Fire as a Coarse Filter for Snags and Logs[1]

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Abstract

Fire played an important role in maintaining and creating conditions suitable for native flora and fauna in the forests of western North America. Recent coarse filter conservation strategies have advocated creating future landscapes that incorporate historic or natural ranges of variability, including fire regimes. Historic fire regimes were variable across the West, and created quite unique coarse woody debris dynamics in low-, mixed-, and high-severity fire regimes. Moving towards more historic landscape structures will require variable standards for coarse woody debris retention.

Introduction

Fire has been the most pervasive natural disturbance factor across western forest landscapes (Barnes and others 1998), but it did not work independently of other disturbances. Fire has had both local and broad scale effects on the forests of western North America (Agee 1993), but these effects differ considerably by fire regime. For many decades, foresters, ecologists, and others neglected the contribution of dead wood to biodiversity in the forest. In a typical interior West forest, about two-thirds of the birds and up to 90 percent of the small mammals, reptiles, and amphibians utilize dead wood for cover, roosting, or foraging for food (Thomas 1979). The dead wood can be snags (standing dead trees) or logs (dead trees or portions of them lying on the ground).

The concept of ecosystem ranges of variability (Morgan and others 1994) has been suggested as a framework for coarse filter conservation strategies (Hunter 1990). A coarse filter conservation strategy seeks to preserve biological diversity by maintaining a variety of naturally-functioning ecosystems across the landscape. If it is possible to produce or mimic the historic ranges in stand size, composition, and connectivity by forest type on current and future landscapes, then much of the habitat for native flora and fauna might well be present. Mimicking the historic ranges of coarse woody debris should also help these conservation strategies. Fine-filter strategies, such as individual species plans or snag retention, might still be needed, but most species and ecosystem elements should be present if natural ranges in habitat are provided (Haufler and others 1996). Although coarse woody debris is an important structural component of forest ecosystems, managing for maximization of coarse woody debris, or having uniform standards across historically variable landscapes, is a fine-filter strategy that can literally backfire. The use of coarse

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woody debris levels characteristic of historical disturbance regimes is recommended as an alternate system more likely to be sustainable (Edmonds and Marra 1999).

The Historical Fire Regime

Natural disturbances range from benign to severe and can be generated from within or outside of the ecosystem (White 1987). The disturbance effects in either case are due in part to current pattern or structure and to the nature of the disturbance. Disturbance is usually characterized by a combination of factors: type, frequency, variability, magnitude, extent, seasonality, and synergism with other disturbances (White and Pickett 1985). The fire regimes of western forests are usually described in terms of historical fires (defined here as pre-European settlement). They are interpreted much the same way as potential vegetation (Daubenmire 1968), namely what occurred historically and what the trajectories of change may be with or without management (Agee 1993). The effect of Native Americans on fire ignitions is inextricably confounded with lightning ignitions, and the historical fire regime therefore includes native ignitions.

Fire regimes based on fire severity (Agee 1993) are defined by effects on dominant organisms, such as trees, and, although broadly described in three classes, can be disaggregated to the forest type or plant association level if desired. The historical high-severity fire regimes were those in which the effect of a fire was usually a stand replacement event. Fire return intervals were generally 100 or more yrs. The mixed-severity fire regimes had a complex mix of severity levels, with fire return intervals usually 25 to 75 yrs. The low-severity fire regimes were those in which the typical fire was benign to dominant organisms across much of the area it burned, and fire return intervals were generally 5 to 25 yrs. The Interior Columbia Basin Ecosystem Management Project (ICBEMP) has the synonymous fire regimes of lethal, mixed, and nonlethal, respectively (Quigley and others 1996). Because landscape ecology varied widely across the forest landscapes of western North America *(fig. 1)*, coarse-filter conservation strategies, including attention to coarse woody debris, should recognize that variability.

The Low-Severity (Nonlethal) Fire Regimes

Low-severity fire regimes typically had large fires (Wright 1996) but small patch sizes. Fires burned frequently in these forests (Agee 1993), and by regularly consuming fuels, killing small trees, and pruning the boles of residual trees, maintained a relatively fire-resistant landscape. Forests with significant components of ponderosa pine *(Pinus ponderosa* Dougl. ex Laws.) had very small patch sizes, ranging from 0.02 to 0.35 ha (Agee 1998b, Bonnicksen and Stone 1981, Cooper 1960, Morrow 1985, West 1969, White 1985), due to group kill of pines by bark beetles *(Dendroctonus* spp.), or perhaps root disease pockets, and subsequent consumption of the debris by several fires. Because these dead patches were small and limited in extent, patch edge was also limited. Most of the forest was a fairly uniform mosaic of mature tree clusters and grassy understories.

Before getting carried away by the idyllic vision of an equilibrium forest, it is important to note that exceptions did occur, even in ponderosa pine forests. Defoliation by pine butterfly *(Neophasia menapia* [Felder and Felder]) created much larger patches, at least in some areas of south-central Washington (Weaver 1961), and the Black Hills of South Dakota had pine stands that appear to have had less frequent but more severe fires, and much larger patch sizes (Shinneman and Baker 1997). These latter stands are transitional to boreal forest, containing some white spruce *(Picea glauca* [Moench] Voss). Clearly, though, the wide range of studies in low-severity fire regimes support the notion of an equilibrium system, including at least some of the Black Hills (Shinneman and Baker 1997).

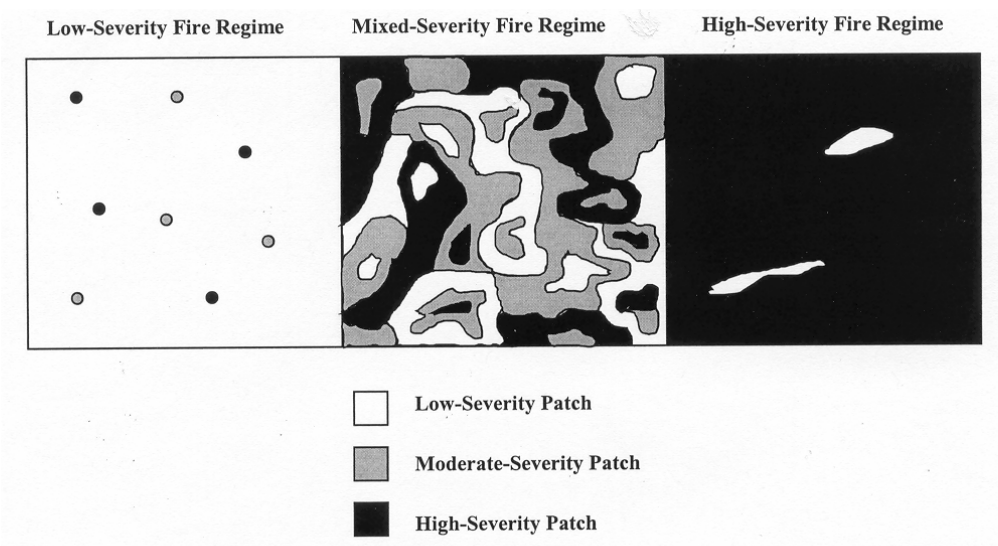

Figure 1—A schematic landscape pattern of fire regimes. Black dots in low-severity fire regimes are very old patches of large, old trees being killed by insects and decomposed by fire, and gray dots are emerging small-sized stands that have less-defined edge with older forest than the recently killed patches. The mixed-severity fire regime is typically a complex mosaic of larger patches of the three fire severity levels, while the high-severity fire regime has large, stand replacement patches (Agee 1998b).

As individual tree clusters became senescent, they would be attacked by bark beetles, creating a patch of coarse woody debris that would be consumed by the next several fires passing under the forest. Coarse woody debris under such a regime, both snags and logs, would have been limited and clustered. Over the landscape was a highly connected system of older forest, dotted with regenerating patches and clusters of coarse woody debris.

For example, a small set of stands in an eastern Cascades mixed-conifer forest might be divided into 16 age classes (patches), each separated from the next by 25 years so that the age range covers 400 years. Each is 0.1 ha in size, and every 25 years, pine beetles attack the oldest stand and group-kill it. Every 10 years fires underburn through the stands. Most thinning occurs when stands are young, so that little substantial snag component is produced except in the beetle-killed patches. Tree density averaged 50 to 60 trees ha^{-1} in historic *Pinus ponderosa* and *Pseudotsuga menziesii* ([Mirb.] Franco) forest series in the eastern Cascades (Agee 1998a, Harrod and others 1999). Therefore, six trees per 0.1 ha were used as the average tree density of an individual patch.

Fires will help to decompose a snag patch by consuming the woody debris, and in this example it will be assumed that after five fire events (50 years) the snags are completely burned down. At any time in this scenario, there is one fresh snag patch (0 to 25 yrs) and one patch in advanced "decay" (25 to 50 yrs). Harrington (1996) found about 80 percent of fire-killed small ponderosa pine fell in less than 10 years; thus, an assumption that a fresh snag patch will have six large, old trees and a decaying patch (25 to 50 yrs) two trees appears reasonable, if perhaps a bit on the high (conservative) side. Therefore, on our landscape of 1.6 ha, composed of sixteen 0.1 ha patches, we have at any one time about eight snags. This is equivalent to 500 snags 100 ha^{-1} (about 200 100 ac^{-1}) and would constitute a sustainable snag density over time in the natural forest. Harrod and others (1998) estimated higher densities of 1,457 to 3,483 100 ha^{-1} (590 to 1,410 100 ac^{-1}) but assumed snags would fall on their own rather than fall being accelerated by fire.

Logs will be a limited resource in this scenario, as they are clustered in the snag patches and the concentration aids ignition and consumption of the logs. Just as the snags were spatially dynamic, logs were as well, but probably had a shorter residence time than the snags because of their proximity to the recurring surface fires. If we assume that the average tree size in the mature clumps was about 75 cm dbh, then snag biomass would have totaled about 8.1 Mg ha^{-1}, and log biomass somewhat less than 5 Mg ha^{-1} for the frequently burned low-severity fire regime.

The Mixed-Severity (Moderate) Fire Regimes

Mixed-severity fire regimes had larger patch sizes and considerable edge *(fig. 1)*. These fires maintained both a naturally fragmented forest structure and fuel structure. Patch size in the mixed-severity fire regimes is typically larger than for the low-severity fire regimes. Patch size for mixed-severity forests (including some drier westside Cascade forests) ranges from 2.5 to 250 ha (Agee 1998b). Patch edge is typically much higher for mixed-severity fire regimes than for high-severity fire regimes (although the methods for defining a patch will significantly influence any edge metric). The result, both from fire and other disturbances, was considerable local-scale patchiness on the landscape (Taylor and Halpern 1991). Patches burned with light fires had surface fuels removed and only understory trees killed. Patches burned with higher intensity fires had some overstory removed (similar to the first entry on a shelterwood) and resulted in a favorable environment for regeneration of a new age class of trees (generally shade-tolerant species: white fir [*Abies concolor* {Gord. and Glend.} Hildebr.] or grand fir [*Abies grandis* {Dougl. ex D. Don} Lindl.], Douglas-fir [on dry sites], red fir [*Abies magnifica* A. Murr.], and/or sugar pine [*Pinus lambertiana* Dougl.]). Patches burned with very high intensity within the mixed-severity fire regime had all the overstory killed and created an environment for shrubfields or new shade-intolerant tree species (typically western larch (*Larix occidentalis* Nutt.) or lodgepole pine (*Pinus contorta* Dougl.) (Antos and Habeck 1981, Cobb 1988). Landscape position in part explains differential severity: lower slope positions had the least amount of severe fire, while upper slopes, particularly of west or south aspect, and ridgetops experienced more severe fire (Taylor and Skinner 1998).

Coarse woody debris dynamics were quite complex in the mixed-severity fire regimes (Agee 1993). Periodic fires consumed log biomass, and in underburned patches, coarse woody debris would decrease. In the patches where either thinning or stand-replacement fire occurred, some log consumption occurred, but snags were also created. A net increase, or pulse, of coarse woody debris was likely after a typical fire event. Decomposition would decrease woody debris loads over time, but replenishment would occur from the periodic fires at 25- to 100-year intervals. Data from Wright (1998) showed for a mixed-severity fire regime in Douglas-fir about 40 Mg ha^{-1} in snags and 55 Mg ha^{-1} in logs, with the totals varying among stands from 20-250 Mg ha^{-1}. Because this fire regime has low-, moderate-, and high-severity patches closely mixed, these levels would probably serve as an integrated average level of coarse woody debris across the variety of patch types and sizes in this fire regime.

The High-Severity (Lethal) Fire Regimes

Disturbance events in high-severity fire regimes often have large patch sizes *(fig. 1).* Although the large majority of fires historically remained quite small, the vast majority of area affected by fire is from the few large events that cover thousands of hectares (Bessie and Johnson 1995, Romme 1982, Romme and Despain 1989). Small fires tend to have little edge, while larger events tend to be more patchy and leave more residual islands (unburned stringers) (Eberhart and Woodard 1987). Generally, the edge created in the high-severity fire regimes is less than in the mixed-severity fire regimes (Agee 1998b).

The distribution of stand ages in the high-severity fire regimes is not clear. Even if an assumption about the nature of disturbance allows a fit of age classes to a distribution such as the Weibull or negative exponential, there are still assumptions about long-term stability (e.g., stable climate over centuries) that may alter the age class structure. Several characteristics of the high-severity fire regimes of western forests are unquestionable: the fire return intervals were long (usually >100 yrs); some stand ages exceed the average fire return interval, suggesting that either the concept of "refugia" (Camp and others 1997) or just random chance are operating; and fires often impose a new landscape mosaic by burning stands of various ages (Bessie and Johnson 1995).

Coarse woody debris dynamics in the high-severity fire regimes typically followed a "boom and bust" cycle (Agee and Huff 1987, Spies and others 1988). After a large fire event, coarse woody debris was at a high, as the live trees were all converted to snags and then logs *(fig. 2).* As the new stand developed, the coarse woody debris levels dropped as the fire-created material slowly decomposed, and snags created by self-thinning of the new stand were too small to add much volume. In mid-succession, perhaps 100 to 200 years, severe thinning by disease and insects could create pulses of coarse woody debris, and as succession proceeded these levels slowly increased by additions of individual trees. Wright (1998), working in high-severity Douglas-fir forests of the Oregon Cascades, showed an average of 150 Mg ha^{-1} in stands generally 200 years post-fire and older. Agee and Huff (1987) showed the variability over a chronosequence in moist western hemlock (*Tsuga heterophylla* [Raf] Sarg) Douglas-fir forest *(table 1).*

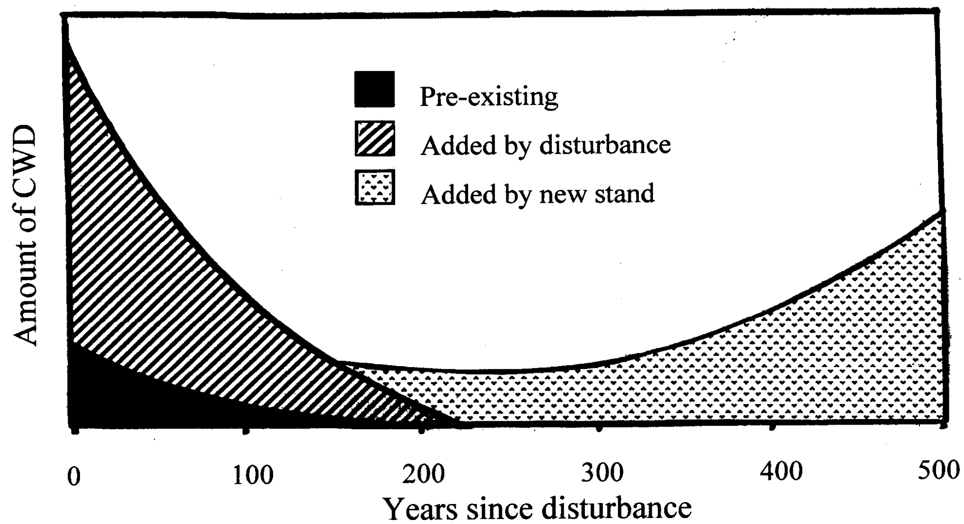

Figure 2—Trends in variation in coarse woody debris loads in high-severity fire regimes in moist western hemlock/Douglas-fir forest, Olympic Mountains, Washington (Agee and Huff 1987).

Table 1—*Coarse woody debris loads over a 500-year chronosequence in western hemlock forest in the Olympic Mountains, Washington (Agee and Huff 1987). This is a high-severity fire regime.*

Type of coarse woody debris	**Post-fire stand age (years)**					
	1	3	20	100	180	500
	mg ha^{-1}					
Snags	775	1,066	279	35	33	84
Logs	282	230	438	118	112	441
Total	1,057	1,296	717	153	145	525

Coarse Filter Implications

The examples of coarse woody debris dynamics discussed imply quite unique amounts and patterns among the low-, mixed-, and high-severity fire regimes *(fig. 3).* The low-severity fire regime had quite low biomass with minor fluctuations; the mixed-severity fire regime had higher loads on a sustainable basis but more fluctuation in levels over time; and the high-severity fire regimes had the highest loading, and substantial fluctuation over time. Coarse woody debris standards, if they are to mimic the natural forest, must be designed to fit the forest to which they are applied.

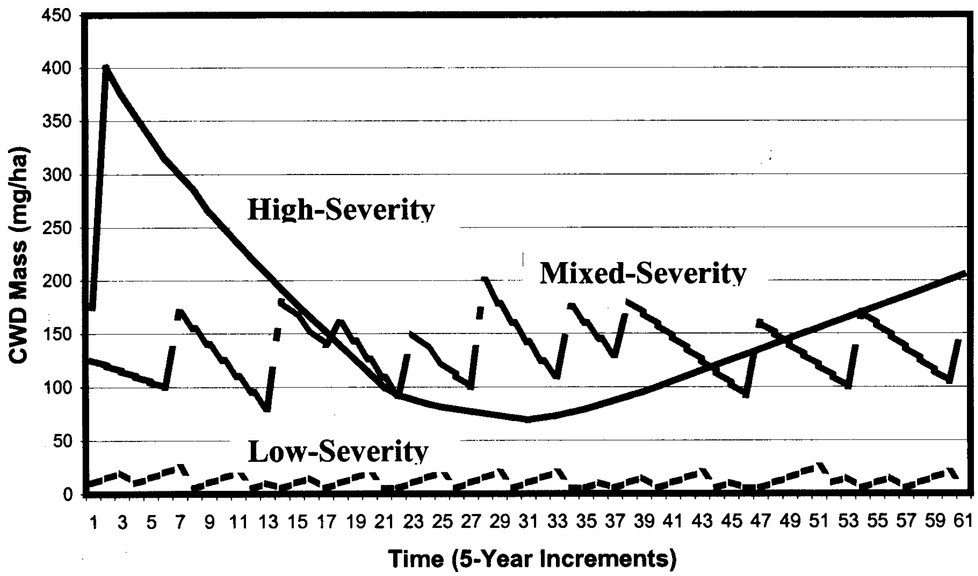

Figure 3—A model of coarse woody debris dynamics in low-severity, mixed-severity, and high-severity fire regimes in western forests. Average amounts of coarse woody debris and fluctuations vary by fire regime.

Natural processes such as fire can be restored to create ecologically sustainable forests (e.g., Dale and others 1999) only if coarse woody debris standards are tailored to the forest type and historic fire regime. For example, in a mixed conifer forest with a historic low-severity fire regime, prescribed fire in either spring or fall *(fig. 4)* will substantially reduce coarse woody debris. Residual coarse woody debris loads in this example were about 40 Mg ha^{-1} (Thomas and Agee 1986), still well above the levels of historic forests with a similar historic fire regime. Burning prescriptions designed to retain most coarse woody debris can produce a "non-window": duff moisture levels so high that such moisture contents are rarely if ever attained on these sites. Constraints to preserve all or most coarse woody debris effectively eliminate the use of fire for restoration purposes and leave the dry forest types at risk for stand-replacing fire. When such high-severity fire occurs, it brings with it the "boom and bust" coarse woody debris dynamics of the high severity fire regimes. This is a classic case of the fine-filter (log preservation) trumping the coarse-filter (restoring the natural process), and in the long run is likely to result in a failed conservation strategy (Agee 1999).

Unfortunately, few coarse-filters can be successful on their own. We can reintroduce the friendly flame, but in many western forests the historic structure is gone: too few large trees, too many little ones, and substantial time before new large coarse woody debris will be produced. Today many species are at the brink of extinction so that natural processes like fire, reintroduced at historic levels in a damaged ecosystem, may be inappropriate. The role of fire as a coarse-filter conservation strategy (Agee 1999) cannot be blindly applied as a "natural" solution; it will have to come in many shapes and sizes. However, understanding the historic role of fire will provide a template for designing appropriate coarse woody debris loads in our western forest landscapes. Levels of coarse woody debris, as well as temporal and spatial variability, need to be addressed.

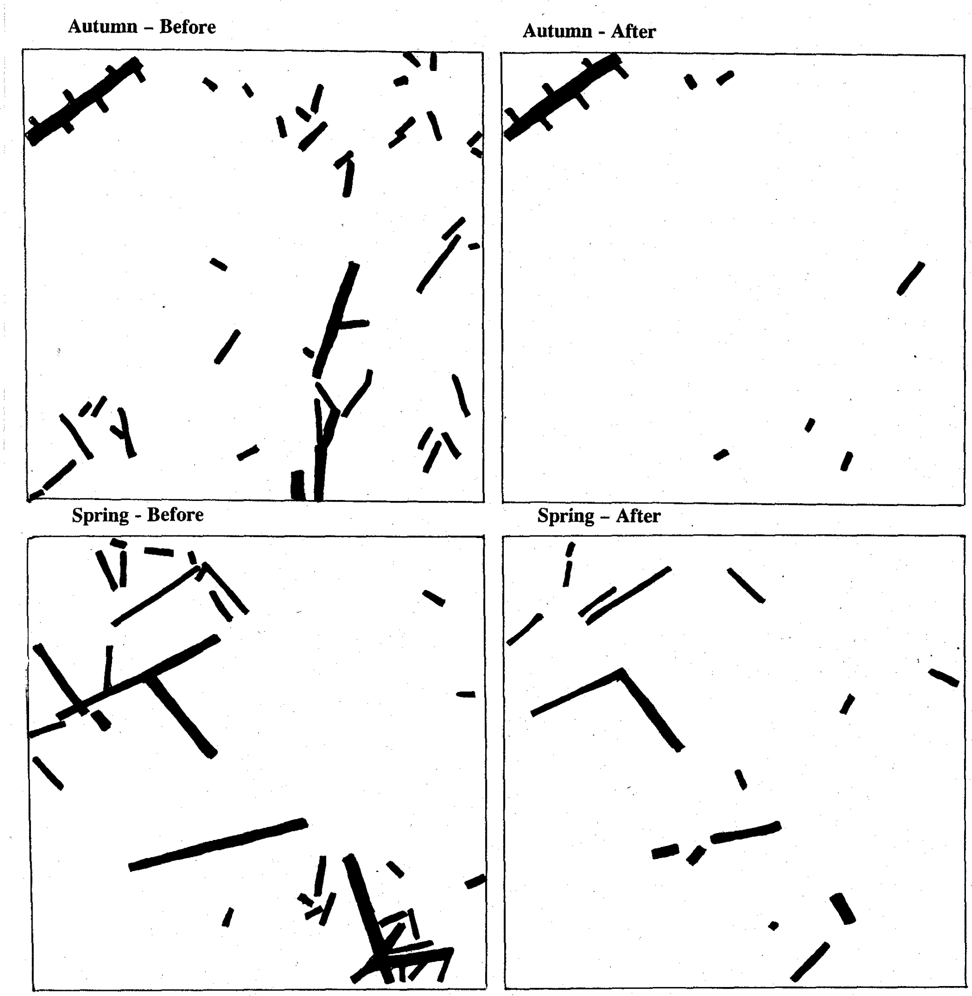

Figure 4—Consumption of logs in spring and autumn burning in mixed-conifer forest of southern Oregon (data used in Thomas and Agee 1986). Plots are 0.25 ha in size (50 x 50 m).

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