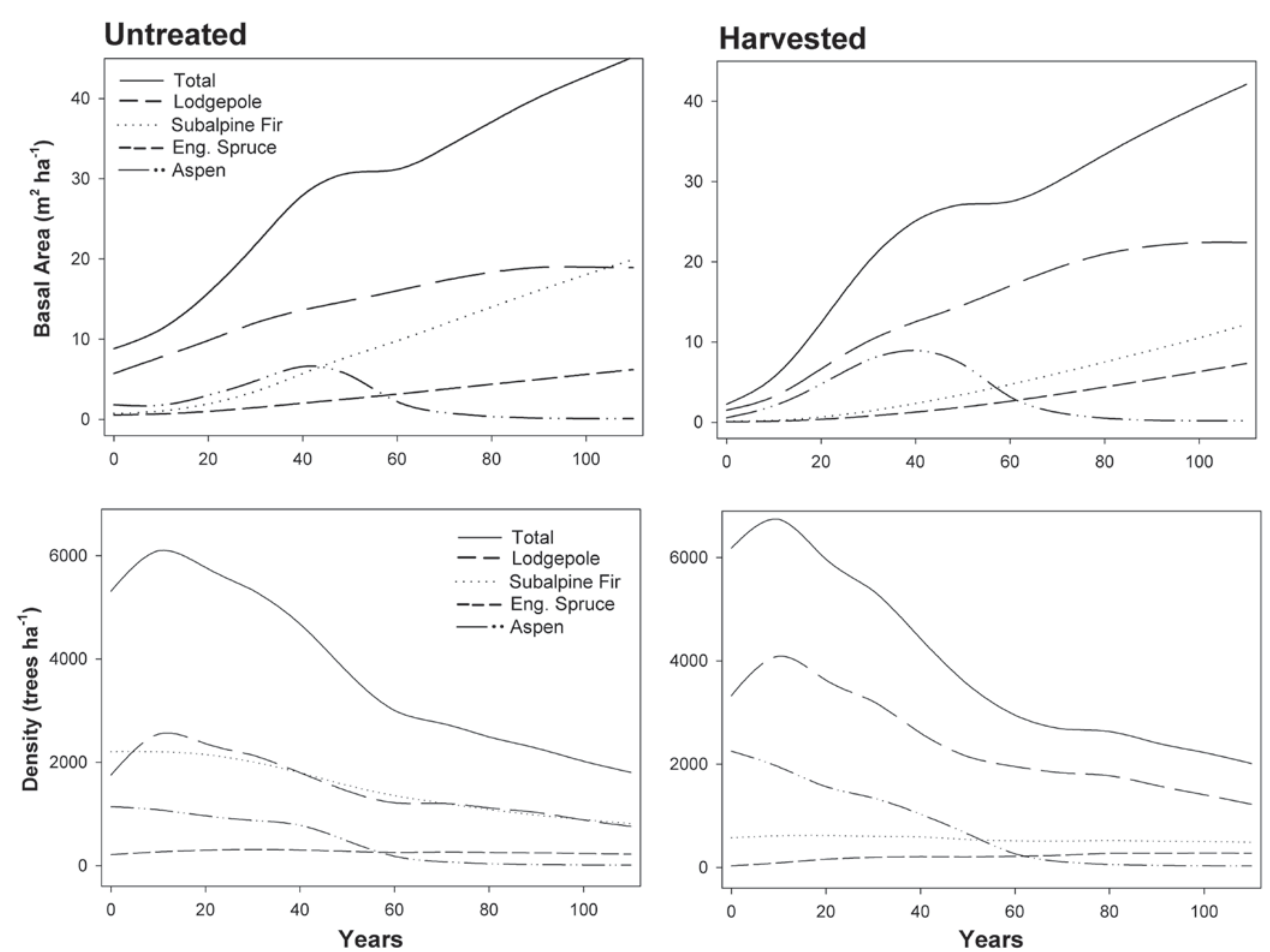

Figure 1.—*Projected stand development based on initial observations in harvested (n = 24) and untreated stands (n = 24). Growth was simulated using the Forest Vegetation Simulator (Dixon 2002). Projections were based on observed regeneration, overstory conditions, and site index.*

subalpine fir and lodgepole pine are projected to be the dominant species a century after the beetle infestation. Pre-outbreak stand conditions (about 35.5 m^2 ha^{-1} of basal area; quadratic mean diameter of 13.5 cm) are expected to recover after 75 and 90 years in untreated and harvested stands, respectively (fig. 1). Due to an increased presence of subalpine fir in untreated stands, canopy bulk density is expected to reach pre-infestation levels (i.e., 0.15 kg m^{-3}) three to four decades sooner than in harvested areas.

Fuel Dynamics in Harvested and Untreated Beetle-Killed Stands

Salvage logging increased the total mass of woody surface fuels 2.7 times compared with untreated stands following salvage logging (17.6 versus 47.8 Mg ha^{-1}). Harvesting increased the mass of fine (i.e., less than 7.6 cm in diameter) and sound (coarse 7.6 cm in diameter or greater) fuels 3.3- and 3.5-fold compared with untreated stands, respectively. The observed increases in fine-surface fuels are expected to be transient, however, declining within three decades as a result of decomposition and low input from the developing canopy (fig. 2).

Standing dead trees are projected to deteriorate and fall within the first three decades after beetle attack, adding branches and boles as surface fuels. Coarse wood mass is expected to increase 5.5-fold above preinfestation levels as dead trees topple in untreated stands (fig. 2). Tree boles are expected to decompose slowly, keeping coarse fuel loads high in untreated stands for more than a century after the outbreak.

Our findings suggest that salvage logging in beetle-killed, gray-stage, lodgepole pine stands will dampen the behavior and severity of potential future wildfires.

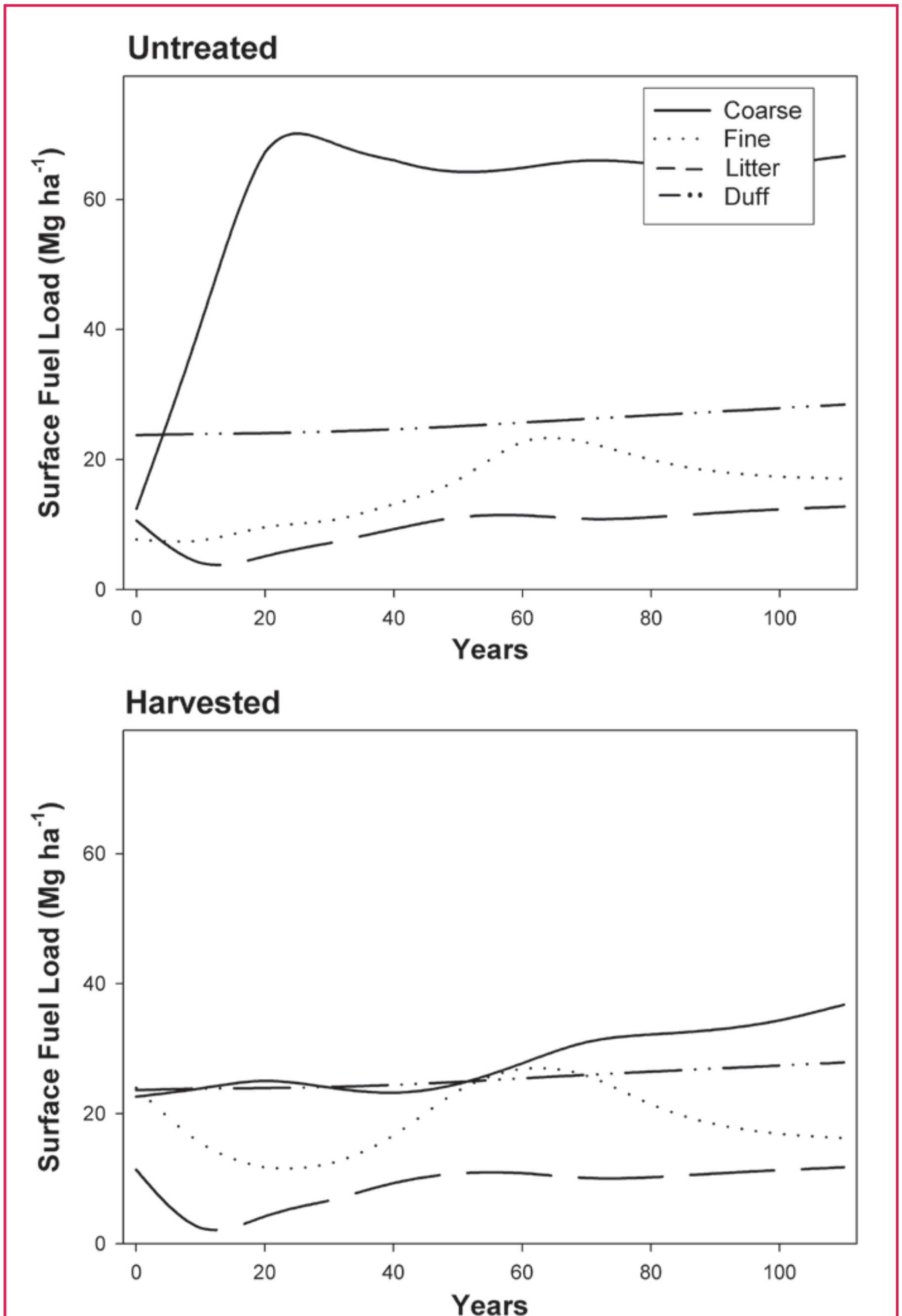

Figure 2.—*Changes in surface fuel loads in harvested and untreated mountain pine beetle management areas as estimated by the Forest Vegetation Simulator (FVS) (Dixon 2002). Projected changes based on initial observations of fuel loads in 24 untreated and 24 harvested areas. Fine woody fuels are less than 7.6 cm in diameter (3 in); coarse fuels are greater than or equal to 7.6 cm in diameter.*

Potential Fire Behavior in Untreated and Harvested Beetle-Killed Stands

Salvage logging in beetle-infested Colorado forests is expected to affect future fires by favoring regeneration of pine and aspen over subalpine fir, a species with a dense crown and branches that extend to the ground. Abundant subalpine fir in untreated, beetle-killed stands will act as ladder fuels that allow fires burning on the surface to spread into the forest overstory. Initial measurements indicated harvest treatments increased woody surface fuels compared with untreated stands, but potential fire behavior did not differ between treatments because of the sparse overstory canopy (fig. 3). Elevated coarse fuel loads will increase the potential for larger and more severe wildfires by increasing soil heating, increasing the production of airborne burning material, and hindering fire suppression. We expect harvesting will substantially alter potential fire behavior in beetle-killed forests, although salvage operations will treat only a small fraction of infested Colorado forests.

The difference in tree species composition and the higher fuel loads in untreated, beetle-killed stands creates the potential for more extreme fire behavior compared with harvested areas (fig. 3). Following the loss of foliage in dead trees (i.e., gray-stage), a lack of canopy fuels will result in similar fire behavior in untreated and harvested areas. As the forest overstory develops, however, abundant subalpine fir will increase the canopy bulk density and lower canopy base height of untreated stands. These crown conditions allow for torching at lower wind speeds and increase active crown fire potential during extreme weather. As a result, passive crown fires (i.e., fires that ignite individual tree crowns but do not spread between canopies) are expected to occur in untreated stands under average weather conditions (i.e., 50th percentile weather); in contrast, under similar weather conditions, surface fires are expected in harvested areas (fig. 3).

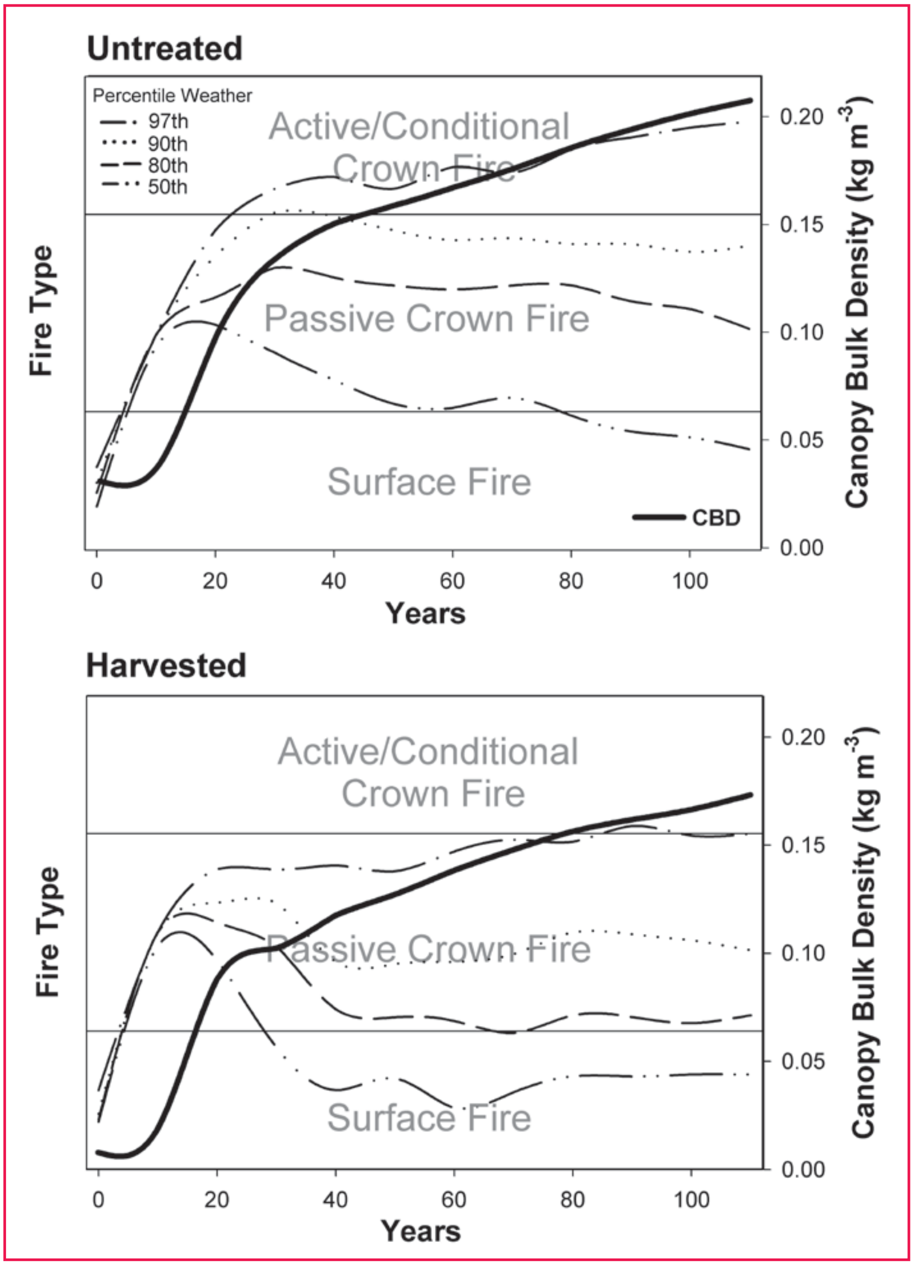

Figure 3.—*Potential fire behavior and canopy bulk density based on inventory of untreated (n = 24) and harvested beetle-killed stands (n = 24). Fire behavior was predicted from measured observations of tree regeneration, stand structure conditions, fuel loads, site productivity, and historic weather data (Reinhardt and Crookston, 2003, WRCC 2011). The canopy bulk density of preinfestation lodgepole pine dominated-forests averages 0.15 kg m*$^{-3}$ *(Klutsch et al. 2011).*

Implications

Our findings suggest that salvage logging in beetle-killed, gray-stage, lodgepole pine stands will dampen the behavior and severity of potential future wildfires. Harvesting favored establishment of lodgepole pine seedlings and aspen sprouts (figs. 1 and 3) and decreased the dominance of subalpine fir in recovering stands (lowering crown bulk density 25 percent). These differences in species composition and stand structure translate to lower risk of active crown fire and higher post-fire survival rates as treated stands mature. Harvesting also reduced coarse fuel loads by greater than 50 percent compared with untreated stands. In the event of a post-infestation wildfire, the removal of coarse fuels would reduce the duration and magnitude of soil heating associated with combustion of heavy fuels, which is known to damage plant root systems and soil biota, to increase soil losses, and to delay post-fire ecosystem recovery (Monsanto and Agee 2008, Moody and Martin 2001).

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