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Managing Coarse Woody Debris in Forests of the Rocky Mountains

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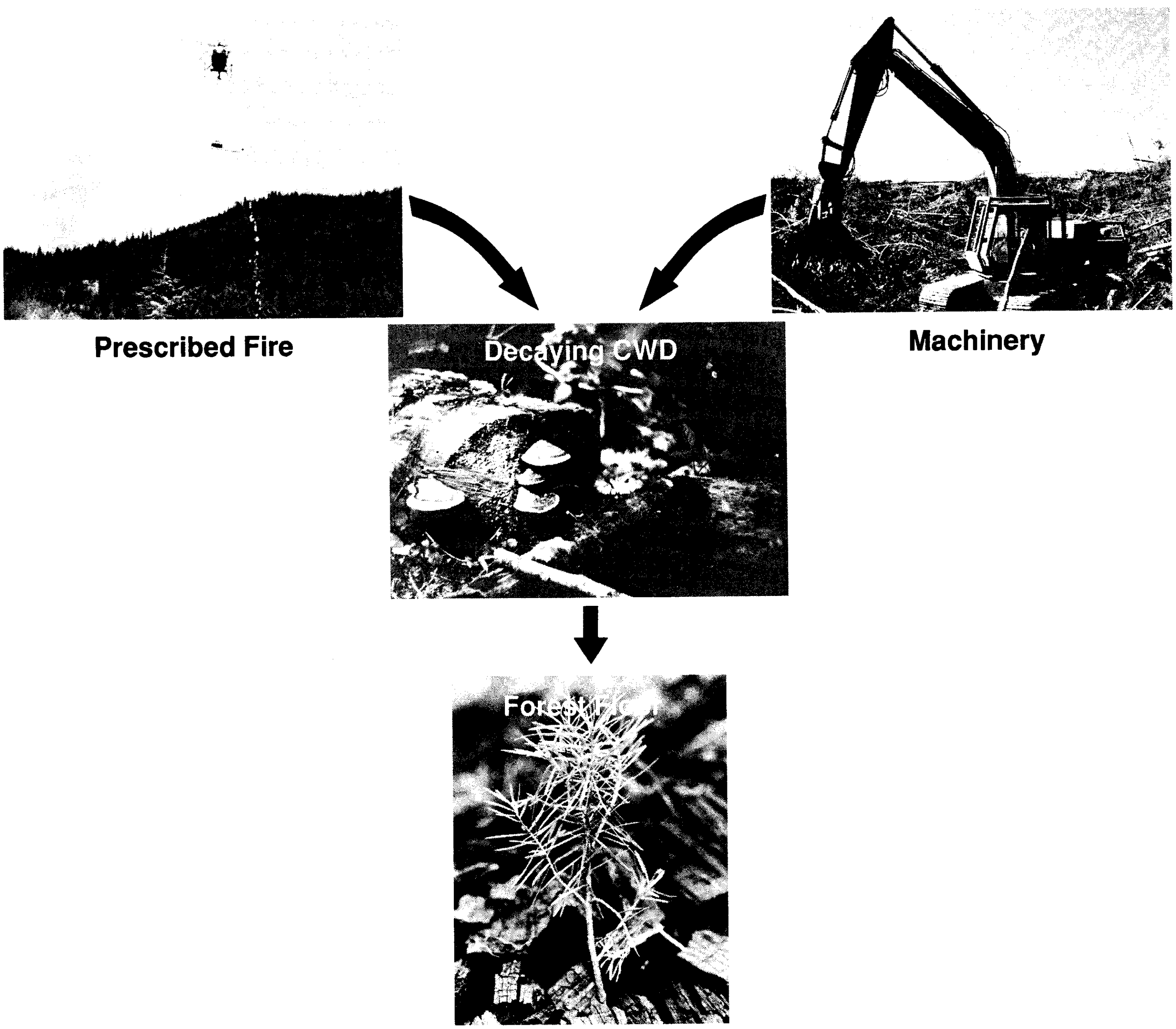

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Research Summary

Coarse woody debris is a major component of Rocky Mountain forests. Debris has many functions ranging from soil protection to wildlife and microbial habitat. The management of coarse woody debris is critical for maintaining functioning ecosystems in the Rocky Mountains. These forests have great diversity, with each forest habitat type developing and retaining different amounts of debris. Fourteen habitat types were examined, ranging from ponderosa pine (*Pinus ponderosa*) habitat types of Arizona to subalpine fir (*Abies lasiocarpa*) habitat types of western Montana. Coarse woody debris management recommendations were developed by using ectomycorrhizae as a bioindicator of healthy, productive forest soils. These recommendations are intentionally conservative to ensure that enough organic matter is available after timber harvest to maintain long-term forest productivity.

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Introduction

Coarse woody debris (CWD) is woody material derived from tree limbs, boles, and roots in various stages of decay. The decay stages of woody debris in the Northern Rocky Mountains have been categorized as: new residue—recently dead material with little or no decay; incipient residue—decay is beginning; and advanced residue—decay has consumed much of the material (Jurgensen and others 1984). These materials can occur in many sizes and shapes. Residue with minimum diameters from 2.5 cm (1 inch) to 15 cm (6 inches) are often termed CWD (Harmon and others 1986). For our purposes, and to make our research consistent with those of fire researchers and managers in the Rocky Mountain region, we are defining CWD as any woody residue larger than 7.5 cm (3 inches) in diameter.

Forested ecosystems evolve with a continual flux of CWD. The creation and accumulation of CWD depends on forest type, successional stage, insect and disease activity, weather events, fire-return intervals, decay rates, and timber management activities. In some forest ecosystems, CWD can persist for hundreds of years (500 years); in other ecosystems its life span is rather short (60 years) (Harmon and others 1986; Harvey and others 1987). In the more productive, moist ecosystems, such as those dominated by western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) and western redcedar (*Thuja plicata* Donn ex D. Don), fire frequencies are relatively long (greater that 200 years). Coarse woody debris has greater longevity in such ecosystems than in those dominated by ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) where fire frequencies are often less than 10 years. In the cedar/hemlock forests of the Northern Rocky Mountains an average of 66 Mg per ha (29.4 tons per acre) of CWD has accumulated. In the ponderosa pine forests an average of 23 Mg per ha (10.3 tons per acre) of CWD has accumulated (Brown and See 1981). During the last 100 years, the fire frequencies in all of the Rocky Mountain ecosystems have been greatly extended, potentially increasing CWD accumulations.

Coarse woody debris performs many physical, chemical, and biological functions in forest ecosystems. Physically, CWD protects the forest floor and mineral soil from erosion and mechanical disturbances (Page-Dumroese and others 1991) and it protects new seedlings from livestock damage (Graham and others 1992). It also is a key habitat component (especially large logs) for many forms of wildlife (Reynolds and others 1992) and is important in stream ecology (Harmon and others 1986). Coarse wood debris disrupts air flow and provides shade, insulating and protecting new forest growth. In moist forest types it can be a seedbed and nursery area for new conifer seedlings (Harmon and Franklin 1989; Minore 1972). When decay has advanced, CWD can hold large amounts of water, making it an important source of moisture for vegetation during dry periods (Harmon and others 1986; Harvey and others 1987).

Many nutrients especially sulfur, phosphorous, and nitrogen are released as CWD decays or is burned. Especially in the advanced stages of decay, CWD has high concentrations of nutrients (Larson and others 1982; Means and others 1992). In the absence of nitrogen-fixing plants, such as *Ceanothus* spp., CWD is a very important site for nonsymbiotic nitrogen fixation (Larson and others 1978). This form of nitrogen input can be very significant (Jurgensen and others 1991, 1992).

Organic materials, especially humus and buried residue in the advanced stage of decay, are excellent sites for the formation of ectomycorrhizal root tips (Harvey and others 1981). Even though these materials may make up only a small portion of a soil horizon they may contain the majority of ectomycorrhizae. Ectomycorrhizae help woody plants take up water and nutrients, and their fruiting bodies play important roles in the food chains of many small rodents and larger predators (Maser 1990; Maser and others 1986; Reynolds and others 1992).

Coarse woody debris can be incorporated into the surface soil horizon as freezing and thawing cycles move CWD into the soil. Additionally, CWD can be covered as soil moves downhill. Depending on the forest type, large amounts of CWD can be left in the form of decaying tree roots. All of these materials, in the advanced stages of decay, can be active parts of the soil system as soil wood.

Because CWD is an important component of a functioning ecosystem, a portion of this material must be maintained. As the demand for forest products and the ability to utilize more fiber increases, less material is being left after timber harvesting or after salvage operations. These operations, in combination with past practices of slash disposal and site preparation, have reduced organic material in the forest floor, making CWD management critical (Harvey and others 1987). Consequently, recommendations for maintaining CWD for different ecosystems and forest types are needed.

This study was undertaken to provide managers with initial recommendations for managing CWD to maintain long-term forest productivity in different forest types of the Rocky Mountains. Recommendations were developed on the amounts of CWD needed after timber harvesting for specific habitat types using data from undisturbed stands.

Methods

The habitat types for this study were selected in consultation with forest managers, soil scientists, and silviculturists of the Northern, Intermountain, and Southwestern Regions of the Forest Service, U.S. Department of Agriculture. The habitat types chosen represented a range of the environmental conditions normally encountered within each of the Regions (fig. 1). The habitat types were:

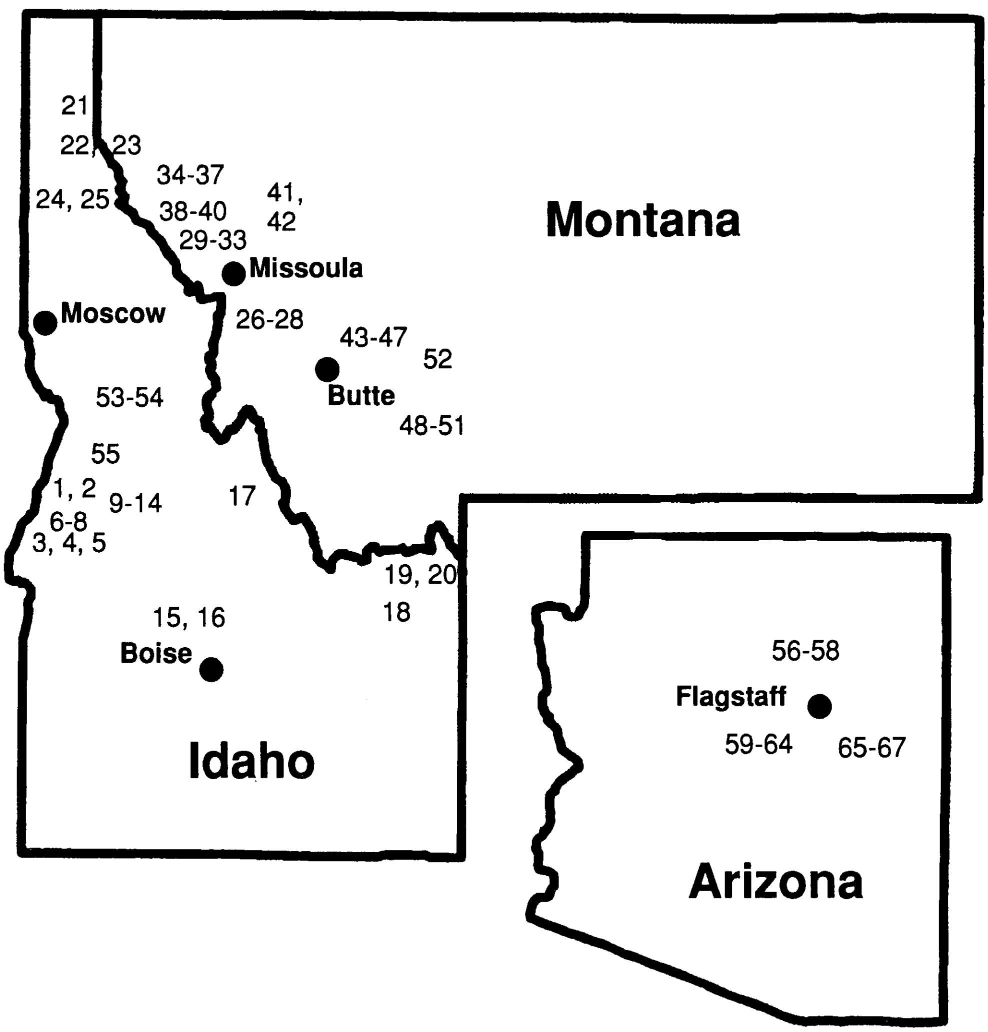


Figure 1—Location of stands sampled throughout western Montana, Idaho, and Arizona.

Central Idaho (Steele and others 1981)
Grand fir/snowberry (*Abies grandis* [Dougl. ex D. Don] Lindl./*Spiraea betulifolia* [Dougl.] Hitchc.), GF/SPBE
Grand fir/mountain maple (*Abies grandis* [Dougl. ex D. Don] Lindl./*Acer glabrum* Torr.), GF/ACGL
Subalpine fir/huckleberry (*Abies lasiocarpa* [Hook.] Nutt./*Vaccinium globulare* Rydb.), AF/VAGL
Douglas-fir/ninebark (*Pseudotsuga menziesii* [Mirb.] Franco./*Physocarpus malvaceus* [Greene] Kuntze), DF/PHMA
Douglas-fir/pinegrass (*Pseudotsuga menziesii* [Mirb.] Franco/*Calamagrostis rubescens* Buckl.), DF/CARU

Western Montana (Pfister and others 1977)
Douglas-fir/ninebark (*Pseudotsuga menziesii* [Mirb.] Franco/*Physocarpus malvaceus* [Greene] Kuntze), DF/PHMA
Grand fir/beargrass (*Abies grandis* [Dougl. ex D. Don] Lindl./*Xerophyllum tenax* [Pursh] Nutt.), GF/XETE
Subalpine fir/beargrass (*Abies lasiocarpa* (Hook.) Nutt./*Xerophyllum tenax* [Pursh] Nutt.), AF/XETE
Douglas-fir/pinegrass (*Pseudotsuga menziesii* [Mirb.] Franco/*Calamagrostis rubescens* Buckl.), DF/CARU
Subalpine fir/twinflower (*Abies lasiocarpa* [Hook.] Nutt./*Linnaea borealis* L.), AF/LIBO
Subalpine fir/whortleberry (*Abies lasiocarpa* [Hook.] Nutt./*Vaccinium scoparium* Leiberg), AF/VASC

Northern Idaho (Cooper and others 1991)
Western hemlock/queencup beadlily (*Tsuga heterophylla* [Raf.] Sarg./*Clintonia uniflora* [Schult.] Kunth.), WH/CLUN

Arizona (Larson and Moir 1986)
Ponderosa pine/Arizona fescue (*Pinus ponderosa* [Dougl. ex Laws.]/*Festuca arizonica* Vaspy), PP/FEAR
Ponderosa pine/Gambel oak (*Pinus ponderosa* [Dougl. ex Laws.]/*Quercus gambelii* Nutt.), PP/QUGA

Data Collection

After the habitat types were chosen, we assembled a list of minimally disturbed mature old forest stands located in each of the habitat types. For each of the habitat types, a minimum of three stands were randomly selected having similar elevations, slopes, and aspects (table 1).

The stands were verified in the field to ensure that they met the selection criteria. Within each stand 12 randomly located soil cores were systematically extracted using a 10-cm (4-inch) diameter core sampler to a mineral soil depth of 10 cm (4 inches) (Jurgensen and others 1977). After extraction, each core was separated into its organic and mineral soil components including: litter (horizon O_i), humus (horizon O_a), soil wood, advanced stage decay of CWD, and mineral soil (up to 10 cm, 4 inches). Each component was labeled and placed in a cloth bag; the depth of each layer was recorded.

Analysis

The proportion by volume of the organic component for each soil core was computed using the depths recorded in the field. Computation was based on the total volume of the soil core to a depth of 10 cm of mineral soil and the volume of each organic layer following the formula:

$$\text{Percent Organic Materials} = \frac{LV + HV + SWV + CWDV}{\text{Total volume} * 100}$$

where

LV = Litter volume
HV = Humus volume
SWV = Soil wool volume
CWDV = Advanced CWD volume.

Based on the proportion of organic materials in each soil core the core was assigned to one of four classes (for instance, 0-15 percent, 16-30 percent, 30-45 percent, >45 percent). The organic matter volume class limits were chosen to balance the distribution of cores in each class within each habitat type.

In the laboratory each soil component was sieved through a 2-mm mesh screen to remove root systems and rocks. All active ectomycorrhizal root tips on the conifer roots were counted using 20X binocular microscopes (Harvey and others 1976). After the ectomycorrhizae were counted, the root systems were oven-dried at 60 °C (140 °F) for 24 hours and weighed. The number of ectomycorrhizal root tips and weight of fine woody roots were totaled for each soil core. In addition, the root biomass and the number of ectomycorrhizae in each core were summed to form another variable (root weight + total ectomycorrhizae). For each habitat type the proportion of ectomycorrhizal root tips, fine root biomass, and the sum of the root tips plus the root biomass for each organic matter volume class was computed according to the formula:

$$\text{Percentage } Y \text{ for each habitat type} = \frac{T_{VC}}{T_{HT} * 100}$$

where

Y = Ectomycorrhizae, root biomass, or ectomycorrhizae and root biomass
T_{VC} = Total ectomycorrhizae, root biomass, or ectomycorrhizae and root biomass in each volume class
T_{HT} = Total ectomycorrhizae, root biomass, or ectomycorrhizae and root biomass in each habitat type.

Table 1—Description of stands sampled. See table 2 for an explanation of the habitat type acronyms

National Forest	District		Habitat type	Cover type	Age	Aspect	Slope	Elevation	Parent material
					Years	*Degrees*	*Percent*	*Meters*	
Payette	New Meadows	1	GF/ACGL	GF/DF/PP	350	30	58	1,433	Basalt[1]
		2	GF/ACGL	GF/DF/PP	100	184	30	1,646	Basalt
	Weiser	3	GF/SPBE	GF/DF/PP	135	67	45	1,585	Basalt
		4	GF/SPBE	GF/DF/PP	100	350	55	1,494	Basalt
		5	GF/SPBE	GF/DF/PP	100	96	20	1,585	Basalt
	Council	6	GF/SPBE	GF/DF/PP	150	173	50	1,798	Basalt
		7	GF/SPBE	GF/DF/PP	100	194	40	1,798	Basalt
		8	GF/ACGL	GF/DF/PP	150	85	45	1,433	Basalt
	McCall	9	AF/VAGL	AF/ES/LP	130	313	5	1,951	Granitic[2]
		10	AF/VAGL	AF/ES/LP	180	342	14	1,890	Granitic
		11	AF/VAGL	AF/ES/LP	140	313	5	1,890	Granitic
		12	AF/VAGL	AF/ES/LP	86	290	15	2,012	Granitic
		13	AF/VAGL	AF/ES/LP	86	290	8	2,085	Granitic
		14	AF/VAGL	AF/ES/LP	105	284	24	1,951	Granitic
Boise	Lowman	15	DF/CARU	DF/PP	80	250	35	1,798	Granitic
		16	DF/CARU	DF/PP	80	0	40	1,829	Granitic
Salmon	Ledore	17	DF/CARU	DF	150	10	40	2,134	Belt[3]
Targhee	Dubois	18	DF/CARU	DF	179	296	40	2,134	Volcanic[4]
	Island Park	19	DF/CARU	DF	130	226	5	2,164	Volcanic
		20	DF/CARU	DF	130	208	16	1,280	Volcanic
Idaho Panhandle	Priest Lake	21	WH/CLUN	WH/DF/WL/WP	100	310	45	1,280	Ash/Belt[5]
	Fernan	22	WH/CLUN	WH/DF/WL/WP	100	45	30	823	Ash/Belt
		23	WH/CLUN	WH/DF/WL/WP	100	30	30	853	Ash/Belt
	Wallace	24	WH/CLUN	WH/DF/WL/WP	250+	90	3	975	Ash/Belt
		25	WH/CLUN	WH/DF/WL/WP	250+	90	12	1,280	Ash/Belt
Lolo	Missoula	26	DF/PHMA	DF/PP/WL/LP	113	90	68	1,737	Belt
		27	DF/PHMA	DF/PP/WL/LP	125	116	58	1,554	Belt
		28	DF/PHMA	DF/PP/WL/LP	97	130	55	1,707	Belt
	Nine-Mile	29	DF/PHMA	DF/PP/WL/LP	144	42	15	1,311	Belt
		30	DF/PHMA	DF/PP/WL/LP	129	140	35	1,097	Belt
		31	DF/PHMA	DF/PP/WP/LP	69	100	35	1,311	Belt
		32	AF/XETE	AF/ES/LP	85	138	45	1,707	Belt
		33	AF/XETE	AF/ES/LP	76	150	45	1,737	Belt
	Thompson Falls	34	GF/XETE	GF/DF/WL/LP	77	50	60	1,402	Belt
		35	GF/XETE	GF/DF/WL/LP	70	230	28	1,097	Belt
		36	GF/XETE	GF/DF/WL/LP	67	60	26	1,097	Belt
		37	AF/XETE	AF/ES/LP	127	5	40	1,585	Metasediments[6]
	Superior	38	GF/XETE	GF/DF/WL/LP	60	227	48	1,341	Metasediments
		39	GF/XETE	GF/DF/WL/LP	75	302	40	1,585	Metasediments
		40	AF/XETE	AF/ES/LP	76	119	54	1,524	Metasediments
	Seeley Lake	41	AF/XETE	AF/ES/LP	98	280	20	1,768	Metasediments
		42	AF/XETE	AF/ES/LP	78	40	24	1,433	Metasediments
Deerlodge	Butte	43	DF/CARU	DF/LP	86	260	20	1,920	Granitic
		44	DF/CARU	DF/LP	92	120	14	2,073	Granitic
		45	DF/CARU	DF/LP	80	192	15	2,073	Granitic
		46	AF/VASC	AF/LP/ES	65	124	21	2,073	Volcanic
		47	AF/VASC	AF/LP/ES	65	110	33	2,073	Volcanic
	Jefferson	48	DF/CARU	DF/LP	79	327	10	1,951	Granitic
		49	AF/LIBO	AF/LP/ES	67	54	10	2,042	Volcanic
		50	AF/LIBO	AF/LP/ES	119	270	35	2,012	Granitic
		51	AF/VASC	AF/LP/ES	127	38	15	2,105	Granitic
Helena	Townsend	52	AF/VASC	AF/LP/ES	68	104	17	2,195	Granitic
Nez Perce	Clearwater	53	DF/PHMA	DF/PP/WL	100	90	70	914	Metamorphic[7]
		54	DF/PHMA	DF/PP/WL	81	96	30	1,219	Metamorphic
	Salmon River	55	DF/PHMA	DF/PP/WL	125	60	45	1,585	Basalt
Kaibab	North Kaibab	56	PP/FEAR	PP	127	0	0	2,460	Limestone[8]
		57	PP/FEAR	PP	125	0	0	2,469	Limestone
		58	PP/FEAR	PP	123	0	0	2,487	Limestone

(con.)

Table 1 (Con.)

National Forest	District		Habitat type	Cover type	Age	Aspect	Slope	Elevation	Parent material
					Years	*Degrees*	*Percent*	*Meters*	
Coconino	Mormon Lake	59	PP/QUGA	PP	141	0	0	2,134	Basalt
		60	PP/QUGA	PP	150	0	0	2,134	Basalt
		61	PP/QUGA	PP	145	0	0	2,134	Basalt
		62	PP/QUGA	PP	114	0	0	2,134	Basalt
		63	PP/QUGA	PP	145	0	0	2,134	Basalt
		64	PP/QUGA	PP	103	0	0	2,134	Basalt
Apache-Sitgreaves	Chevelon	65	PP/FEAR	PP	156	0	0	2,316	Limestone
		66	PP/FEAR	PP	135	0	0	2,316	Limestone
	Heber	67	PP/FEAR	PP	139	0	0	2,336	Limestone

[1]Black volcanic rock rich in iron, calcium, and magnesium; composed primarily of augite and plagioclase feldspar.
[2]Crystallized igneous rock composed mostly of orthoclase and plagioclase feldspar along with quartz and either mica or hornblende.
[3]Mildly metamorphosed sedimentary rocks, including argillites, siltites, quartzites, and dolomites.
[4]Rhyolite: lava or shallow intrusion, fine grained, with composition equivalent to granite.
[5]Volcanic ash from Mount Mazama over belt series rocks.
[6]Weakly weathered layers of metasedimentary rock that produce hard angular rock fragments.
[7]Igneous or sedimentary rocks that have been altered and reconstituted by crystallization of new minerals under great pressure or heat or both.
[8]Sedimentary rock consisting of calcium carbonate.

Harvey and others (1987) developed a model relating ectomycorrhizal activity to organic material. This model indicated the relationship between active ectomycorrhizal root tips and organic matter was normally distributed within a habitat type (fig. 2). The proportion of ectomycorrhizae occurring in a habitat in a given volume class of forest soil increased until the proportion of the organic components in surface soil approached or exceeded 30 percent. At higher concentrations, the proportion of ectomycorrhizae occurring in a habitat for a given class of soil usually decreased. Therefore, the optimum volume class of organic matter for the formation of ectomycorrhizal root tips was identified for each habitat type (fig. 2).

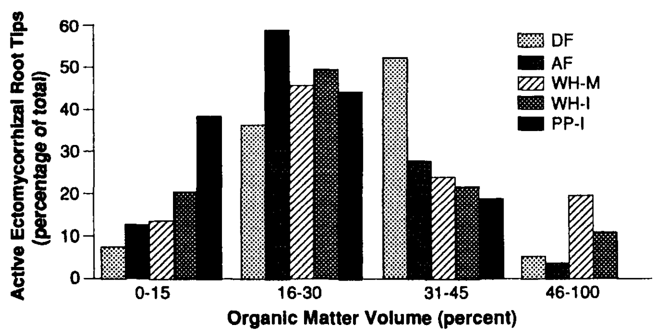


Figure 2—The distribution of active ectomycorrhizal root tips (percentage of total) to soil organic matter content in undisturbed stands: DF = Douglas-fir habitat series, WH-M = Western hemlock series in western Montana, WH-I = Western hemlock series in Idaho, AF = Subalpine fir series in Montana, PP-I = Ponderosa pine series in Idaho (Harvey and others 1987).

We also tested the relationship of organic matter volume classes with fine root weights and with the sum of ectomycorrhizal root tips and fine root weight. Those relationships were similar to the relationship between organic matter volume classes and the percentage of ectomycorrhizal root tips. Therefore, only the percentage of ectomycorrhizae was used in our analysis.

After determining the optimum volume class of forest soil for the formation of ectomycorrhizae, the amount of organic matter for this class was estimated. Using the ovendried weights of each organic component, the total weight of organic matter per unit area for each volume class was computed.

Obviously, not all of the organic matter in the forest floor is derived from CWD; some is derived from foliage, fine woody material, or other organic components. Harmon and others (1986) summarized the few studies showing the contribution of CWD to the forest floor and found it to range from 24 to 74 percent. Our past work showed that CWD contributed up to 58 percent of the organic materials to the forest floor; in this study CWD contributed up to 100 percent of the organic materials. Because of this variation, the range of 25 to 50 percent seemed suitable and conservative for the sites we sampled in the Rocky Mountains.

Before fresh CWD becomes an active part of the soil system, it loses about 40 percent of its mass, leaving most of the lignin and a portion of the cellulose fractions, depending on species and piece size. Therefore, we adjusted the ranges of organic matter that CWD contributes to the forest floor to 60 percent of the weight of undecayed materials. These computations resulted in the amount of fresh CWD we recommend leaving after timber harvesting.

Results and Discussion

Ectomycorrhizae absorb moisture and nutrients, and translocate them to their host plants, making ectomycorrhizae essential for the development of forest ecosystems (Harley and Smith 1983; Harvey and others 1979; Harvey and others 1987; Marks and Kozlowski 1973; Maser 1990). Therefore, we assume their presence and abundance to be a good indicator of a healthy, functioning forest soil. Ectomycorrhizae have a strong positive relationship with soil organic materials (Harvey and others 1981). Soil wood, humus, and the upper layers of mineral soil that are rich in organic matter are the primary substrates for the development of ectomycorrhizae. Using these strong relationships, Harvey and others (1987) developed a model relating ectomycorrhizal activity to organic materials (fig. 2).

Until a good process model is available for modeling the diverse functions of organic matter in forested ecosystems, it seems rational and relatively conservative to use ectomycorrhizal activity as a primary indicator of a healthy forest soil. Using this approach, Harvey and others (1987) made a generic recommendation of leaving 22 to 36 Mg per ha (10 to 15 tons acre) of CWD after timber harvesting for most sites in the Northern Rocky Mountains. While this model still appears appropriate, it will be refined as more information on the function of CWD becomes available.

In this study the relationships between ectomycorrhizae and organic matter volume classes was similar to those found by Harvey and others (1987), except for the PP/QUGA, GF/ACGL, AF/LIBO, and WH/CLUN habitat types (fig. 3, tables 2, 3). The optimum volume of organic matter for the formation of ectomycorrhizal root tips in the GF/ACGL habitat type was less than 30 percent; the optimum volume was less than 20 percent in the PP/QUGA habitat type. Ectomycorrhizal activity never decreased with increasing organic matter volume in the AF/LIBO and WH/CLUN habitat types, even when the volumes exceeded 40 percent.

The amount of organic material that accumulates and is used by ectomycorrhizae in Rocky Mountain forests is highly dependent on climate and fire cycles. Natural fire-return intervals as short as 2 to 5 years occur in ponderosa pine ecosystems; fire-return intervals range to more than 100 years in high elevation subalpine-fir ecosystems (Arno 1980, 1988). Fire frequencies control the accumulation of organic materials and the amount available for the use by ectomycorrhizae. For example, in the drier habitat types (such as PP/QUGA, DF/PHMA, GF/SPBE) the optimum

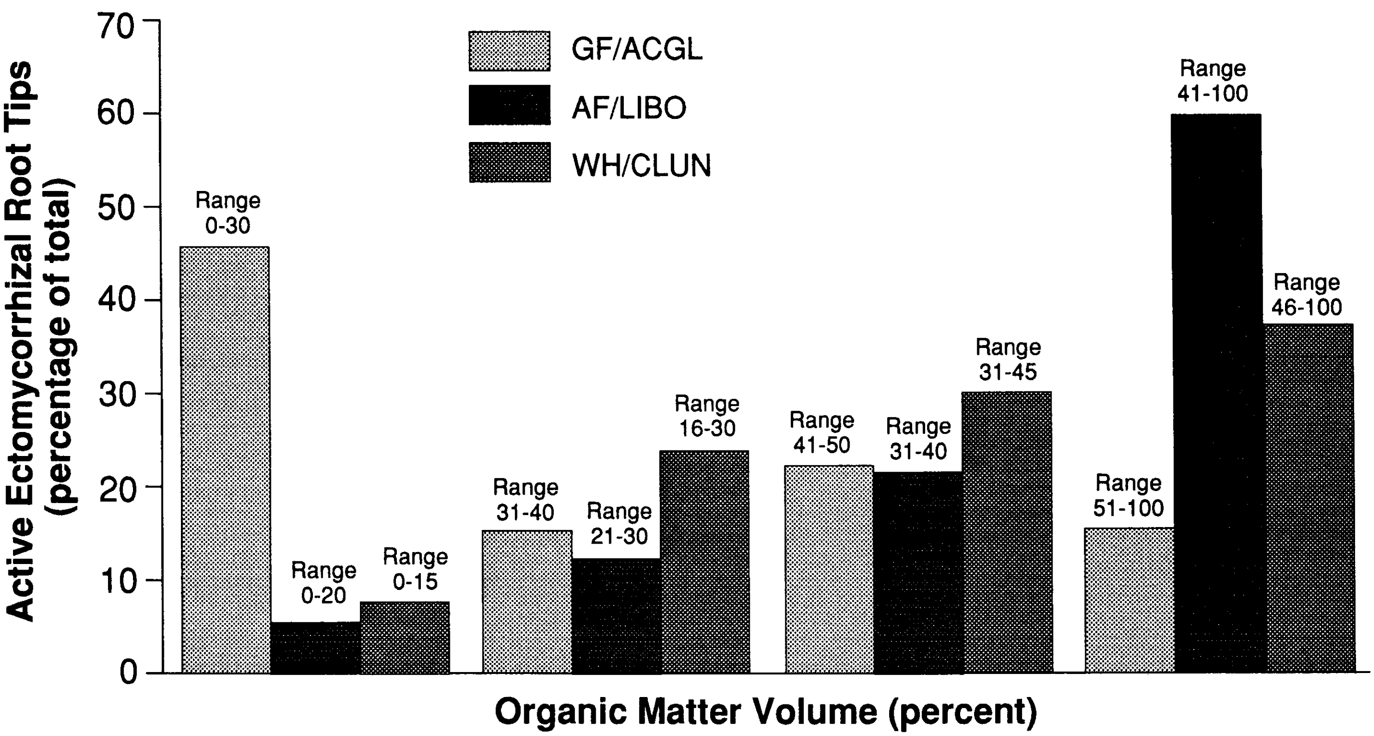


Figure 3—The distribution of active ectomycorrhizal root tips (percentage of total) to soil organic matter content in undisturbed stands. To balance the distribution of soil core samples among volume classes, different class limits were used: GF/ACGL = Grand fir/mountain maple (*Abies grandis/Acer glabrum*), AF/LIBO = Subalpine fir/twin flower (*Abies grandis/Linnaea borealis*), WH/CLUN = Western hemlock/queen cup beadlily (*Tsuga heterophylla/Clintonia uniflora*).

Table 2—Acronyms for habitat types

Acronym	Habitat type
AF/LIBO	Subalpine fir/twinflower (*Abies lasiocarpa/Linnaea borealis*)
AF/VAGL	Subalpine fir/huckleberry (*Abies lasiocarpa/Vaccinium globulare*)
AF/VASC	Subalpine fir/whortleberry (*Abies lasiocarpa/Vaccinium scoparium*)
AF/XETE	Subalpine fir/beargrass (*Abies lasiocarpa/Xerophyllum tenax*)
DF/CARU	Douglas-fir/pinegrass (*Pseudotsuga menziesii/Calamagrostis rubescens*)
DF/PHMA	Douglas-fir/ninebark (*Pseudotsuga menziesii/Physocarpus malvaceus*)
GF/ACGL	Grand fir/mountain maple (*Abies grandis/Acer glabrum*)
GF/SPBE	Grand fir/snowberry (*Abies grandis/Spiraea betulifolia*)
GF/XETE	Grand fir/beargrass (*Abies grandis/Xerophyllum tenax*)
PP/FEAR	Ponderosa pine/Arizona fescue (*Pinus ponderosa/Festuca arizonica*)
PP/QUGA	Ponderosa pine/Gambel oak (*Pinus ponderosa/Quercus gambelii*)
WH/CLUN	Western hemlock/queencup beadlily (*Tsuga heterophylla/Clintonia uniflora*)

organic matter volume class for ectomycorrhizae was less than 30 percent, even though higher volumes of organic matter were present in the habitat type. The large accumulations of organic material in the forest floor (more than 45 percent) on some of these sites was probably due to fire exclusion. Because of low precipitation, these large amounts or organic materials were probably too dry for ectomycorrhizal growth much of the year.

The AF/LIBO habitat type occurs at higher elevations. It is a moist habitat type with a short growing season (Pfister and others 1977). Organic matter on the forest floor appears to retain moisture throughout the growing season. It is highly decomposed, making

Table 3—Distribution of active ectomycorrhizal root tips (percentage of total) to soil organic matter content and number (n) of samples in each organic matter volume class. Asterisks indicate the volume class with the most ectomycorrhizal activity. See table 2 for an explanation of the habitat type acronyms

Forest	Habitat type	Organic matter volume class[1]							
		1(0-10)		**2(11-20)**		**3(21-30)**		**4(31-100)**	
		Percent	*n*	*Percent*	*n*	*Percent*	*n*	*Percent*	*n*
Boise, Salmon, Targhee	DF/CARU	18.3	24	36.0	16	*42.8	25	3.0	8
Payette	GF/SPBE	10.5	12	26.6	9	*40.5	24	22.3	15
Deerlodge	AF/VASC	14.9	8	32.8	18	*45.2	12	7.2	10
		1(0-15)		**2(16-30)**		**3(31-45)**		**4(46-100)**	
Nez Perce	DF/PHMA	7.0	8	*50.9	10	16.1	12	25.9	6
Lolo	DF/PHMA	11.7	9	*51.7	40	18.3	17	18.3	6
Idaho Panhandle	WH/CLUN	7.4	4	23.9	29	30.6	21	*38.1	6
Lolo	AF/XETE	1.5	10	34.5	30	*47.9	20	16.1	12
Payette	AF/VAGL	8.3	7	37.7	28	*38.4	27	15.7	11
		1(0-20)		**2(21-30)**		**3(31-40)**		**4(41-100)**	
Deerlodge	DF/CARU	15.5	15	30.0	18	*30.9	8	23.6	7
Deerlodge	AF/LIBO	5.1	3	12.1	9	22.0	6	*60.8	6
Coconino	PP/QUGA	*40.0	26	24.4	20	14.9	12	20.7	14
Kaibab and Apache-Sitgreaves	PP/FEAR	25.0	19	*41.8	21	25.9	28	7.4	13
		1(0-25)		**2(26-35)**		**3(36-45)**		**4(46-100)**	
Lolo	GF/XETE	27.8	26	*34.2	13	22.6	9	15.3	12
		1(0-30)		**2(31-40)**		**3(41-50)**		**4(51-100)**	
Payette	GF/ACGL	*45.9	18	15.3	8	22.7	5	15.9	5

[1]Organic matter volume classes are based on the proportion of a soil core in organic materials to a mineral depth of 10 cm (3.94 inches) plus the surface organic layers. Different class sizes were used to balance the distribution among the classes.

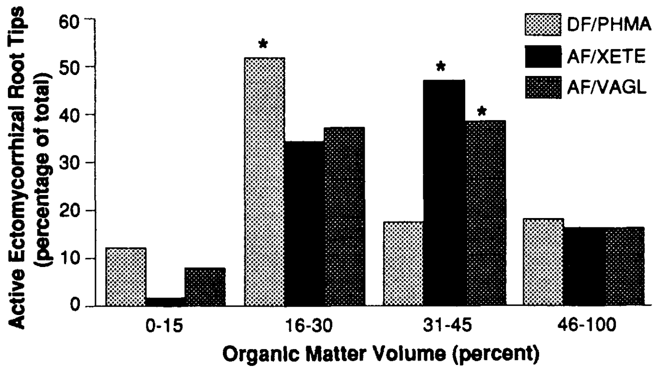


Figure 4—The distribution of active ectomycorrhizal root tips (percentage of total) to soil organic matter content in undisturbed stands. Bars marked with asterisks (*) indicate the optimum organic matter class for ectomycorrhizal activity: DF/PHMA = Douglas-fir/ninebark (*Pseudotsuga menziesii*/*Physocarpus malvaceus*), AF/XETE = Subalpine fir/beargrass (*Abies lasiocarpa*/*Xerophyllum tenax*), AF/VAGL = Subalpine fir/huckleberry (*Abies lasiocarpa*/*Vaccinium globulare*).

it an important part of the soil system even when the majority of the soil surface and upper mineral layers are composed of organic materials. Similarly, WH/CLUN sites are moist (Cooper and others 1991). The humus and soil wood stay wet, making them ideal ectomycorrhizae habitat even when the amount of organic materials in the surface soil exceeds 45 percent.

The majority of habitat types we sampled had an optimum level of organic matter for the formation of ectomycorrhizae when the percentage of organic matter was represented by volume classes 2 and 3 (similar to the results of Harvey and others 1987) (table 3). A small proportion of ectomycorrhizal activity occurred in the highest volume class (class 4), while ectomycorrhizal activity remained minimal in the first volume class. For example, in the DF/PHMA habitat type the optimum volume of organic matter for ectomycorrhizae formation was volume class 2 (16 to 30 percent); in the AF/XETE and AF/VAGL, it was volume class 3 (31 to 45 percent) (fig. 4, table 3).

The amount of organic matter on the forest floor represented by the optimum volume class (table 4) ranged from 15.5 Mg per ha (6.9 tons per acre) to 89 Mg per ha (39.7 tons per acre) depending on the habitat type. The DF/PHMA habitat type had 24 Mg per ha (10.7 tons per acre), the AF/XETE habitat type had 61.2 Mg per ha (27.3 tons per acre) and the AF/VAGL habitat type had 50.4 Mg per ha (22.5 tons per acre) of organic materials on sites represented by the optimum volume classes (fig. 5, table 4).

After adjusting these values for the proportion contributed by CWD (25 to 50 percent), the range of optimum organic matter derived from CWD on a DF/PHMA habitat type would range from 6.0 to 12.0 Mg per ha (2.7 to 5.4 tons per acre), on the AF/XETE habitat type it would range from 15.3 to 30.6 Mg per ha (6.8 to 13.6 tons per acre), and on the AF/VAGL habitat type it would range from 12.6 to 25.2 Mg per ha (5.6 to 11.2 tons per acre) (fig. 6).

Because CWD loses 40 percent of its weight before it becomes an active part of the soil system, 10.0 to 20.0 Mg per ha (4.5 to 8.9 tons per acre) of fresh CWD would need to be left after timber harvesting on the DF/PHMA habitat type for the optimum amount of organic matter. Similar calculations established the recommended amounts of CWD for the other habitat types (fig. 7). These amounts should ensure sufficient organic materials to replace the organic matter of the forest floor and upper mineral soil.

Application

We believe the CWD recommendations presented here are conservative for maintaining forest productivity; they are the best currently available, based on our limited knowledge of the function of CWD in forest ecosystems. As more information becomes available on the role of CWD in Rocky Mountain forests, particularity in the area of nitrogen cycling, these recommendations could change. Douglas-fir and western larch (*Larix occidentalis* Nutt.) stems are particularity good sources of CWD and soil wood because of their longevity (Harvey and others 1987; Sollins and others 1987), but CWD from all species contributes organic matter to the forest floor. The true firs do not persist long as CWD and soil wood because they decay relatively quickly. The pines are intermediate in their decay rates and residence times (Harmon and others 1986).

Our recommendations for CWD do not include stumps. We recognize that considerable amounts of CWD can be derived from stumps, but these materials always remain on site, even after stand-replacing wildfires or extensive timber harvesting and site preparation. The CWD recommendations developed by this study are for wood larger than 7.5 cm (3.0 inches) in diameter. These materials have the greatest probability of contributing to the forest floor and soil wood before they totally decay or are consumed by fires. On the wetter habitat types, fire is not as prevalent but decay can be rapid; large pieces of CWD have more heartwood than small pieces; therefore, they last longer. Smaller materials, such as needles and small branches, are usually considered hazard fuels by fire managers and are easily consumed by both

Table 4—Mean amounts of organic matter and standard errors for organic matter volume classes by habitat types. Asterisks indicate the volume class with the most ectomycorrhizal activity. See table 2 for an explanation of the habitat type acronyms

Forest	Habitat type	Organic matter volume class[1] 1(0-10) Mean	SE	2(11-20) Mean	SE	3(21-30) Mean	SE	4(31-100) Mean	SE
		Mg/ha							
Boise, Salmon, Targhee	DF/CARU	6.1	1.3	21.6	4.5	*32.7	5.6	55.4	14.3
Payette	GF/SPBE	7.6	2.2	20.8	5.8	*37.4	5.8	43.3	7.8
Deerlodge	AF/VASC	10.3	4.5	32.3	6.9	*39.5	9.4	52.7	14.1
		1(0-15) Mean	SE	2(16-30) Mean	SE	3(31-45) Mean	SE	4(46-100) Mean	SE
Nez Perce	DF/PHMA	11.9	4.7	*35.4	8.7	60.5	12.8	91.5	30.0
Lolo	DF/PHMA	6.1	3.8	*24.0	3.1	46.2	7.6	73.1	22.2
Idaho Panhandle	WH/CLUN	24.0	14.1	32.7	5.8	54.2	10.5	*88.8	30.3
Lolo	AF/XETE	0.7	0.4	34.5	4.5	*61.2	10.5	86.8	20.4
Payette	AF/VAGL	3.1	1.8	26.9	4.0	*50.4	7.2	76.9	17.9
		1(0-20) Mean	SE	2(21-30) Mean	SE	3(31-40) Mean	SE	4(41-100) Mean	SE
Deerlodge	DF/CARU	12.1	3.4	30.7	7.8	*65.9	20.6	66.6	14.8
Deerlodge	AF/LIBO	33.6	15.0	39.0	14.1	56.8	25.6	*66.0	38.3
Coconino	PP/QUGA	*26.9	4.7	46.4	5.2	49.8	6.1	74.6	8.5
Kaibab and Apache-Sitgreaves	PP/FEAR	21.1	3.1	*35.2	2.9	43.5	4.3	44.4	5.2
		1(0-25) Mean	SE	2(26-35) Mean	SE	3(36-45) Mean	SE	4(46-100) Mean	SE
Lolo	GF/XETE	27.3	4.3	*37.7	7.2	54.7	11.9	62.3	15.2
		1(0-30) Mean	SE	2(31-40) Mean	SE	3(41-50) Mean	SE	4(51-100) Mean	SE
Payette	GF/VAGL	*15.5	4.5	31.8	10.1	46.6	7.2	49.7	18.6

[1]Organic matter volume classes are based on the proportion of a soil core in organic materials to a mineral depth of 10 cm (3.94 inches) plus the surface organic layers. Different class sizes were used to balance the distribution among the classes.

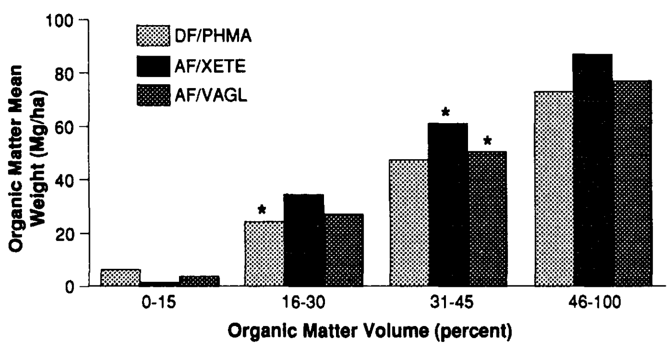


Figure 5—The mean weight of organic matter found on the forest floor for each of the organic matter volume classes. Bars marked with asterisks (*) indicate the optimum organic matter class for ectomycorrhizal activity: DF/PHMA = Douglas-fir/ninebark (*Pseudotsuga menziesii/Physocarpus malvaceus*), AF/XETE = Subalpine fir/beargrass (*Abies lasiocarpa/Xerophyllum tenax*), AF/VAGL = Subalpine fir/huckleberry (*Abies lasiocarpa/Vaccinium globulare*).

wild and prescribed fires; they decay easily in most forest types. Such fine materials are not included in these recommendations.

Historically, Rocky Mountain wildfires left large amounts of CWD. For example, if fires did not consume the standing boles on the poorest ponderosa pine site, over 100 Mg per ha (44.6 tons per acre) of CWD could remain. Similarly, on a good site in northern Idaho, over 600 Mg per ha (267.6 tons per acre) of CWD could be left after a wildfire. These calculations are based on the yield of a ponderosa pine stand with a site index 40 at age 200 years (4,200 ft^3) (Meyer 1938) and the yield of a western white pine stand with a site index 80 at age 160 years (21,000 ft^3) (Haig 1932) and assuming a conversion of 25 lb/ft^3 for ponderosa pine and 28 lb/ft^3 for western white pine.

However, we are not recommending that such amounts be left after timber harvesting. Other resource issues, such as wildfire potential, reforestation, and future management options should be considered. Considering some of these other resource values, Reinhardt and others (1991) recommended

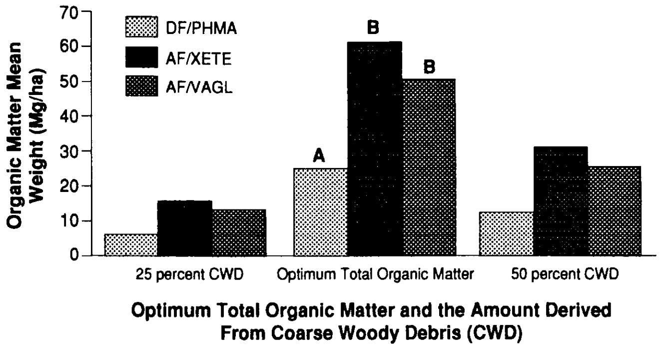


Figure 6—The weight of the active organic matter found on the forest floor for the optimum organic matter classes for ectomycorrhizal activity (A = 16-30 percent, B = 31-45 percent) and the weight that would be derived from coarse woody debris if coarse woody debris made up 25 percent or 50 percent of the total: DF/PHMA = Douglas-fir/ninebark (*Pseudotsuga menziesii/Physocarpus malvaceus*), AF/XETE = Subalpine fir/beargrass (*Abies lasiocarpa/Xerophyllum tenax*), AF/VAGL = Subalpine fir/huckleberry (*Abies lasiocarpa/Vaccinium globulare*).

that no more than 89.6 Mg per ha (40 tons per acre) of CWD be left after harvesting mixed stands in the WH/CLUN habitat type.

The recommended amount of CWD should be distributed across harvest units. Localized concentrations of CWD, such as at a landing after whole tree harvesting or at machine-made piles, should be minimized. Dozer piling logging slash to reduce fire hazard and prepare sites for tree regeneration could distribute CWD, but fine fuels are often difficult to separate, from large fuels and operations are limited by slope angle and soil conditions. Grapple piling of logging slash appears to more easily separate fine fuels from CWD; often these machines provide more flexibility on steeper slopes than dozers and minimize soil compaction (USDA Forest Service).

Roller chopping, chipping, or smashing of logging slash should be done with care. These procedures have the potential to create deep or compacted layers of organic matter that can insulate the mineral soil surface. These deep layers could keep soil temperatures cool, slowing organic matter decomposition and interfering with root growth, especially on the subalpine fir habitat types (Benson 1982). Also, chopping or chipping of slash likely destroys many of the attributes of CWD that are important for nitrogen fixation, animal habitat, and site protection.

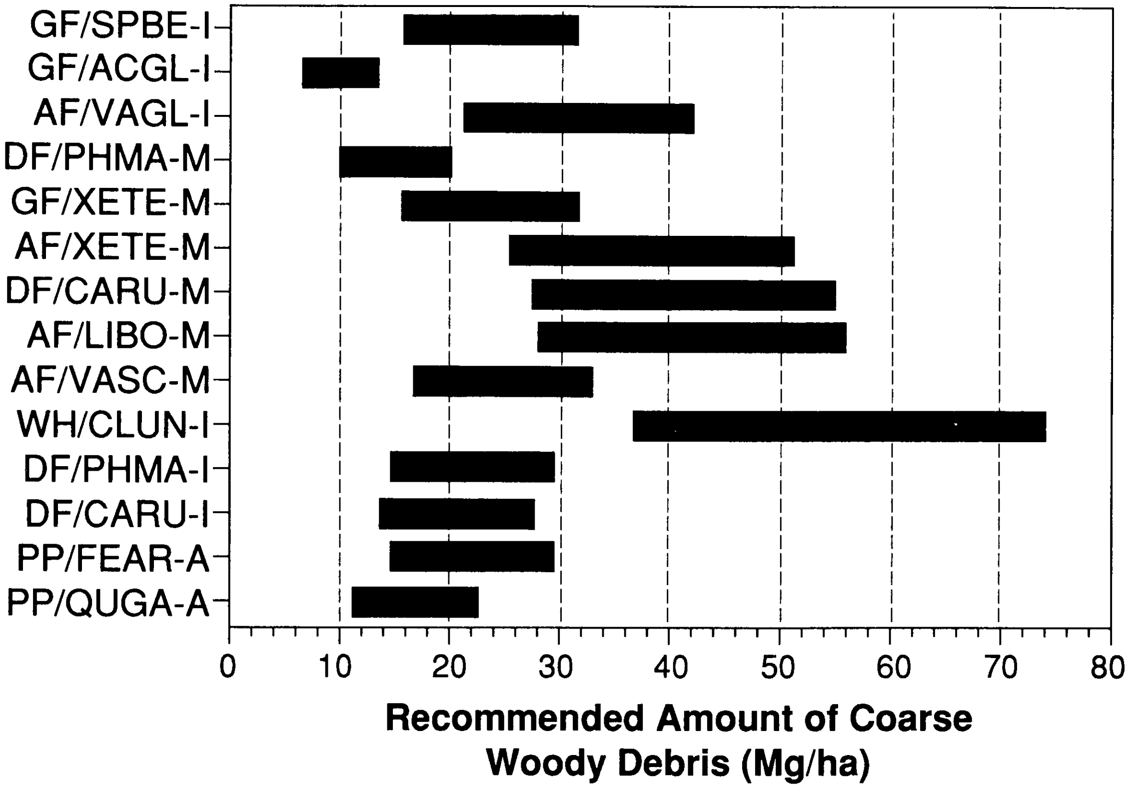
Prescribed fire can be applied so it primarily removes the needles and small branches (the hazard fuels) and maintains much of the organic matter on and in the forest floor. The fine materials can also be an important source of nutrients as they decay; if properly handled, nutrient losses can be minimal during prescribed fires. For example, if the moisture conditions are high (about 100 percent) in the lower forest floor, and the forest floor is not consumed when logging slash is broadcast burned, nutrients released from the fine fuels can be deposited or condensed in these lower layers (Harvey and others 1989).

Prescribed fire is an excellent method for managing CWD. Charring does not interfere substantially with the decomposition or function of CWD. From our observations charred CWD checks and cracks, especially after the first winter, allowing decay fungi to colonize most pieces. The greatest limitation on the use of fire arises when desired burning conditions do not exist or when they exist only for short periods. Also, smoke emission standards may limit the use of prescribed fire.

These recommendations for CWD are based on maintaining forest productivity. On some forest sites productivity might be enhanced by leaving even more CWD. For example, the productivity of the GF/ACGL habitat type, which had little organic matter, may benefit from more CWD than the recommended 6.3 Mg per ha (2.8 tons per acre). Additional CWD could increase the amount of nitrogen fixation occurring on the site and help protect the soil from erosion. Also, more material than we recommended might enhance or maintain wildlife habitat, particularly in riparian zones (Harmon and others 1986).

Coarse woody debris will have little effect if the forest floor is destroyed or the shallow mineral soil is displaced or compacted by poor log yarding or poor site preparation. Depending on CWD decomposition rates, new residue may take hundreds of years to become fully incorporated into the forest floor and play an active role in the soil system. These recommendations are not designed to immediately replace the present forest floor and mineral soil organic matter, but to ensure their replacement over the next 100 years or more. Coarse woody debris is left after harvesting for the development and function of the next forest as much as for the present forest.

Management of CWD should be integrated into silvicultural systems designed for sustaining forest ecosystems.



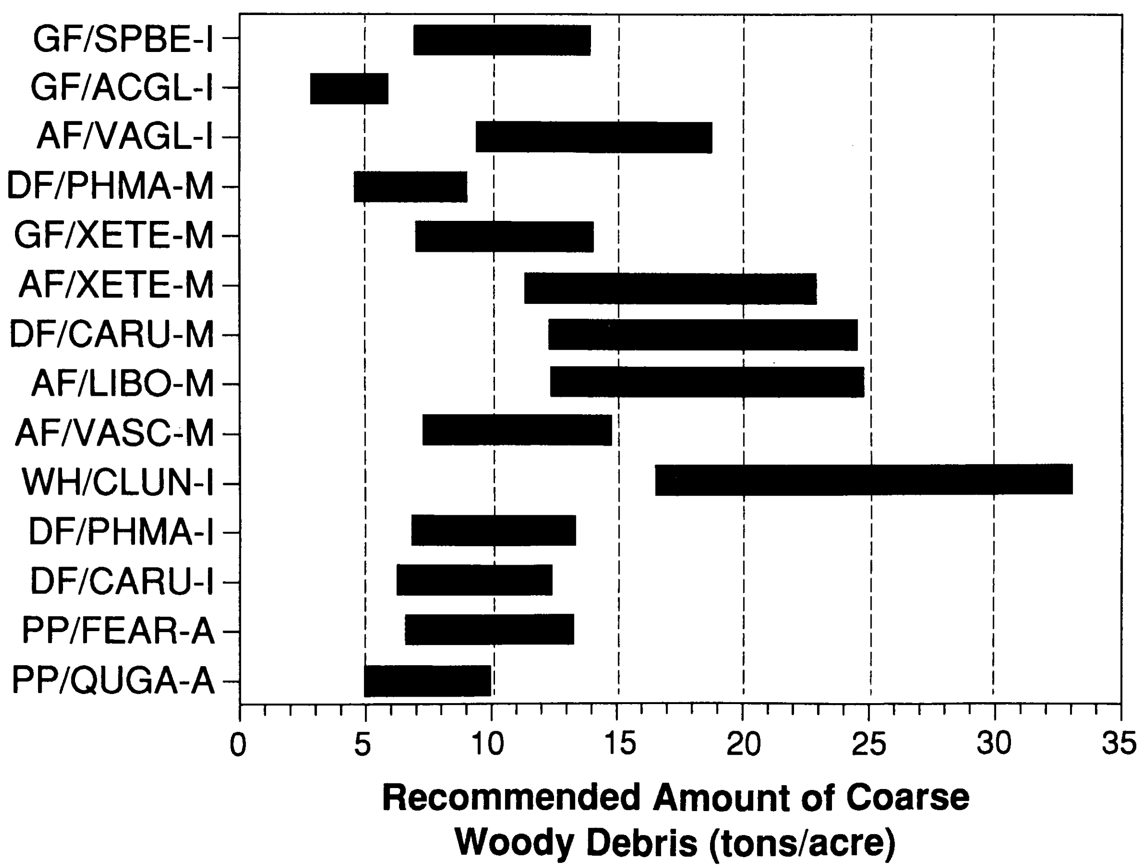


Figure 7—Recommended amount of coarse woody debris to leave after timber harvesting to maintain forest productivity. See table 2 for an explanation of the habitat type acronyms. "I" stands for Idaho; "M" stands of Montana; and "A" stands for Arizona.

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Graham, Russell T.; Harvey, Alan E.; Jurgensen, Martin F.; Jain, Theresa B.; Tonn, Jonalea R.; Page-Dumroese, Deborah S. 1994. Managing coarse woody debris in forests of the Rocky Mountains. Res. Pap. INT-RP-477. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 12 p.

Recommendations for managing coarse woody debris after timber harvest were developed for 14 habitat types, ranging from ponderosa pine (*Pinus ponderosa*) habitat types of Arizona to subalpine fir (*Abies lasiocarpa*) habitat types of western Montana. Ectomycorrhizae were used as a bioindicator of healthy, productive forest soils. Undisturbed stands were studied to determine the optimum amounts of organic material for ectomycorrhizal activity. The management recommendations are intentionally conservative to ensure that enough organic matter is left after timber harvest to maintain long-term forest productivity.

Keywords: slash, ectomycorrhizae, soil organic matter, silviculture, utilization, forest ecology, habitat type, Idaho, Montana, Arizona

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