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Working Papers in Southwestern
Ponderosa Pine Forest Restoration

Managing Coarse Woody Debris in Fire-adapted Southwestern Forests

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Ecological restoration is a practice that seeks to heal degraded ecosystems by reestablishing native species, structural characteristics, and ecological processes. The Society for Ecological Restoration International defines ecological restoration as "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability….Restoration attempts to return an ecosystem to its historic trajectory" (Society for Ecological Restoration International Science & Policy Working Group 2004).

In the southwestern United States, most ponderosa pine forests have been degraded during the last 150 years. Many ponderosa pine areas are now dominated by dense thickets of small trees, and lack their once diverse understory of grasses, sedges, and forbs. Forests in this condition are highly susceptible to damaging, stand-replacing fires and increased insect and disease epidemics. Restoration of these forests centers on reintroducing frequent, low-intensity surface fires—often after thinning dense stands—and reestablishing productive understory plant communities.

The Ecological Restoration Institute at Northern Arizona University is a pioneer in researching, implementing, and monitoring ecological restoration of southwestern ponderosa pine forests. By allowing natural processes, such as fire, to resume self-sustaining patterns, we hope to reestablish healthy forests that provide ecosystem services, wildlife habitat, and recreational opportunities.

The ERI Working Papers series presents findings and management recommendations from research and observations by the ERI and its partner organizations. While the ERI staff recognizes that every restoration project needs to be site specific, we feel that the information provided in the Working Papers may help restoration practitioners elsewhere.

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Cover: Several classes of coarse woody debris at Fort Valley Experimental Forest near Flagstaff, Arizona.
Photo by Dave Egan

Introduction

Fire-adapted forested ecosystems in the Southwest evolved with a continual flux of downed woody material—a structural component that is considered essential to a properly functioning forest ecosystem. The creation and accumulation of downed woody material depends on forest type, tree species, stage of succession/decay, the amount of insect and disease activity, climate, fire return intervals, windthrow, and management activities. In general, more downed woody material accumulates in forests with long fire return intervals (subalpine, mixed conifer, pinyon-juniper woodlands) than in forests with short fire return intervals, such as ponderosa pine.

While early foresters saw downed woody material as waste, a potential source of insect and disease problems or a wildfire hazard, today's foresters and researchers have identified the large-size component of downed woody material—coarse woody debris (CWD)—for its vital role in the maintenance of long-term site productivity, site protection, and wildlife habitat in fire-adapted forested ecosystems. Many studies (Harvey et al. 1979, 1980, 1987, 1988; Graham et al. 1994; Brown et al. 2003, Cram et al. 2007) report that CWD is important for developing nitrogen-fixing bacteria and ectomycorrhizae, and for protecting the soil surface from water erosion. Harvey et al. (1987) noted that decaying wood and humus supply organic matter across the forested landscape—material that not only serves as a growth medium for seedlings but plays an integral part in supporting ongoing tree growth. Brown et al. (2003), Carey and Johnson (1995), and Patton (personal communication) point out the importance of CWD to the life cycles of forest insects, reptiles, mammals, and birds.

Published research by Graham et al. (1994) recommends varying amounts of CWD depending on the type of forest ecosystem. However, research and management recommendations are lacking with regards to the spatial distribution and amount of CWD by size class as well as the different CWD decomposition states needed for maintaining and improving site productivity, soil quality and wildlife habitat (Bunnell et al. 2002), and for the safe use of natural or prescribed fire.

This need for additional research and land management recommendations regarding CWD is especially important in order to maintain the levels of existing and future CWD necessary to preserve fundamental ecological functions (e.g., site and soil productivity, wildlife habitat) in light of the increasing interest in, and government support of, using large quantities of woody biomass to produce wood products and energy (Skog and Barbour 2006, Hubka 2007, U.S. Forest Products Lab 2007).

In this ERI working paper, we provide insights into these and other questions about CWD.

One key assumption that underlies this discussion is that the site has been restored—that is, after treatment, a major portion of the project area is within its natural range of variability for tree density, the natural openings are restored, the pre-European settlement fire regime is re-established, and the soils are functioning properly. Without the benefit of lower trees per acre, and the value that a more open forest structure has in terms of bringing the site closer to its historic fire regime, wildfires will be very difficult to control even when CWD is managed within the scope of the recommendations derived from Graham et al. (1994) and found in the Region 3 Supplement to the Soil and Water Management Handbook (USDA Forest Service Region 3 1999).

Defining Coarse Woody Debris

Coarse woody debris consists of dead fallen logs, stumps, and limbs that are at least 3 inches in diameter at the point where they are sampled (Harmon et al. 1986, Brown et al. 2003). Standing snags and upright stumps are not considered CWD (USDA Forest Service 2004, U.S. Forest Service Region 3 Supplement 2509.18-99-1). Smaller material, including litter or small twigs less than 3 inches in diameter (new residue with little or no decay), are defined as fine woody debris (FWD) (USDA Forest Service Northern Research Station 2007). Fine fuels are beneficial to soil quality (primarily for stability) but may be considered a fire hazard unless they are properly managed to meet both soil- and fire-related objectives.

Coarse woody debris is also distinguished from FWD by the length of time it takes to dry. Whereas the moisture content of FWD reaches the same level as the moisture in the atmosphere relatively quickly (1-100 hours depending on its diameter), CWD is rated as 1,000+-hour fuels because it takes significantly longer to reach the same moisture content level as the atmosphere (Maser et al. 1979, USDA Forest Service Northern Research Station 2007).

Coarse woody debris is classified into five categories according to its degree of decay with class 1 being the most sound and class 5 the most decayed (see Figure 1 and Table 1).

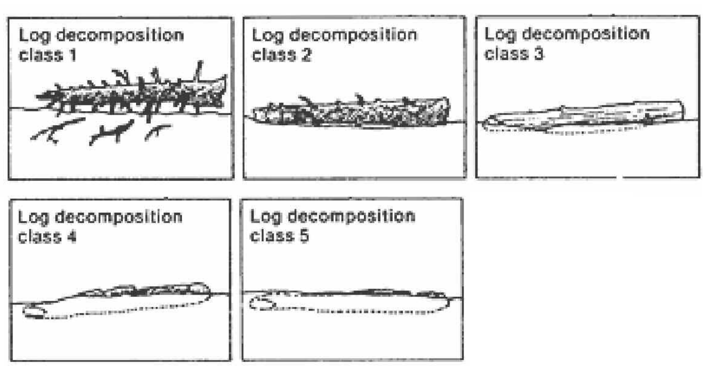

Figure 1. The classification of standing snags and decomposing logs. *From Thomas et al. 1979*

Decay Class	Structural Integrity	Wood Texture	Wood Color	Presence of Invading Roots	Condition of Branches/Twigs
1	Sound	Intact, no rot; conks on stem absent	Original color	Absent	If branches present, fine twigs still attached with tight bark
2	Heartwood sound, sapwood somewhat decayed	Mostly intact; sapwood partly soft and starting to decay; wood cannot be pulled apart by hand	Original color	Absent	If branches present, many fine twigs gone; attached fine twigs have peeling bark
3	Heartwood sound; log supports its weight	Large, hard pieces of sapwood can be pulled apart by hand	Red-brown or original color	Present in sapwood only	Large branch stubs will not pull out
4	Heartwood rotten; log does not support its own weight, but shape is maintained	Soft, small, blocky pieces, metal pin can push heartwood apart	Red-brown or light brown	Present throughout log	Large branch stubs will pull out easily
5	No structural integrity; no longer maintains shape	Soft, powdery when dry	Red-brown to dark brown	Present throughout log	Branch stubs and pitch pockets have rotted away

Table 1. Decay classes of coarse woody debris. *From Waddell 2002*

Importance of Coarse Woody Debris: Soils, Wildlife, and Fire Hazard

Soils

Coarse woody debris performs many physical, biological, and chemical functions in forest ecosystems. Physically, CWD protects the forest floor and mineral soil from erosion and mechanical disturbances. Brown et al. (2003) report that CWD helps protect soils from erosion on steep slopes, and disrupts the flow of water near the ground reducing the erosive potential of water and preventing losses to soil productivity. Coarse woody debris also interrupts airflow and provides shade, insulating and protecting new forest growth. When decay is advanced (log decomposition classes 3-5), CWD can hold large amounts of water, making it an important source of moisture for vegetation during dry periods (Graham et al. 1994).

Graham et al. (1994) noted that the breakdown of CWD provides most of the nutrients that are recycled through the ecosystem--the most important being sulfur, phosphorous, and nitrogen. Microbial processes and the overall potential for soils to provide nutrients is tied directly to the presence and maintenance of soil organic matter, which is, ultimately, the breakdown product from CWD and other organic materials (Brown et al. 2003).

Nitrogen has been identified as the most limiting soil nutrient in southwestern forest soils (Selmants et al. 2003). Moreover, it is also well known that maintaining adequate levels of organic matter, especially decayed wood, is important for maintaining the microbes involved in nitrogen fixation (Brown et al. 2003). Harvey et al. (1980, 1987) noted that symbiotic nitrogen-fixing plants are infrequent in most forest ecosystems and that non-symbiotic bacteria are widely distributed and have the most influence on nitrogen fixation. Decaying woody material that is not yet incorporated into the soil, such as CWD, provides the highest per unit weight, nitrogen-fixing capacity of any material available on the forest floor (Harvey et al. 1979).

Harvey et al. (1981) found that ectomycorrhizae—a type of fungus associated with pine tree roots—have a strong positive relationship with soil organic materials. Graham and his colleagues (1994) recognized this relationship when developing their recommendations for the amount of CWD to leave after timber harvesting. In general, they assumed that more organic matter would result in more ectomycorrhizae. However, they found that in drier forest types, such as Southwestern ponderosa pine, the highest amounts of active ectomychorrhizal root tips occurred when the organic volume was relatively low—from 0-20 percent in ponderosa pine/Gambel oak on basalt soils and from 21-30 percent in ponderosa pine/Arizona fescue on limestone soils. This finding suggested to them that the amounts of CWD in these dry habitats should be relatively low compared to more mesic vegetation types: 5-10 tons/acre of CWD on limestone soils supporting ponderosa pine/Gambel oak, and 7-13 tons/acre on basalt soils supporting ponderosa pine/Arizona fescue.

Recent studies that looked at the effects of forest restoration treatments on mycorrhizae (Korb et al. 2003, Griffiths et al. 2005) revealed that, after thinning and burning, endomycorrhizae increased significantly but there was little effect on the levels of ectomycorrhizae. This finding suggests that once ectomycorrhizae are in the soil they tend to maintain their populations, and that even minimal levels of CWD may have little correlation to sustaining adequate amounts of ectomycorrhizae.

Wildlife

Wildlife benefit from the presence of CWD because downed woody material is important in the life cycles of a wide variety of animals from mites to mammals (Brown et al. 2003). Patton (unpublished manuscript 2007) found that many species of animals, including rabbits, snakes, lizards and small rodents, use the openings that result from decayed roots for tunnels and dens. Coarse woody debris adds another level of diversity within forested ecosystems that can be beneficial for several species of chipmunks, ground squirrels, rabbits, turkeys, and ground-nesting birds (Patton unpublished manuscript 2007).

Payne and Bryant (1994) noted that larger logs have more wildlife potential than smaller logs. Carey and Johnson (1995) stated that while a multiplicity of environmental factors determine animal species abundances, two factors—CWD and prevalence of shrub cover--play primary roles. They concluded that CWD, especially large, standing or fallen dead trees, is not only an important habitat component for forest floor small mammals, it also provides critical habitat elements for birds and amphibians.

Probably one of the most persuasive reasons for managing CWD for wildlife exists in the Reynolds et al. (1992) report about prey species for the northern goshawk. They listed the following goshawk prey species and their relation to CWD:

Chipmunks: Downed logs and woody debris are important for nesting, lookout points, shelter, escape cover, and travel corridors.
Northern flicker: Downed logs and woody debris are sources of insect food.
Red squirrel: Snags and downed logs are essential with the smaller woody debris being of less value.
Stellar's jay: Downed logs and woody debris are used as habitats for insect food.
Tassel-eared squirrel: Downed logs and woody debris are crucial for food substrate and cover.
Williamson's sapsucker: Downed logs and woody debris are significant foraging sites.

Almost half of the important prey species identified by Reynolds and his colleagues are directly linked to CWD. Ward and Block (1995) listed these same species as key food sources for Mexican spotted owls, which indicates the importance of maintaining specific levels and sizes of CWD for sustaining populations of prey for these valuable birds.

Fire Hazard

Small and large woody debris contribute differently to a site's fire hazard (which I define as the potential fire behavior for a given fuel type and its resistance to control). For instance, the influence of duff and continuous FWD on the spread rate and intensity of surface fires is substantial (Brown et al. 2003). In contrast, models that predict the influence of CWD on the spread and intensity of initiating surface fires show that this size class of downed woody material has little influence on fire hazard, although CWD can contribute to the development of large fires and high fire severity (Brown et al. 2003). This same study noted that if large woody fuel is decayed and broken up, its contribution is considerably greater to a large fire event—similar to fire in heavy slash. Graham et al. (2004) explained why this is the case when they noted that decayed CWD (log decomposition classes 4 and 5) produces firebrands that can create numerous ignitions points far from of the main fire. Rotten wood is also more receptive to ignition when sparks land on it. Brown et al. (2003) also noted that burning large CWD can negatively affect nearby soil surface horizons, causing, among other outcomes, an increase in water repellency and a loss of soil nutrients and microorganisms.

Given their findings, Brown et al. (2003) concluded that a range of 5-20 tons per acre appeared reasonable in ponderosa pine/dry mixed conifer, whereas a range of 10-30 tons per acre could be allowed in cool, subalpine forest types without creating a high fire hazard (Figure 2). The current management recommendations for CWD for long-term forest health in U.S. Forest Service Region 3 are below these maximum amounts. Brown et al. (2003) also noted that higher loadings of CWD are acceptable where larger pieces of CWD predominate, which is typically the case once a forest's spatial pattern and structure are restored and frequent ground fire is reintroduced.

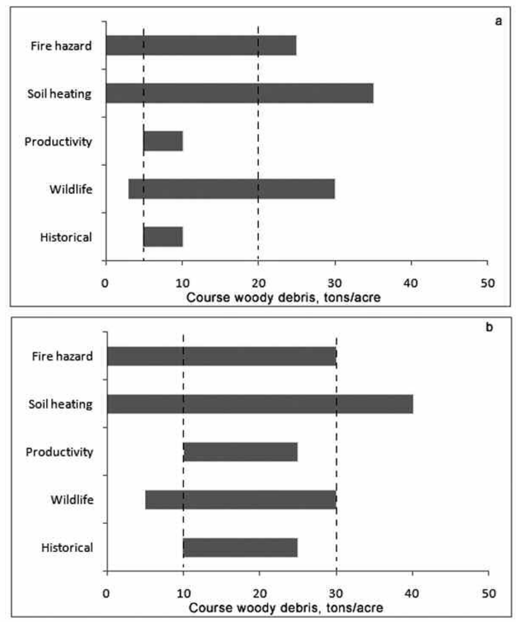

Figure 2. Optimum ranges of CWD that provide both acceptable risks of fire hazard and desirable levels for soil productivity, soil protection, and wildlife habitat. Dotted lines indicate a range that meets all or most resource needs. Chart A shows the range for warm, dry forest types, while Chart B displays the range for cool and lower subalpine forest types. *From Brown et al. 2003*

Existing Forest Service Management Recommendations

The Forest Service Southwestern Region (Region 3) identifies CWD as a critical component for sustaining ecosystem functions (USDA Forest Service 1999). Region 3 recommends that 5-10 tons/acre of CWD remain on-site in ponderosa pine/Gambel oak forest, 7-14 tons/acre of CWD in areas dominated by ponderosa pine/Arizona fescue, and 8-16 tons/acre are in the mixed conifer forest. These CWD recommendations for ponderosa pine were derived from research by Graham et al. (1994) and from an unpublished document by Graham et al. (1996) for mixed conifer.

These recommendations, along with continued sustainable management practices, will ensure that soil function is being sustained and the soil is functioning properly. If CWD requirements are less than what is recommended, a loss of soil function could occur.

Additional direction for management of CWD, at least in U.S. Forest Service Region 3, can be found in Appendix C, Standards and Guidelines in Selected Alternative G, which amended all existing forest plans in the region and clarified management direction for Mexican spotted owl and northern goshawk (USDA Forest Service 1996a). For example, the recommended guidelines for northern goshawk in the foraging areas are:

- *Ponderosa pine*: Leave at least two snags, three downed logs at least 12 inches in diameter and at least 8 feet long, and 5-7 tons of CWD per acre.
- *Spruce-fir and mixed conifer*: Leave at least three snags, five downed logs at least 12 inches in diameter and at least 8 feet long, and 10-15 tons of CWD.

While no specific Forest Service guidelines exist for CWD in pinyon-juniper ecosystems, Region 3 has developed minimum structural attributes criteria for determining old growth in such ecosystems. These guidelines call for two 8- to 10-foot downed logs, with a diameter of 9-10 inches, per acre (USDA Forest Service 1996a). Observations of pinyon-juniper ecosystems indicate that some level of CWD needs to be left on-site for soil protection and to provide sites for the regeneration of native grasses and trees (Dave Huffman personnel communication, Gottfried and Severson 1994, Stoddard 2006, see Figure 3).

Figure 3. Over time, coarse woody debris may function as a "nucleus" around which woodlands develop after severe disturbance. This image shows (A) coarse wood left after a fire that probably occurred before 1900, (B) a juniper tree that has established and grown since the fire, and (C) younger pinyon pine trees that have established beneath the older juniper. *Photo courtesy of Dave Huffman, ERI*

Estimating the Amount of CWD Prior to Twentieth Century Fire Suppression

Land managers in the frequent-fire regimes of the Southwest often ask: How much CWD existed in pre-European settlement southwestern forests? While the literature to support the following idea is quite limited, it seems reasonable that frequent ground fires during the pre-European settlement period resulted in relatively low amounts of CWD. Moir et al. (1997), for example, suggest that downed woody material was "sparse" prior to the exclusion of fire. Brown and his colleagues (2003) support this idea when they state that high-frequency, surface-fire disturbances that were typical in pre-European settlement warm/dry ponderosa pine and Douglas fir ecosystems would result in less downed woody material, including CWD.

However, unpublished research conducted by the Ecological Restoration Institute on several infrequently burned ponderosa pine sites within the Grand Canyon National Park indicates that the average CWD ranged from a low of 6.7 tons/acre reported for Rainbow Point to a high of 19.3 tons/acre at Fire Point. A site on Powell Plateau averaged 8.3 tons per acre, with a low of 5.5 ton/acre and a high of 19.3 tons/acre. The amount of FWD ranged from 1.5-2.6 tons/acre on Powell Plateau in the ponderosa pine zone. The mixed conifer site on Powell Plateau averaged 41 tons/acre of CWD and 6 tons/acre of FWD. These results for CWD fall roughly within the range of 5-15 tons/acre recommended by Graham et al. (1994) and by U.S. Forest Service Region 3 for CWD in ponderosa pine forests in Arizona.

Prior to the exclusion of fire in the Southwest forest landscape, there was probably a wide range of CWD concentrations that surged and declined on a cyclical basis depending on the frequency and intensity of fire. However, in general, it seems reasonable to assume that with the frequent-fire regime typical of the pre-fire suppression era, there would have been more large, sound CWD (greater than 14 or 16 inches) and less FWD and rotten CWD (Covington and Sackett 1984). Restoring the spatial pattern and structure of today's overstocked ponderosa pine forests, and reintroducing fire will most likely result in similar concentrations of CWD and FWD after some period of time.

Management Considerations

Most of the ponderosa pine and mixed conifer forests are significantly outside their natural range of variability with regards to trees per acre. This situation coupled with fuel loadings, even when they are within the range recommended by Graham et al. (1994), Brown et al. (2003) and Region 3 of the Forest Service, presents land managers with a potentially high fire hazard and calls for sound management of CWD.

In the restoration of frequent-fire forest ecosystems, land managers need to make decisions about CWD based on their resource goals. If, for example, the goal is to reduce the potential for fire next to a human community (i.e., in a Wildland-Urban Interface), it might be appropriate to have CWD in amounts at the lowest end of the Forest Service's recommended range (5 tons/acre), or possibly lower. On the other hand, if the goal is to maintain and improve prey species for goshawks and other raptors, it might be best to maintain a higher amount of CWD (20-25 tons/acre) in a variety of decay classes.

From an ecological perspective, land managers should concentrate on retaining a diversity of CWD classes that are distributed across the landscape (Harvey et al. 1987, Graham et al. 1994). Large CWD material, especially old logs that have some level of advanced decay, should receive special attention because of their importance for many species of animals.

Since fire is an evolutionary process that shaped the forests of the Southwest, land managers can use it to manage CWD. As Harvey et al. (1987) pointed out, moisture is so limiting in southwestern ponderosa pine sites that it delays the biological breakdown of organic matter and leads to accumulations of CWD and other smaller materials. Under these conditions, fire has as much influence or more on the cycling of important soil nutrients, especially once the former openings have sufficient grass cover to carry a fire (DeBano et al. 1998, Brown et al. 2003).

Finally, land managers need to remember that adequate levels of CWD calls for maintaining a sufficient population of snags, not only for immediate use by cavity-nesting birds, bats and other animals, but to serve as future CWD (see ERI Working Paper 16 for information about snags).

Measuring Coarse Woody Debris

There are two basic ways to measure coarse woody debris: 1) using a photo series estimation method and 2) planar transect sampling. Both have advantages and disadvantages. Photo series are considered easy-to-use, reasonably fast and inexpensive, while transect sampling is more time consuming and costly, but provides a much higher degree of accuracy than photo series estimates.

Photo series are typically provided in a booklet than can be taken to the field, where the photos can be compared with existing field conditions in order to make an estimate of CWD loading. Each booklet contains a number of photos sets that are organized according to the dominant tree species, tree size class, and management treatment (e.g., precommercial thinning, partial cut, natural). A data sheet accompanies each photograph and provides other information, such CWD loading by size class, percent sound CWD, basic stand information, and an assessment of fire behavior. Land managers in the Southwest who want to use photo series to estimate CWD, may be able to obtain a copy of *Photo Series for Quantifying Forest Residues in the Southwestern Region* (USDA Forest Service 1996b).

Transect sampling methods for CWD are well defined and improved from the earlier work by Brown (1974), Brown and Roussopoulos (1974), and Brown et al. (1982). See Waddell (2002) for a summary of these methods and their biases. Fulé and Covington (1994) suggested "double sampling" as an alternative to these transect sampling procedures; their method being as precise, but less costly and time-consuming, than traditional transect sampling. A similar method, although without the double sampling, is now used by the Forest Service's Forest Inventory and Analysis Program (Woodall online, accessed 2007; Lutes and Kean online, accessed 2007). For an even more thorough inventory and monitoring method, consult the FIREMON, Fire Effects Monitoring and Inventory Protocol (FIREMON online, accessed 2007).

Removing Coarse Woody Debris

After inventorying and analyzing the amount of CWD in a stand, land managers may decide that there is enough to meet their resource goals and objectives, or they may decide to decrease the amount. There are a number of standard treatments for removing CWD—prescribed fire/broadcast burn, mastication, pile and burn, and physical removal. While they are described briefly here, more detailed discussion of these methods can be found in ERI Working Paper 13 (https://library.eri.nau.edu:8443/handle/2019/170) or in appropriate Forest Service manuals and handbooks.

Prescribed Fire/Broadcast Burn

Prescribed fire is the preferred method of treating excess CWD to meet or maintain soil quality and long-term site productivity goals. Prescribed fire will remove the needles and small branches (the hazard fuels) while at the same time maintaining much of the on-site organic matter (Graham et al. 1994). Prescribed burns reduce the risk of stand-replacing wildfire by decreasing the overall forest fuel load. Broadcast burns can potentially consume heavy loads of CWD, which in turn can be destructive to soils, fungi, the seedbank and plants, and can kill trees remaining after thinning. Smoke from large fires may require public safety measures (e.g., road signs, public notices, etc.).

Work to ensure that burning is done at low intensity. Don't expect to reduce the CWD in one burn; several burns may be required. Large CWD will likely only scorch (Maser et al. 1979) and will not be consumed, which is fine. Identify Class

4 and 5 CWD and make sure that they do not become the source for a larger fire; fire line them or wet them down, as necessary.

Mastication

Mastication is a mechanical thinning treatment in which a machine is used to reduce CWD and other woody material to wood chips or wood mulch (Windell and Bradshaw 2000). The resulting material is left on the ground to decompose or be consumed by a prescribed burn. If done properly, masticated CWD breaks down faster than undisturbed CWD and it can help reduce the intensity of prescribed burns. Compressed slash holds less oxygen and is not in a vertical arrangement, resulting in lower tree mortality when broadcast burned (Jerman et al. 2004). Mastication may be used as a substitute for burning in areas where fire is not desirable (e.g., rights-of-way for utilities or transportation, areas where smoke is a concern).

Roller chopping, chipping, smashing of logging slash should be done with care, however, because deep compacted layers of organic matter can develop. These layers insulate the mineral soil, which can lead to lower soil temperatures, slow organic matter decomposition, nitrogen deficiency, and retarded root growth (Graham et al. 1994). Chopping and chipping of slash destroys many of the attributes of CWD that are important to nitrogen fixation, animal habitat, and site preparation (Graham et al. 1994). Thick concentrations of chips or mulch will also likely prevent the establishment or reduce the herbaceous vegetation component until the masticated material decomposes or is burned. Damage to tree roots and erosion are real concerns (although see Hatchett et al. 2006).

Mastication is typically not effective in narrow areas (i.e., less than 66 feet) or on steep slopes (i.e., greater than 20%) or areas with broken terrain. Costs run from $150-$255/acre on relatively flat sites with road access and wide spacing between trees, and up to $1,500/acre on steeper, less accessible sites (Rummer online, accessed 2007).

To minimize soil compaction, use low ground pressure machines. Use a machine with either vertical or horizontal shaft cutters if areas will be treated with a prescribed burn. If no burn is planned, use horizontal shaft cutters because they produce a finer material that will decompose quickly (Rummer online, accessed 2007). Monitor the mastication operation and check the soil for several months post-treatment to see if there is any change in soil chemistry due to the presence of the chips or mulch.

Pile and Burn

Unmarketable wood and debris can be mechanically or manually gathered and piled throughout the site. The advantages of this method are 1) piles can be burned in a controlled manner and 2) it is relatively inexpensive. However, burning piles causes excessive soil heating and slash pile scars often remain bare for a long time unless revegetated. In some cases, invasive species take hold at slash pile sites and spread from them (Korb et al. 2004). Creating piles with machines typically results in large, heavy piles that can produce severe soil compaction. In addition, the machinery used has the potential to compact soil in areas near the piles. Hand-piling produces less severe and extensive soil disturbances, but it is very labor intensive and produces more piles within a project area. Grapple piling of logging slash appears to more easily separate fine fuels from CWD and provide more flexibility on steeper slopes (Graham et al. 1994).

When possible, build small slash piles on existing roads or disturbed areas to minimize damage to undisturbed soils. If piles are built on previously undisturbed forest soils, inoculate the soil after the piles are burned with a commercially purchased arbuscular mycorrhizae (see http://www.AgBio-Inc.com) and then revegetate with certified native seeds. Research suggests that, if properly done, this action will increase the density of native forb and grass cover (Korb et al. 2004).

Physical Removal

This method is generally used only if the project is small and there is minimal CWD. In this process, the CWD is loaded on trucks and taken to another location, where it is burned or chipped. This can be a very expensive method and is often not economically practical unless some value can be derived from turning the CWD into chips or mulch.

Before choosing any of these treatment methods, a land manager may want to run some different scenarios using a U.S. Forest Service tool called My Fuel Treatment Planner (http://www.fs.fed.us/pnw/data/myftp/myftp_home.htm).

Providing Additional Coarse Woody Debris

While in most cases there will be an abundance of CWD even after restoration treatments (due to decades without ground fires), there may be some instances where creating CWD is necessary to meet resource goals and objectives. In such cases, land managers can simply take logs or limbs from treatment areas, and move them into areas where they will provide effective wildlife habitat and soil protection (especially on steep slopes). Managers can also designate trees to be cut and dropped and left on site as CWD. These forms of CWD can be tops, cull and sound logs, and snags, in situations where snags are abundant and can be dropped safely.

References

Brown, J.K. 1974. Handbook for inventorying downed woody material. General Technical Report INT-16. Ogden, UT: USDA Forest Service Intermountain Forest and Range Experiment Station. http://www.fs.fed.us/rm/pubs_int/int_gtr016.pdf.

Brown, J.K. and P.J. Roussopoulos. 1974. Eliminating biases in the planar intersect method for estimating volumes of small fuels. *Forest Science* 20:350-356.

Brown, J.K., R.D. Oberhu, and C.M. Johnston. 1982. Handbook for inventorying surface fuels and biomass in the Interior West. General Technical Report INT-129. Ogden, UT: USDA Forest Service Intermountain Forest and Range Experiment Station.

Brown, J.K., E.D. Reinhardt, and K.A. Kylie. 2003. Coarse woody debris: Managing benefits and fire hazard in the recovering forest. General Technical Report RMRS-GTR-105. Ogden, UT: USDA Forest Service Rocky Mountain Research Station.

Bunnell, F.L., M. Boyland, and E. Wind. 2002. How should we spatially distribute dying and dead wood? Pages 739-752 in W.F. Laudenslayer, Jr., P.J. Shea, B.E. Valentine, C.P. Weatherspoon, and T.E. Lisle, tech. coordinators. Proceedings of the conference on the ecology and management of dead wood in western forests. November 2-4, 1999 Reno, Nevada. General Technical Report PSW-GTR-181. Albany, CA: USDA Forest Service Pacific Southwest Research Station.

Carey, A.B. and M.L. Johnson. 1995. Small mammals in managed, naturally young, and old-growth forests. *Ecological Applications* 5(2):336-352.

Covington, W.W. and S.S. Sackett. 1984. The effect of a prescribed burn in southwestern ponderosa pine on organic matter and nutrients in woody debris and forest floor. *Forest Science* 30(1):183-192.

Cram, D.S., T.T. Baker, A.G. Fernald, A. Madrid, and B. Rummer. 2007. Mechanical thinning impacts on runoff, infiltration, and sediment yield following fuel reduction treatments in a southwestern dry mixed conifer forest. *Journal of Soil and Water Conservation* 62(5):359-366.

DeBano, L.F., D.G. Neary, and P.F. Ffolliot. 1998. *Fire's effects on ecosystems*. New York: Wiley.

FIREMON (Fire Effects Monitoring and Inventory Protocol). Online, accessed October 2007. http://frames.nbii.gov/portal/server.pt?open=512&objID=286&&PageID=495&mode=2&in_hi_userid=2&cached=true.

Fulé, P.Z. and W.W. Covington. 1994. Double sampling increases the efficiency of forest floor inventories for Arizona ponderosa pine forests. *International Journal of Wildland Fire* 4(1):3-10.

Gottfried, G.J. and K.E. Severson. 1994. Managing pinyon-juniper woodlands. *Rangelands* 16(6):234-236.

Graham, R.T., A.E. Harvey, M.F. Jurgensen, T.B. Jain, J.R. Tonn, and D.S. Page-Dumroese. 1994. Managing coarse woody debris in forests of the Rocky Mountains. Research Paper INT-RP-477. Ogden, UT: USDA Forest Service Intermountain Research Station.

Graham, R.T., T.B. Jain, A.E. Harvey, M.F. Jurgensen, J.R. Tonn, D.S. Page-Dumroese. 1996. Recommendations for managing coarse woody debris in mixed conifer forests of Arizona and New Mexico. Unpublished.

Graham, R.T., S. McCaffrey, and T.B. Jain, tech.eds. 2004. Science basis for changing forest structure to modify wildfire behavior and severity. General Technical Report RMRS-GTR-120. Fort Collins, CO: Rocky Mountain Research Station.

Griffiths, R., M. Madritch, and A. Swanson. 2005. Conifer invasion of forest meadows transforms soil characteristics in the Pacific Northwest. *Forest Ecology and Management* 208:347–358.

Hatchett, B, M.P. Hogan, and M.E. Grismer. 2006. Mechanical mastication thins Lake Tahoe forest with few adverse impacts. *California Agriculture* 60(2):77-82. Online, accessed October 2007 http://CaliforniaAgriculture.ucop.edu.

Harmon, M. E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research* 15:133–302.

Harvey, A.E., M.F. Jurgenson, and M.J. Larson. 1979. Role of forest fuels in the biology and management of soil. General Technical Report INT-GTR-65. Ogden, UT: USDA Forest Service Intermountain Forest and Range Experiment Station.

___. 1981. Organic reserves: Importance of ectomycorrhizae in forest soils of western Montana. *Forest Science* 27:442-445.

Harvey, A.E., M.F. Jurgensen, and R.T. Graham. 1988. The role of residues in soils of ponderosa pine forests. Pages 141-147 *in* D.M. Baumgartner and J.E. Lotans, eds. Proceedings of symposium--Ponderosa pine: The species and its management. Pullman, WA: Washington State University Cooperative Extension.

Harvey, A.E., M.F. Jurgenson, M.J. Larson, and R.T. Graham. 1987. Decaying organic materials and soil quality in the Inland Northwest: A management opportunity. General Technical Report INT-225. Ogden, UT: USDA Forest Service Intermountain Forest and Range Experiment Station.

Harvey, A.E., M.J. Larson, and M.F. Jurgenson. 1980. Biological implications of increasing harvest intensity on the maintenance and productivity of forest soils. Pages 211-220 in Proceedings of a symposium: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests; September 11-13; Missoula, MT. General Technical Report INT-90. Ogden, UT: USDA Forest Service Intermountain Forest and Range Experiment Station.

Hubka, T. 2007. Team studying ways to convert forest fodder into energy. *The Curry Pilot*, September 29. Online, accessed October 2007, http://www.currypilot.com/news/story.cfm_no=15989.

Jerman, J.L., P.J. Gould, and P.Z. Fulé. 2004. Slash compression treatment reduced tree mortality from prescribed fire in southwestern ponderosa pine. *Western Journal of Applied Forestry* 19(3):149-153.

Lutes, D.C. and R.E. Keane. Fuel Load (FL) Sampling Method. Online, accessed October 2007, http://frames.nbii.gov/projects/firemon/Fuel_Load.pdf.

Korb, J.E., N.C. Johnson, and W.W. Covington. 2003. Arbuscular mycorrhizal propagule densities respond rapidly to ponderosa pine restoration treatments. *Journal of Applied Ecology* 40(1):101-110.

___. 2004. Slash pile burning effects on soil biotic and chemical properties and plant establishment: Recommendations for amelioration. *Restoration Ecology* 12(1):52-62.

Maser, C., R.G. Anderson, K. Cromack, Jr., J.T. Williams, and R.E. Martin. 1979. Dead and down woody material. Pages 78-95 (Chapter 6) in J.W. Thomas, ed. Wildlife habitats in managed forests in the Blue Mountains of Oregon and Washington. Agricultural Handbook Number 53. Portland, OR: USDA Forest Service Pacific Northwest Region.

Moir, W. H., B. Geils, M.A. Benoit, and D. Scurlock. 1997. Ecology of southwestern ponderosa pine forest. Pages 3-27 in W.M. Block and D.M. Finch, tech. eds. Songbird ecology in southwestern ponderosa pine forests: A literature review. General Technical Report RM-GTR-292. Fort Collins, CO: USDA Forest Service Rocky Mountain Forest and Range Experiment Station. http://www.fs.fed.us/rm/pubs_rm/rm_gtr292/rm_gtr292_003_027.pdf.

Payne, N.F. and F.C. Bryant. 1994. *Techniques for wildlife management of uplands.* New York: McGraw-Hill.

Reynolds, R.T., R.T. Graham, M.H. Reiser, R.L. Bassett, P.L. Kennedy, D.A. Boyce, Jr., G. Goodwin, R. Smith, and E.L. Fisher. 1992. Management recommendations for the northern goshawk in the southwestern United States. General Technical Report RM-217. Ft. Collins, CO: USDA Forest Service Rocky Mountain Forest and Range Experiment Station.

Rummer, R. Mechanical reduction equipment: Case studies. Online, accessed October 2007, http://www.srs.fs.usda.gov/forestops/presentations/Case%20Studies.pdf.

Selmants, P.C., A. Elseroad, and S.C. Hart. 2003. Soils and nutrients. Pages 144-160 *in* P. Friederici, ed. Ecological restoration of southwestern ponderosa pine forests. Washington, D.C.: Island Press.

Skog, K.E. and R.J. Barbour. 2006. Estimating woody biomass supply from thinning treatments to reduce fire hazard in the U.S. West. Pages 657-672 in P.L. Andrews and B.W. Butler, compilers. Conference proceedings RMRS-P-41—Fuels management: How to measure success. Ft. Collins, CO: USDA Forest Service Rocky Mountain Research Station.

Stoddard, M.T. 2006. Slash addition: A tool for restoring herbaceous communities in degraded pinyon-juniper woodlands. Masters thesis. Northern Arizona University. Online, accessed November 2007, https://library.eri.nau.edu:8443/handle/2019/252.

Thomas, J.W., ed. 1979. Wildlife habitats in managed forests in the Blue Mountains of Oregon and Washington. Agricultural Handbook Number 53. Portland, OR: USDA Forest Service Pacific Northwest Region.

U.S. Forest Products Laboratory. 2007. 2008 Woody biomass grants. Online, accessed October 2007, http://www.fpl.fs.fed.us/tum/.

USDA Forest Service. 1996a. Appendix C. Standards and guidelines in selected alternative (G). Region 3 1996 Record of Decision for amendment of forest plans: Arizona and New Mexico. Albuquerque, NM: USDA Forest Service. http://www.fs.fed.us/r3/projects/decisions/rod_appendix_c.pdf.

___. 1996b. Photo series for quantify forest residues in the southwestern region. Albuquerque, NM: USDA Forest Service Southwestern Region.

___. 1999. Region 3 Supplement to the Soil and Water Management Handbook R-3 Supplement No. 2509.18—99-1. Albuquerque, NM: USDA Forest Service.

___. 2004. Down woody material field manual of 2004. St. Paul, MN: USDA Forest Service North Central Research Station, National Forest Inventory and Analysis Program of the North Central Research Station. Online, accessed November 2007, http://www.ncrs.fs.fed.us/4801/national-programs/indicators/dwm/documents/dwm-field-manual-2004.pdf.

___. 2007. Down wood materials: Glossary. USDA Forest Service Indicator Advisor Band. Online, accessed November 2007, http://nrs.fs.fed.us/fia/topics/dwm/glossary.

Waddell, K.L. 2002. Sampling coarse woody debris for multiple attributes in extensive resource inventories. *Ecological Indicators* 1(3):139–153.

Ward, J.P., Jr. and W.M. Block. 1995. Mexican spotted owl prey ecology. Pages 1-48 (Chapter 5) in Recovery plan for the Mexican spotted owl, Volume 11. Albuquerque, NM: USDI Fish and Wildlife Service.

Windell, K. and S. Bradshaw. 2000. Understory biomass reduction methods and equipment catalog. Technical Report 0051-2826-MTDC. Missoula, MT: USDA Forest Service Missoula Technology Development Center. Online, accessed December 2007, http://www.fs.fed.us/eng/php/library_card.php?p_num=0051%202826.

Woodall, C.W. The national inventory of down woody materials: Methods, outputs and future directions. St. Paul, MN: USDA Forest Service North Central Research Station. Online, accessed October 2007, http://ncrs.fs.fed.us/pubs/jrnl/2002/nc_2002_woodall_001.pdf.

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