FUEL: LOGS, STICKS, NEEDLES, DUFF, AND MUCH MORE

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ABSTRACT

Fuels burned by either prescribed or wildfires are complex and important components of forested ecosystems. Fine fuels consisting of fallen limbs, twigs, and leaves of shrubs and trees are rich in nutrients. If these fuels are not immediately burned, nutrients can leach from these materials into the forest floor, especially if they overwinter. Larger fuels consisting of standing dead trees, large limbs, and down logs or coarse woody debris (CWD) play critical roles in fixing and storing nitrogen (N), protecting the soil surface, and suppling organic matter to the forest floor. Up to 40% of the top 30 cm of a forest soil can be composed of rotten CWD buried (soil wood) in the mineral soil. In addition the litter layer (duff) composed of rotten wood, leaves, twigs, needles, cones, and other fine fuels decompose to form the humus layer. These surface layers coupled with soil wood store and release nutrients, are sites for nitrogen fixation, and provide habitat for ectomycorrhizae. Depending on the ecosystem, amounts of CWD desired for maintaining soil productivity range from 15 Mg ha^{-1} (7 tons ac^{-1}) in ponderosa pine forests of northern Arizona to 74 Mg ha^{-1} (33 tons ac^{-1}) in western hemlock forests of northern Idaho. Fires occurring when the lower organic layers are moist ensures preservation of much of the microbiological and nutrient properties of these organic components. These organic components are critical for sustaining forested ecosystems and how they are burned can have both short- and long-term impacts on forest productivity. Therefore both mechanical and fire fuel treatments used to meet reforestation and hazard reduction objectives should conserve these materials.

Key words: Forest soils, nutrition, productivity, coarse woody debris, wildfire, prescribed fire

FIRES

Fires are an integral component of most forest ecosystems. Both wild and prescribed fires burn much of the western landscape every year producing a variety of effects which can have both negative and positive effects on forest ecosystems (Agee 1993, Debano et al. 1998). For example, in climax ponderosa pine (*Pinus ponderosa*) forests many of these fires burn with low intensity and severity, cleaning the forest floor and regenerating forest vegetation. These surface fires burn dead branches, twigs, needles, cones, and leaves on the forest floor. In contrast, other wildfires burn live crowns and tree boles with high intensity and severity, killing large expanses of vegetation often destroying property and lives (Mutch 1994). These differential fire effects are often attributed to successful fire exclusion that allowed large amounts of fuels to accumulate (Covington and Moore 1994). Moreover, because of these large fuel loads and burning conditions, both prescribed and wildfires can cause unexpected damage to vegetation and soils (Auclair and Bedford 1994, Covington et al. 1997). Even low intensity fires burning deep duff at the base of trees can damage root systems or cambial tissues and subsequently kill standing trees. Prescribed fires burning when lower duff and upper mineral soils are dry can cause hydrophobic soils, volatilize nutrients, and increase soil erosion (Hungerford et al. 1991, Dimitrakopoulus and Martin 1994).

FUELS

Ground Level Vegetation

The amount and kind of ground level vegetation varies widely depending on the forest setting as does their contribution to the fuel matrix. Routinely prescribed fires are designed to destroy or inhibit shrubs, forbs, and grasses so desired conifers can be regenerated and maintained. These species range from the high shrubs like alder (*Alnus* spp.), to tough tree competitors such as pine grass (*Calamagrostis rubescens*) and elk sedge (*Carex geyeri*). Each of these and similar plants have different tolerances to growing in closed conditions and also have different strategies for responding to disturbance (Stickney 1990). For example, when a fire burns through a forest containing alder the species will not readily colonize the freshly burned site but will likely sprout from the root collar. In contrast, ceanothus (*Ceanothus* spp.) does not readily survive fires but aggressively colonizes an area after it is burned. The responses ground level plants have to fires can be used to design and execute prescribed fires to increase or decrease the amount of plants depending on the management objectives (Table 1).

Species	Tolerance	Reproduction strategy	
		Survivor	Colonizer
Alder	Mod.	Root crown	No
Pinegrass	Mod.	Roots	No
Elk sedge	Mod.	Roots	Yes
Ceanothus	Inter.	Poor	Yes
Menziesia	Toler.	Root crown	Yes
Ninebark	Toler.	Root crown	No
Beargrass	Toler.	Roots	No
Maple	Mod.	Root crown	No

Table 1. Examples of ground-level vegetation and their tolerance for growing in closed conditions and strategies for reproducing and surviving fires (Stickney 1990).

Not only does ground level vegetation have different strategies for surviving fires the role these species play in nutrient cycles is key in many forest ecosystems. Vegetation that quickly occupies a site after a fire, provides protection to the soil, decreases erosion, and captures nutrients. In addition to capturing nutrients many species fix nitrogen (N). This process is important since most forest stands and soils of the Rocky Mountains tend to be N limited and sources for N can limit productivity (Harvey et al. 1987b). Nitrogen fixation is the process of either plants (symbiotic) or free living bacteria (nonsymbiotic) converting atmospheric N to a form plants can use (Jurgensen et al. 1992). Depending on the plant and its coverage less than 1 kg ha^{-1} yr^{-1} (0.9 lbs) can be added to a site covered by lupine (*Lupinus* spp.) but a dense stand of ceanothus and alder can fix over 100 kg ha^{-1} yr^{-1} (89 lbs) of N (Jurgensen et al. 1991). Ground level vegetation not only adds nutrients, but also are important in maintaining nutrient cycles. Shrubs in general have a high ratio of leaf to stem material and a high proportion of their biomass and nutrients are replaced annually (Chapin 1983, Tappenier and Alm 1975). Even though ground level vegetation may be a minor component of some forested ecosystems its litter can contain the majority of some nutrients (potassium) that occur on site (Yarie 1980).

Fine Fuels

Nutrient cycling and nutrient conservation are not only important for forest growth, but there is evidence that nutrition and especially potassium (K) plays an important role in insect and disease relations in western forests (Moore 1994). It appears that mortality from both bark beetles and root diseases is less for trees with higher levels of foliar K compared to trees with lower levels. In contrast to N which is acquired from the atmosphere through fixation, K becomes available to plants only through the weathering of rocks, a long process. Depending on the forest and tree species, in general the greatest proportion of K is stored in the limbs and leaves of most trees with the bole storing minimal amounts (Kramer and Kozlowski 1979). In general the majority of the K in the branches and foliage leaches from these materials if they overwinter on the forest floor (Moore 1994). Therefore, prescribed burning, piling slash after it overwinters, and leaving tree tops when whole tree harvesting are some techniques that can be used to conserve K.

Coarse Woody Debris

Large fuels (material larger than 7.5 cm (3 in) in diameter) consisting of standing dead trees, large limbs, and down logs or coarse woody debris (CWD) range in decay states from new (recent dead logs) to advanced (primarily brown cubical rot). Coarse woody debris play critical roles in fixing and storing nitrogen, protecting the soil surface, and suppling organic matter to the forest floor (Jurgensen et al. 1997). After timber harvesting, prescribed fire, or other stand replacing events CWD should be left to maintain soil productivity. In northern Idaho in the western hemlock habitat type a maximum of 74 Mg ha^{-1} (33 tons) of CWD is recommended to maintain soil productivity and in the white fir (*Abies concolor*) habitat types of Arizona and New Mexico a maximum of 35 Mg ha^{-1} (16 tons) is recommended (Figure 1).

These amounts only include material larger than 7.5 cm (3 in) and do not include stumps. Large boles or stems decay slower than smaller materials, are not usually considered hazard fuel, and they tend to persist longer than smaller materials in frequent fire regimes.

Forest Floor (Duff)

Relatively diminutive components such as microorganisms, often play a key role in the functioning of an entire system (Yarie 1980). The role of the organic components in forest soils is one such example. The

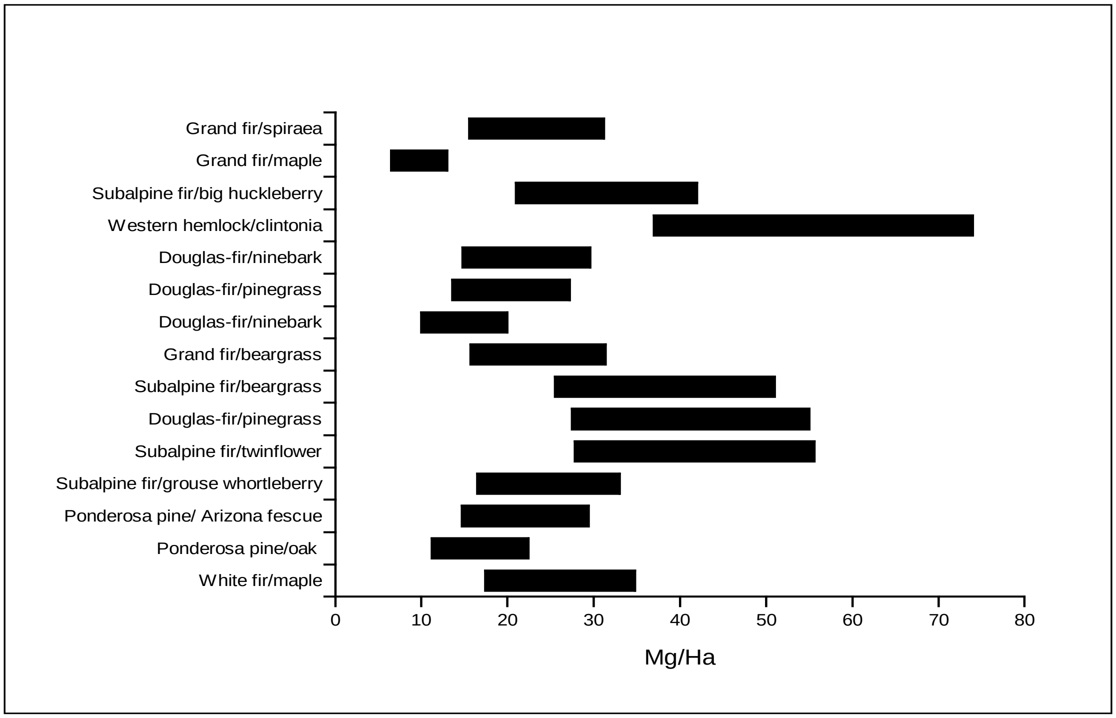

Figure 1. Coarse woody debris recommendations for maintaining forest soil productivity for Rocky Mountain habitat types. See Graham et al. 1994 for details.

surface (duff) of forest soils is usually covered by litter consisting of freshly fallen leaves, needles, twigs, brown cubical rotten wood, and other debris. As these layers decay they form a fermentation layer where individual plant parts start losing their identity. When plant materials become unrecognizable, a dark layer of humus is formed. Depending on the forest type and the time since disturbance these surface layers can be shallow (< 2.5 cm, 1 in) which often occurs in frequently burned ponderosa pine forests or can be deep (> 30 cm, 12 in) which often occurs in undisturbed western redcedar (*Thuja plicata*)/western hemlock (*Tsuga heterophylla*) forests. In addition to these distinguishable layers on the surface, forest soils also contain buried rotten wood or what we call "soil wood." This material is similar to the brown cubical rotten wood found in litter but is surrounded by mineral soil. In some forest types soil wood can exceed 40% of the top 30 cm of forest soil. This material forms when CWD is incorporated into mineral soil through soil freezing and thawing or buried as soil creeps. Also, decomposed tree roots can produce large amounts of soil wood (Harvey et al. 1987b, Graham et al. 1994) (Figure 2). The organic layers and buried soil wood play many critical roles physically, chemically, and microbiologically in the function of forest soils (Harvey et al. 1987b). Litter physically protects the soil from erosion and compaction, and forms a mulch that maintains soil moisture. Many nutrients including nitrogen (N), phosphorus (P), calcium (Ca), magnesium (Mg), and potassium (K) are stored in litter, and released when it decays or is burned. In some of the moist (western hemlock) forests these layers can also contain ectomycorrhizae. Ectomycorrhizae fungi have a symbiotic relationship with plants that aid in the uptake of water and certain nutrients and may offer protection against other soil borne organisms (Harvey et al.1976). In addition, because they have such a strong association with organic materials they are an excellent bio-

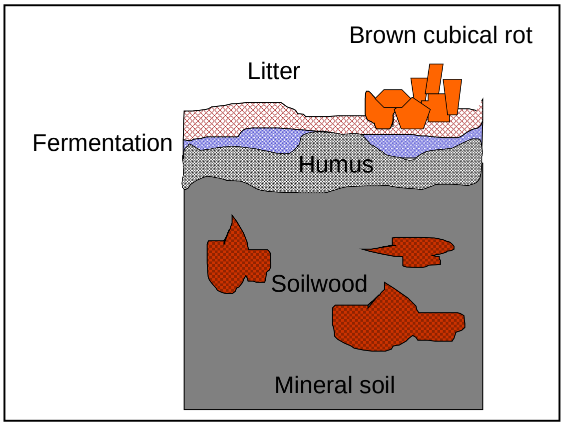

Figure 2. Forest soils include many organic components including soil wood, litter, and humus.

indicator of soil function (Harvey et al. 1981, Graham et al. 1994). The humus layer of a forest soil is a very active rooting zone where up to 15% of the nitrogen fixation occurs and up to 35% of the nitrogen is stored. In addition, up to 70% of the ectomycorrhizae occurring in the rooting zone can be located in the humus layer even though it may be very shallow (Harvey et al. 1981). Similar to litter, humus stores and releases nutrients and is excellent in holding moisture. Soil wood is also an important site for nitrogen fixation as well as nitrogen storage. Even in some of the driest ecosystems these materials are rich in moisture, nutrients (N, P, Ca, Mg, K), and ectomycorrhizae. Because of these conditions and the physical properties that soil wood possesses it is an active rooting medium (Harvey et al. 1987a, Harvey et al. 1996, Harvey et al. 1997).

The organic layers on the surface and soil wood contribute organic matter to the mineral soil making the mineral soil immediately beneath the surface organic layers an important rooting zone and a site for nutrients, moisture, and ectomycorrhizae (Graham et al. 1991). The amount of organic matter in the surface mineral soil is dependent on the organic components on and in the soil. Nearly all forest activities including recreation, grazing, timber harvesting, and natural and prescribed fires impact and change the character of the organic materials and the top mineral layer of forest soils.

FUEL TREATMENTS

Prescribed fire is ideal for managing the organic resource of Rocky Mountain forests. Burning fine fuels in place and not concentrating them by piling, ensures that nutrients remain dispersed across the forest floor. This is especially appropriate when a large portion of the K on a site is located in the limbs and foliage of trees and shrubs. Moreover when prescribed fires are conducted when the lower duff (fermentation and humus layers) moisture exceeds 100% much of these materials can be conserved. Fires burning under these conditions can release nutrients from the small material which subsequently condenses in the humus and upper mineral soil layers (Mroz et al. 1978). Fires consuming the fine fuels will appreciably reduce the hazard for wildfire and the remaining large material can slowly decompose adding to the organic component of the soils (Rheinhardt et al. 1991) because of readily available inoculum from airborne spores and mycelia in the forest soils, and the cracking and checking of CWD, charring does not appreciably interfere with decomposition or function of CWD. The greatest restriction to using prescribed fire to manage the organic resource in forests is the limitation placed on burning because of smoke production (Graham et al. 1994).

Soil wood can be consumed by both wild and prescribed fires but when moisture contents exceed 100% in these materials consumption is minimal. Moreover, when fires burn under these conditions the temperatures in the humus and upper mineral soils seldom reach temperatures that cause volatilization of nutrients or hydrophobic soils. In general N volatilizes about 300^{o} C, and potassium about 600^{o} C but water repellency begins to occur at 200^{o} C (Hungerford et al. 1991). If slash is piled, desired amounts of CWD should be distributed across the sites and preferably piling should occur after slash overwinters on the forest floor, allowing nutrients (especially K) to leach from the foliage. Slash can be piled by a variety of equipment but grapple (backhoe tractor) piling of slash appears to be the most effective in creating desired conditions with minimal disturbance to the surface organic layers and mineral soil. Dozers can be used to pile slash but they are more prone to compacting and displacing the soil surface layers and it is usually difficult so separate fine fuels from CWD.

Fire is a native process that burns western forests at different intervals and intensities (Arno 1980). Because fire has been successfully excluded from many forests in the West, the return of fire to these systems should be done fully understanding the effects fires might have on the plant, organic, and soil components. In ponderosa pine forests, litter from needles and bark slough often create deep organic layers. When burned these deep layers may not have long flame lengths but the heat they transfer to the forest floor and to the roots and cambium of standing trees may easily exceed the temperatures which cause tissue death. Tree death may not immediately occur but increases over time (Covington et al. 1997). Moreover, returned fires might create more shrub fields, reduced organic layers, and lesser total amounts of soil organic matter over the long-term.

SUMMARY

Leaving CWD after harvesting will not ameliorate poor harvesting or site preparation practices. Depending on the decomposition rates and fire return intervals it may take 100s of years before CWD is incorporated into the forest floor and mineral soil to become an active part of the soil system. Coarse woody debris left after forest treatments is not intended to replace the present forest floor it is for the development and function of the next forest.

Organic materials are important components of a functioning forest soil. Shrubs and their ability to cycle nutrients and organic matter are important contributors to maintaining a functioning systems. An indicator of a healthy productive forest is a soil rich in organic matter overlain by coarse woody debris. Soils exhibiting these qualities will support the development of ectomycorrhizae, nitrogen fixation, and carbon and nitrogen cycles, all critical processes. These conditions in turn would give rise to healthy forest vegetation, which would support populations of wildlife and produce timber and water. If a healthy productive forest soil exists it is difficult not to have a healthy productive above ground system and both prescribed and wildfire are important processes that maintain these systems.

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