Silvicultural Tools Applicable in Forests Burned by a Mixed Severity Fire Regime

Russell T. Graham
Theresa B. Jain
USDA Forest Service
Rocky Mountain Research Station
Moscow, ID, USA

ABSTRACT

The silvicultural tools applicable for use in forests burned by mixed severity fire regimes are as highly variable as the structures and compositions the fires have historically created. Singly or in combination chunking, chipping, slashing, and piling can alter the character of surface fuels (e.g., small trees, shrubs, branches, and stems). These treatments can be combined with fire to reduce continuity and the amount of ground fuels (e.g., needles, litter, and rotten wood). Ground fuels, especially uncharacteristically deep layers at the base of trees, can be reduced by mechanically mixing or burning when conditions favor the retention of nutrients and/or fine roots that can occur in these layers. The continuity and amount of ladder fuels (e.g., shrubs and small trees) can be modified using fire or mechanical means either singly or in combination. To reduce the bulk density and continuity of canopy fuels, mechanical methods can most readily be used but prescribed fire is an option in some settings. Surface fuels and crown base height appear to have a large impact on the initiation and continuance of crown fires. Prescribed fire and/or mechanical methods can be used to simultaneously treat these forest attributes. Even though there are a large number of silvicultural tools that can be used in the forests historically burned by mixed fire regimes, their application is predicated on the management objectives of the forest owner and the short- and long-term desired forest conditions that fulfill these objectives.

SILVICULTURE

Silviculture is the art and science of controlling the establishment, growth, composition, health, and quality of forests to meet the diverse needs and values of landowners and society on a sustainable basis (Helms. 1998). Forest management objectives based on these needs and values historically and presently include: the production of high quality timber products, enhancing old-forest structures, the production of clean water, the production of wildlife habitat, and all possible combinations of these (Graham and Jain. 2004). Currently, especially in the western United States as exemplified by the passing of the Forest Health and Restoration Act, developing and maintaining fire resistant and/or resilient forests is a major management focus. This objective is emphasized especially in the wildland urban interface to protect societal values, property, and lives (USDA. 2004). The stand structure and composition, the arrangement of multiple stands within landscapes, and the short- and long-term objectives of the landowner or administrator will dictate the type and manner in which silvicultural treatments are applied (Smith et al. 1997). Silviculture systems describe treatments and their application over time in conjunction with the expected forest development in addition to the natural disturbances that may occur within the time frame. An integral part of silvicultural systems (documented in silvicultural prescriptions) is to convey risks and uncertainty associated with forest management (Nyland. 1996, Smith et al. 1997). Therefore, a silvicultural system incorporates a series of treatments through time within the context of a forest's disturbance regime, vegetation dynamics, and ecology. Circumstances caused not only by mixed fire regimes but also the values and needs of society using these forests, creates a need for a multitude of applicable treatments and treatment options.

FORESTS BURNED BY MIXED FIRES

In the Inland Northwestern United States, the mixed fire regime historically burned over portions of the moist, (e.g., western hemlock, *Tsuga heterophylla*; grand fir, *Abies grandis*; western redcedar, *Thuja plicata*), cold (e.g., subalpine fir, *Abies lasiocarpa*; Engelmann spruce, *Picea engelmannii*), and dry forests (e.g., Douglas fir, *Pseudotsuga menziesii*; ponderosa pine, *Pinus ponderosa*) (Hann et al. 1997). A variety of forest successional stages in a mosaic over landscapes was created and maintained by the interaction among fire, other disturbances (insect, disease), and the vegetation. The canopy openings created by mixed fires (combination of surface and crown fires) ranged from small (< ¼ acre) canopy gaps to relatively large (> 40 acres). These fires not only burned the foliage and killed standing trees, they also burned both standing and dead materials and organic material on the forest floor, which in turn heated the mineral soil often modifying its biological, physical, and chemical properties (Hungerford et al. 1991, Graham et al. 2004).

In the cold forests, lodge pole pine (*Pinus contorta*) is the most common early seral tree species, in the moist forests, western larch (*Larix occidentalis*) Douglas-fir, and western white pine (*Pinus monticola*) dominate the early seral tree species and ponderosa pine dominates the early seral stages in the dry forests (Lotan and Perry 1983, Graham, 1990, Foiles et al. 1990, Daubenmire and Daubenmire 1968). Late seral species of the cold forests include subalpine fir and Engelmann spruce; late seral species in the moist forests include western hemlock, grand fir (*Abies grandis*), and western red cedar, and the late seral species in the dry forests include Douglas-fir and in many settings white fir (*Abies concolor*) and grand fir. In general, fires initiate and facilitate forest succession; they burn organic materials on the forest floor and kill vegetation creating opportunities for vegetation to regenerate, allowing one plant to obtain a competitive advantage over another, and/or allowing plants to grow freely (Jain et al. 2004). Historically, fire created gaps (< 25% canopy opening) favoring the regeneration and development of late seral species (western hemlock, grand fir, Douglas-fir) in most forest settings (Smith et al. 1997). Moderate sized openings (25 to 45% canopy opening) favored mid seral species (western white pine). However, frequent low intensity surface fires that cleaned the forest floor and/or thinned ground level vegetation (e.g., shrubs and trees) tended to perpetuate fire tolerant early seral species such as western larch, Douglas-fir, and ponderosa pine (Agee 1993, Arno 1998). Lethal stand replacing fires created conditions favoring the regeneration of all trees, but early- to mid-seral species, such as western larch, lodgepole pine, and western white pine, were favored by these fires (Smith et al. 1997). Because of the wide range of canopy openings and surface conditions created by a mixed fire regime, silvicultural treatments developed to emulate these disturbances can create highly variable structures and compositions. In addition, the complexity of how disturbances interact with vegetation in these forests show that treatments need to involve all components of the forest ranging from the soil and forest floor to the upper levels of the forest canopy (Harvey et al. 1989, Graham 1994, Graham et al. 1999). In general, because forest dynamics can occur at relatively short (minutes to hours) to long (hundreds of years) intervals and because trees are relatively long-lived, an understanding of treatments over time is recommended especially when forest management objectives may change.

FOREST COMPONENTS

Generally, silvicultural treatments are associated with trees and tree treatments are the most obvious. However, treating or at least understanding the effect treatments have on all forest components, over time and space is essential for successful forest management. The amount of organic material occurring on the forest floor depends on the forest composition, its setting, weather, fire return interval, and other disturbances (insects, diseases, fire, harvesting). These organic materials occur in various stages of decay ranging from newly fallen trees (e.g., boles, limbs, leaves), shrub, forb, and grass materials to advanced decay stages in which plant parts are not distinguishable. These materials can be a critical source of soil organic matter and be important sources of soil chemical (nutrients) and biological (ectomycorrhizae) activities (Harvey et al. 1987). Typically in the moist forests, large amounts of brown cubical rotten wood can occur both on the soil surface and buried in the mineral soil. In the dry forests, in which fire has been excluded for long periods of time, uncharacteristically deep layers of organic material can accumulate. These layers can be relatively deep, especially around the base of large trees, and will be the location of fine root activity. Most often these layers are associated with ground fires that can transfer large amounts of heat to the soil and often facilitate the burning and destruction of buried woody material, volatilize nutrients, kill fine roots, and fuse soil particles (Graham et al. 2004) (Fig. 1).

Ground level vegetation includes shrubs, forbs, grasses, and small trees that contribute to surface fires and often provide ladder fuels that transition surface fires to the upper forest canopy level (Graham et al. 2004) (Fig. 2). Even in the dry forests, shrub and small tree regeneration can be abundant and recurrent creating dense and robust layers of vegetation covering the forest floor (Pearson 1950). In the moist and cold forests tolerant tree and shrub regeneration is common even in forests with continuous canopy cover (Cooper et al. 1991). How these ground vegetative layers develop into mid-canopy layers depends not only on disturbance but by how species differentiate as they develop based on their competitive and successional abilities (Oliver and Larson 1990). Even in even-aged single species forests, stem differentiation can occur as stands self-thin because of inter-tree competition often in association with disturbances such as fires, diseases, and insects. Most often these mid-canopy layers constitute the majority of the ladder fuels (Sandberg et al. 2001) (Fig. 1).

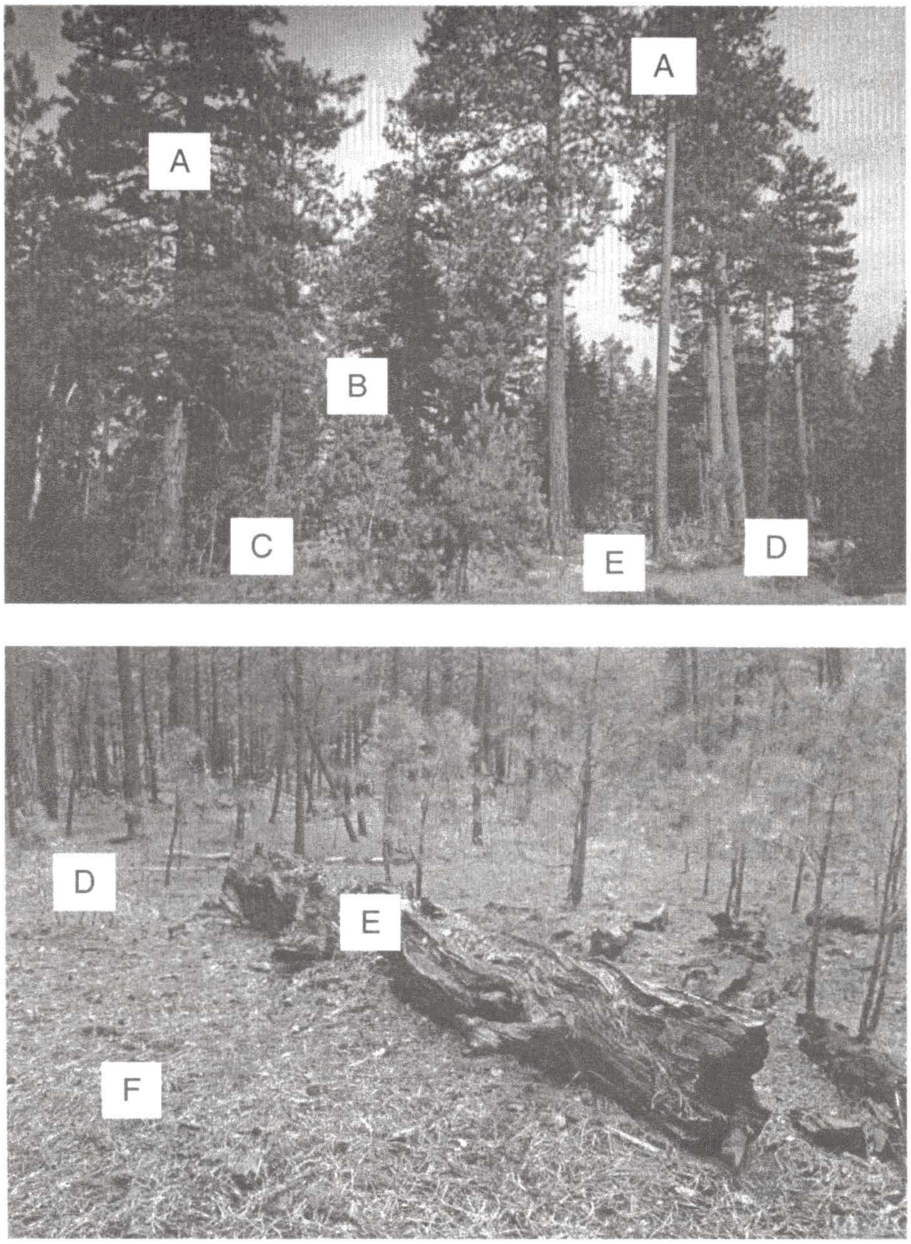

Figure 1. Fuel bed strata have different implications for combustion environment, fire propagation and spread, and fire effects. The canopy (A), ladder fuels (B), and shrub layers (C) contribute to crown fires. Low vegetation (D), woody fuel (E), and ground fuel (F) contribute to surface fires. Woody fuel (E) and ground fuels (F) are most often associated with smoldering fires and residual combustion that can transfer large amounts of heat deep into the soil.

Figure 2. With sufficient fuels and flame lengths (fire intensity), surface fires can ignite ladder fuels and tree crowns (K. Watenmaker photo).

The upper canopy is composed of leaves, branches and boles of trees (Fig. 1) Again, depending on the forest and its setting and inherent disturbances, these layers may be simple and uniform such as those that occur in young (30 to 50 years) to mid-aged (80 to 120 years) early seral species such as lodgepole pine and western larch. In contrast, dense and highly complex upper canopy layers often occur in late seral moist forests in which over five conifer species may occur (Haig et al. 1941). Therefore, silvicultural treatments applicable to forests historically burned by mixed fires should address forest components from the soil to the upper forest canopy. The treatment of one forest component will affect the other forest components and subsequently influence how the forest develops and how fire and other disturbances influence its development (Smith et al. 1997, Harvey et al. 1988).

SILVICULTURAL TREATMENTS

There are several forest components where silviculture treatments can be applied to favor the regeneration and development of different types of vegetation. These include soil disturbance opening size, location of treatments, and the state of the vegetation prior to treatment application. Tree species (up to 10) occurring in forests burned by mixed fire regimes germinate very readily on burned over surfaces, second only to bare mineral soil (Haig et al. 1941). Vegetation, primarily trees, can simultaneously germinate in small gaps created by both natural and artificial disturbances. However, once regeneration occurs and the site is occupied, it is unlikely further tree establishment will occur until another disturbance provides regeneration opportunities (removes established trees) (Jain et al. 2004). In very small gaps (14 to 25% canopy opening) late-seral species are favored and they will respond to future silvicultural treatments and/or disturbances. Therefore, it is important to understand the type, presence, and/or absence of vegetation within stands prior to creating or increasing the size of openings.

CANOPY TREATMENTS

Canopy treatments that change the architecture and composition of the upper forest canopy not only alter the forest as a fuel but also redistribute the forest growth to fewer stems and/or provide opportunities for forest regeneration (Smith et al. 1997). Selection (individual and group) silvicultural systems that maintain high forest cover create small canopy gaps that tend to favor the regeneration of mid to late seral species, for example, Douglas and grand fir in the dry forests, western hemlock, western red cedar, and grand fir in the moist forests and subalpine fir in the cold forests (Graham. 1990, Graham et al. 1999b). These systems remove small amounts of high forest canopy at relatively frequent (10 to 30 year) intervals and facilitate tree regeneration. Larger openings (e.g., ¼ to 2 acre) that often occurred in forests burned by mixed fire regimes can be emulated by group selection systems that create small patches (< 2 acres) of even-aged trees. In general, these systems do not change the canopy structure appreciably to diminish the threat of crown fires except in portions of the dry forests in which ponderosa pine could be spaced as to reduce the canopy bulk density to a level at which crown fires could not be sustained (Graham et al. 1999a). Thinnings are treatments applied in young to mid-aged stands, and, they too modify canopy structure and composition but are not designed to regenerate new tree cohorts. Both selection systems and thinnings can be applied to create and maintain a groupy and patchy character of the forest, if desired, and they do not necessarily need to create the evenly spaced uniform structure that is often associated with these treatments. However, in many moist and cold forests any canopy modification facilitates tree and shrub regeneration (Lotan and Perry. 1983, Jain et al. 2004), which will add to the ladder fuels occurring in a forest. These treatments tend to emulate the disturbances often associated with surface fires occurring at 20 to 30 year intervals.

Canopy openings greater than two acres are most readily created using even-aged systems that are designed to regenerate a cohort of trees of similar ages (Graham et al. 1999a). Clearcutting, shelterwoods, and seed-tree methods exemplify these even-aged systems. Clearcuts remove all of the high forest cover in a stand sometimes creating conditions reminiscent of stand replacing fires. However, depending on how much of the original stand remains after treatment, the conditions after clearcutting may be far different compared to the conditions remaining after a wildfire. Seed-tree and shelterwood systems that reserve some high forest structure may resemble the conditions left after a moderate to severe fire in which some trees survived. Most often trees with thick bark and with high crown base heights were the survivors after these wildfires. Again, with ingenuity and forethought, large canopy openings can be created that tend to favor early seral species such as western white pine, western larch, and lodgepole pine and still leave some residual forest structure reminiscent of many wild fires. Characteristics such as square cutting blocks, uniform spacing of trees and the alike can be avoided. These even-aged methods can be combined with uneven-aged systems and intermediate treatments (thinnings) to create and maintain highly diverse forest structures, compositions, and landscapes (Reynolds et al. 1992). Traditionally, high forest canopy treatments did not consider dead trees and decadence as part of these systems but they also can be manipulated and maintained using these even-aged methods. By incorporating methods into silvicultural systems planned over time, a great number and complexity of forest structures can be initiated, developed, and maintained.

Canopy Treatment Implementation--Weather and fire historically modified the canopy structure of forests burned by mixed severity fires. In general, mechanical treatments using machinery from chainsaws to whole tree harvesters can be used to manipulate forest canopies (Graham et al. 2004) (Fig. 3). However, in the application of the treatments, what's left after treatment is usually of most importance for meeting management objectives of most landowners. Mechanically applying these treatments allows good control of selecting which trees are to be left or removed during the operations. Structures from patchy, clumpy, to evenly spaced trees can be left at various densities and compositions depending on the management objectives. These variable structures and compositions can range from single species to multiple species depending on the forest and the conditions presented. Decadence and dead trees can be readily incorporated into the systems.

Figure 3. Machines can be used to chunk and chip forest residue reducing the fire hazard.

How much of the vegetation that is removed from a site impacts the forest floor components and can affect the nutrient capital of a site (Harvey et al. 1999). In general, leaves, needles, and fine branches are the most nutrient rich and the amount of these components removed from a site can affect site productivity. Whole tree harvesting, which includes the stem and the small branches, removes the greatest amount of nutrients and biomass from a site. However, by limbing the tree in place and only removing the bole, removes the smallest amount of nutrients. Depending on how the foliage and fine materials left on the site are subsequently treated, the nutrients in the foliage can still be lost (Graham et al. 2000, Harvey et al. 2000).

MID-STORY TREATMENTS

Thinning is the most common treatment that influences the mid-story component of forests (Smith et al. 1997, Graham et al. 1999). As with overstory treatments, these treatments can create a variety of forest compositions and structures depending on the forest and its developmental history. Usually compositions and structures inherent to the moist forests provide the greatest latitude for modifying forest structure and composition; using thinnings while even-aged lodgepole stands frequently occurring in the cold forests offers the least flexibility. Thinnings, more than over story treatments, can redirect forest development to selected trees changing their bole and canopy characteristics. Large changes in species composition are not usually addressed with thinnings since the species compostion of stands is largely determined before a thinning would be applied. However, in some situations a thinning from below might remove predominantly one species (e.g., grand fir below ponderosa pine) to address mid-story canopy layers (ladder fuels). Thinnings do not have to be regularly applied even though they have been so traditionally for producing timber crops. With resourcefulness, a multitude of stand characteristics can be created with thinnings, however, they are predicated on the establishment and development history of the stand. Even though thinnings are not designed to offer opportunities for regeneration, most often in the moist forests and to a limited extent in the cold forests, regeneration of tolerant trees is common (Haig et al. 1941, Smith et al. 1997). Grand fir, western hemlock, and western red cedar readily regenerate in small openings in the moist forests and subalpine fir readily regenerates in the cold forests.

Mid-story Treatment Implementation--Mid-story treatments can be accomplished by mechanically removing stems similar to canopy treatments (Graham et al. 2004). In many settings, thinnings occur in material with commercial value so that these materials can be removed from the stand. However, in some circumstances, thinnings can occur in which the material is cut and disposed of on site with further treatments or masticated in place (Fig. 4). Because an intact stand remains after a thinning, the removal of organic material and nutrients from a site is less of an issue but its conservation still needs to be incorporated into the treatment.

GROUND LEVEL VEGETATION TREATMENTS

Depending on the disturbance history and subsequent stand development, ground level vegetation, which includes trees, shrubs, grasses, and forbs in forests burned by mixed fires, can range from quite scarce to extremely rich and complex (Daubenmire and Daubenmire. 1968, Cooper et al. 1991). Even in the driest forests, such as those containing ponderosa pine and Douglas-fir mixes, small trees, and shrub layers can be quite extensive. Additionally, ponderosa pine, in many settings, readily regenerates creating dense layers of small trees (Pearson 1950). Ponderosa pine, because of its thick bark, can become relatively resistant to mortality as a result from surface fires even at a young age and/or small size ($\approx$ 2 inches) (Ryan and Reinhardt. 1988). In the moist and cold forests, high shrub layers composed of species such as maple, ninebark, or ceanothus frequently occur even under relatively dense overstory canopies. These forest components often intermix with a variety of mid-story tree components creating continuous fuels from the surface into the tree canopies. These conditions facilitate the spread of fires from the surface into the tree canopies (Figs.1, 2).

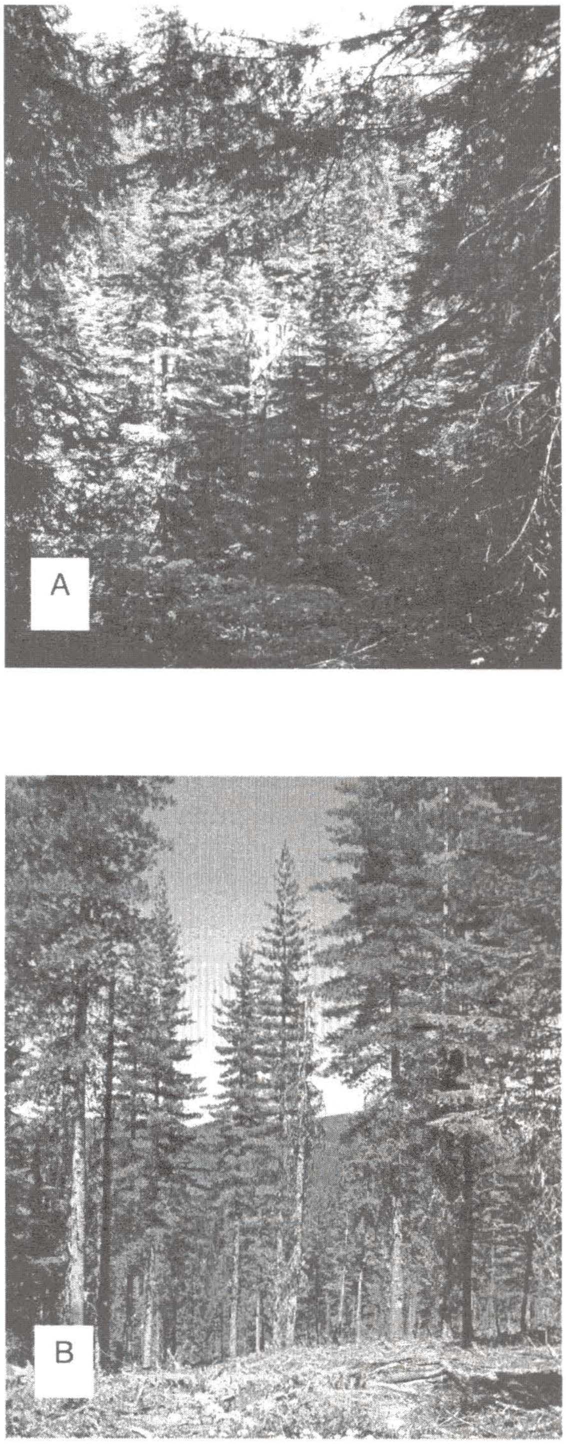

Figure 4. Mechanical treatments can dramatically modify the fuel structure and composition in the moist forests. (A) Young western white pine stand before treatment containing large amounts of ladder fuels. (B) Large amounts of western hemlock were mechanically removed.

Ground Level Treatment Implementation--In general, cleanings and weedings (precommercial thinning) can be used to treat ground level forest structures (Graham et al. 1999). During the sapling period in the life of a forest, the greatest latitude in species composition and spatial arrangement can be achieved (Graham 1988). For example, in the moist forest multi-species and multi-tree spacing can be used during precommercial thinning to create heterogeneous stands and forests. Even in single species stands, such as those commonly occurring with western larch, lodge pole pine or ponderosa pine, variable spacing can be used to create heterogeneous structure. These treatments can most readily be achieved using mechanical means but herbicides are often very successful in reducing the amount of ground level vegetation and fire can be used as well. However, these two latter methods are much less precise in achieving the desired conditions. Herbicides are very effective in reducing the shrub component in forest stands. In addition, in some settings, tractors fitted with special blades have been successful at mechanically treating ground level vegetation. Also, machines with rotating heads can crunch trees leaving large chunks on the forest floor (Figs. 3, 4).

FOREST FLOOR TREATMENTS

Forest floors consist of coarse (three inches and greater in diameter) woody debris, fine woody fuels (less than three inches in diameter), needle and leaf litter, and other organic components all in various forms of decay (Harvey et al 1987) (Fig. 1). As woody material decays, it transforms from solid to rotten wood and, depending on the forest, these materials can take the form of brown cubical rotten wood or white rots (Fig. 1 E). This material is often a site of nitrogen fixation and the site for plant germination and ectomycorrhizal habitat. When it becomes buried in the mineral soil it can become an active part of the soil, and in some moist forests, rotten wood may occupy up to 40 % of the top 12 inches of the soil. Brown rotten wood is much longer lived than white rotten wood and often is a critical soil resource (Harvey et al 1987). The function of these components ranges from seedbeds and nutrient sources to fuels that burn in ground fires. In addition to fuels, these components contribute organic materials to the mineral soil and can interfere with the germination and regeneration of both trees and shrubs. Treatments can reduce these components, alter them, or remove them from the site.

Forest Floor Treatment Implementation--These forest floor components are readily manipulated using both fire and mechanical means (Figs. 2, 3). Woody debris historically has been treated to decrease fire hazard and prepare sites for tree regeneration. Starting in the early 1900s, fuel was piled and burned, left in place, and frequently broadcast burned to prepare sites (Haig et al. 1941). There is evidence that coarse woody debris is important for providing nutrient sites and for providing organic matter to the mineral soil (Fig. 1 E). The amounts of coarse woody debris recommended for maintaining site productivity range from 3 tons per acre in the dry forests to 32 tons per acre in the moist forests (Graham et al. 1994). These recommended amounts and the conservation of organic surface layers (e.g., humus, rotten wood) can be most facilitated using grapple piling and properly applied prescribed fire. Depending on the forest, the fire prescriptions that remove the fine fuels most often associated with hazard fuels can be most readily achieved when lower duff layer moisture contents are greater than 100% (Reinhardt et al. 1994). Under these conditions, duff layers can be reduced but not necessarily removed. Tractor piling and chipping of material can both tie up nutrients and insulate the forest floor and cause detrimental soil impacts.

SILVICULTURAL SYSTEMS

Silvicultural treatments available for use within forests burned by mixed fire regimes are highly variable. They need to be integrated into silvicultural systems that display treatments over time, disclose their risks and uncertainty, and produce the expected forest development in response to these treatments. There is a rich heritage of silvicultural treatment documentation available that can be used in forests burned by mixed fires. However, the applications of silvicultural treatments are predicated on the objectives or the desires of the land owners which is the overriding concept in the application of silvicultural practices in the forests burned by mixed fires.

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Authors:

Russell T. Graham
Research Forester
USDA Forest Service
Rocky Mountain Research Station
Moscow, ID 83843
rtgraham@fs.fed.us

Theresa B. Jain
Research Forester
USDA Forest Service
Rocky Mountain Research Station
Moscow, ID 83843
tjain@fs.fed.us