Dead Wood and Fire Relationships in Southwestern Oregon Western Hemlock Forests[1]

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Abstract
The densities of large snags and down wood in western hemlock forests of southwestern Oregon are highly variable. Fire is a major disturbance process that contributes to the composition and structure of these complex forests. This study examines levels of dead wood by plant association, and relationships of dead wood with fire. Data were collected from 169 plots on the Rogue River, Siskiyou, and Umpqua National Forests in Oregon. Median snag densities ranged from 3 up to 18 snags/ha over the plant associations. Down wood medians ranged from 0 to 113 pieces/ha. Variation was high and there were no significant differences between plant associations within the Western Hemlock Series. Median fire return intervals ranged from 26 years to 85 years. Elevation, slope, and median fire return interval were the best predictors of dead wood density. The R-squared values improved when the warmest, driest plant associations were removed from the analyses. The high degree of variability in dead wood density and fire return intervals suggests that a single standard is not appropriate across southwestern Oregon. Landscape level prescriptions should incorporate extremes along with median values.

Introduction

Snags and down wood are important structure components of forest ecosystems (Harmon and others 1986). They play a role in microclimatic variation in the forest and provide habitat for a variety of life. Little data have been published on levels of dead material in southwestern Oregon.

The abundance of snags and down wood is determined by several factors. The initial density and size of a forest stand will regulate the potential for providing snags and down wood. Agents such as fire, wind, insects, and diseases kill trees often in episodic disturbances. The extent of this mortality depends on the severity and

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frequency of the disturbance. Fire and decay cause breakdown and consumption of snags and down wood.

Although all sizes of snags and down wood are important, recent emphasis by wildlife biologists has been on large diameter material. This material takes longer to grow and would take more time to replace if it were removed from a site.

Standards for large down wood and snags are found in the Northwest Forest Plan (Anonymous 1994). These standards are uniform across the complex climatic, edaphic, and vegetation conditions of southwestern Oregon. In this paper we analyze relevant data to examine variation and pattern of density of dead wood, and the relationship of dead wood with fire. Our objective is to provide a framework and understanding of processes for managers to make landscape level prescriptions for down wood and snags greater than 50 cm diameter.

Study Area

Data were collected from the Rogue River, Siskiyou, and Umpqua National Forests in areas that are characterized as Western Hemlock Plant Series (*Tsuga heterophylla* is the climax tree species). The Western Hemlock Series is partitioned into 14 plant associations, based on floristics and environment (Atzet and others 1996) *(table 1)*. The sites on the Siskiyou National Forest are in the mid-coastal sediments ecoregion, and sites on the Rogue River and Umpqua National Forests are in the southern Cascades and Umpqua Cascades ecoregions (Anonymous 1995). The climatic range is broad, from a mean annual temperature of 12 ˚C to 6 ˚C, and a mean annual precipitation of 292 cm to about 127 cm (Atzet and others 1996).

Table 1—*Plant associations, common names, and plant association codes in the Western Hemlock plant series in southwestern Oregon.*

Plant association	Common name	Code
Tsuga heteropylla-Abies concolor/ Acer circinatum-Berberis nervosa	Western hemlock-white fir/ vine maple-Oregon grape	TSHE-ABCO/ ACCI-BENE2
Tsuga heterophylla-Abies concolor/ Berberis nervosa	Western hemlock-white fir/ Oregon grape	TSHE-ABCO/ BENE2
Tsuga heterophylla-Castenopsis chrysophylla/Gaultheria shallon-Rhododendron macrophyllum	Western hemlock-golden chinkapin/salal-Pacific rhododendron	TSHE-CACH6/ GASH-RHMA3
Tsuga heterophylla-Pseudotsuga menziesii/Gaultheria shallon-SWO	Western hemlock-Douglas-fir/Salal-SWO	TSHE-PSME/ GASH-SWO
Tsuga heterophylla-Thuja plicata Rhododendron macrophyllum /	Western hemlock-Western red cedar/Pacific rhododendron	TSHE-THPL/ RHMA3
Tsuga heterophylla/Acer circinatum/Gaultheria shallon-SWO	Western hemlock/Vine maple/Salal-SWO	TSHE/ACCI-GASH-SWO
Tsuga heterophylla/Acer circinatum-Rhododendron macrophyllum	Western hemlock/Vine maple-Pacific rhododendron	TSHE/ACCI-RHMA3
Tsuga heterophylla/Gaultheria shallon-Berberis nervosa-SWO	Western hemlock/Salal- Oregon grape-SWO	TSHE/GASH-BENE2-SWO

Tsuga heterophylla/Gaultheria shallon-Rhododendron macrophyllum-SWO	Western hemlock/Salal- Pacific rhododendron-SWO	TSHE/GASH-RHMA3-SWO
Tsuga heterophylla/Gaultheria shallon/Polystichum munitum-SWO	Western hemlock/Salal/ Western swordfern-SWO	TSHE/GASH/ POMU-SWO
Tsuga heterophylla/Polystichum munitum-SWO	Western hemlock/Western swordfern-SWO	TSHE/POMU-SWO
Tsuga heterophylla/ Rhododendron macrophyllum- Berberis nervosa-SWO	Western hemlock/Pacific rhododendron-Oregongrape-SWO	TSHE/RHMA3 - BENE2-SWO
Tsuga heterophylla/ Rhododendron macrophyllum- Gaultheria shallon-SWO	Western hemlock/Pacific rhododendron-Salal-SWO	TSHE/RHMA3 - GASH-SWO
Tsuga heterophylla/Vaccinum ovatum/Polystichum munitun	Western hemlock/Evergreen huckleberry/Western swordfern	TSHE/VAOV2/ POMU

Soils are of sedimentary and volcanic origin. Soils on the Siskiyou National Forest sites are most commonly derived from sandstones, while sites from the Cascade Mountains of the Rogue River and Umpqua National Forests are commonly derived from andesites and basalts. Other parent materials are present, but at lower proportions.

Field Data Collection

Data were collected from permanent plots that were located on the Rogue River, Siskiyou, and Umpqua National Forests. Plots were located so that the variation in vegetation over the landscape was represented. Within plots, a single plant association was present. The full range of elevation, aspect, slope, and rock types were sampled. Plots were selected to minimize previous human disturbance, and tended toward fully stocked, mature stands.

Five subplots were established around each plot using the USDA Forest Service's Pacific Northwest Region 10-point timber inventory diamond cluster protocol (Anonymous 1970). Within each variable radius subplot, the diameters of all species of trees and snags were recorded. The heights and ages of five site trees of each dominant species and three to five site trees of each codominant species were recorded. The ages were estimated as number of annual rings at dbh when the core reached the pith. Where the cores did not reach the pith, age was estimated by extrapolation using the diameter and rings per inch closest to the inner end of the core. Height, diameter, species and decay class (Cline and others 1980) were recorded for each snag.

The topographic variables of elevation, aspect, percent slope, and microposition were recorded for each plot. Microposition was defined as ridge top, upper one-third of slope, middle one-third of slope, lower one-third of slope, bench, toe of slope, canyon bottom, edge or in wetland basin, and draw or intermittent stream bottom.

Down wood data were collected along three, 21-meter transects with random-direction segments. At the point of intersection with a discernible piece of wood at least 12.5 cm in diameter, we recorded the diameter at the intersect, large end and small end diameters, length, species, and decay class were recorded. Decay was recorded as classes 1 to 5 (Fogel and others 1972).

Analyses

Analyses were conducted at the landscape scale and show the relationship of snags and down wood by plant association.

Densities of live trees, snags, and down wood exhibit a distribution that is skewed to the right. Measures of central tendency were expressed as Weibull medians and quartiles, which account for this skewedness, compared with medians from normal distributions, which simply describe the middle value of the distribution. The Kruskall-Wallace H-test was used to test differences between plant associations. Linear and nonlinear regression were used to show relationships between dead wood density and environmental variables and disturbance variables. The SPSS software[5] (Anonymous 1998) was used for all analyses.

The disturbances were derived by first listing, by species, the aged trees within each plot in descending order of age. Patterns of age and/or species change were noted. When a pioneer species (Douglas-fir, ponderosa pine, Shasta red fir) was present, the age was noted. If one or more trees of a pioneer species in a discernible age class (approximately a 30 year period) were present, that was assumed to be the result of a disturbance event. A surety rating for each disturbance event was assigned based on the tree age estimate, whether more than one tree was present in the age cohort (with multiple trees indicating higher surety), and the species of trees present. The rating ranged from 1 (unsure) to 10 (positive) and only events with a rating of 8 or higher was used in this analysis. A fire severity rating was also assigned: 1 = low severity—climax trees established after the disturbance; 2 = moderate severity—pioneer species established after the disturbance, but with older climax species that survived the event; and 3 = high severity—pioneer species established after the disturbance with climax species coming in later. These are patterned after Brown's (1994) fire regime severity classes. Date of disturbance was calculated using tree ages and plot data. Disturbance dates derived from tree age and stand structure data, rather than fire scar data, is a more liberal approach. It will likely detect disturbances not usually shown by fire scars. This technique has been used by others (Agee 1991, Arno and others 1997). It may be possible that disturbances other than fire were detected. Our data show that fire was overwhelmingly the dominant disturbance in this plant series; hence, the probability of a fire disturbance is quite high. Only disturbances before 1930 were used in the analyses because we believe fire regimes could have been altered by substantial European influence after that time.

Density of down wood was calculated using the methods described by De Vries (1973). Total dead wood was calculated as the sum of snags and down wood.

Results and Discussion

The live tree community forms the pool from which snags are derived. The median density of large live trees range from about 67 to over 134 trees per hectare and provide an abundance of potential dead wood *(table 2)*. The median number of

[5] Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

snags ranges from about 3 up to about 18 per hectare, although there are no significant differences between plant associations. The quartile range of snags shows that snags were absent on several of the plant association plots and that a high degree of variability is associated with these data. Abundance of down wood reflects the same pattern. Large down wood was absent on plots in half of the plant associations. The variation was quite high: for example, in the TSHE-CACH6/GASH-RHMA3 Plant Association, the quartile range was zero to 132 pieces per hectare *(table 2)*.

Table 2—*Comparison of live tree, snag, and down wood (50 cm+ diameter) density per hectare in Western Hemlock Plant Associations in southwestern Oregon.*

Plant association	N[1]	Median and quartile range of trees or pieces per hectare[2]		
		Live trees	**Snags**	**Down wood**
TSHE-ABCO/ACCI BENE2	13	93.5 (66.3-118.4)	10.0 (0-13.8)	25.9 (8.2-95.1)
TSHE-ABCO/BENE2	11	100.5 (66.9-147.7)	3.6 (0-19.2)	30.9 (0-52.4)
TSHE-CACH6/ GASH-RHMA3	6	88.1 (68.3-117.2)	12.2 (7.1-20.6)	13.3 (0-132.2)
TSHE-PSME/GASH-SWO	5	72.9 (27.7-105.8)	8.1 (2.2-20.9)	17.8 (0-60.8)
TSHE-THPL/RHMA3	6	98.4 (81.3-138.0)	16.2 (0-31.8)	18.5 (0-101.3)
TSHE/ACCI-GASH-SWO	10	69.0 (51.5-81.2)	9.6 (0.8-14.8)	91.2 (10.9-147.3)
TSHE/ACCI-RHMA3	29	134.7 (99.1-156.4)	12.2 (3.8-18.9)	16.1 (0-92.7)
TSHE/GASH-BENE2-SWO	17	77.2 (67.5-123.2)	12.3 (7.8-20.8)	32.1 (10.9-118.9)
TSHE/GASH-RHMA3-SWO	20	94.9 (79.3-122.2)	11.0 (3.1-19.9)	24.7 (0-84.8)
TSHE/GASH/POMU-SWO	14	77.5 (63.2-88.6)	13.8 (8.3-30.6)	113.4 (22.7-175.7)
TSHE/POMU-SWO	7	79.7 (72.1-97.9)	13.3 (8.3-30.1)	59.6 (26.9-107.2)
TSHE/RHMA3-BENE2-SWO	5	114.5 (74.1-139.5)	13.2 (7.3-24.5)	3.7 (0-52.1)
TSHE/RHMA3-GASH-SWO	14	103.9 (93.3-166.4)	18.0 (6.3-27.3)	0 (0-13.8)
TSHE/VAOV2/POMU	12	67.3 (50.1-155.3)	12.3 (6.8-20.1)	58.1 (6.7-190.5)

[1] Number of plots.
[2] Median values of live trees per acre are significantly different between plant associations ($P<0.001$; Kruskal-Wallis H-test), median values of snags per acre are not significantly different between plant associations ($P=0.42$, Kruskal-Wallis H-test), and density of down wood is not different between plant associations ($P=0.52$; Kruskal-Wallis H-test).

Disturbance intervals were recorded from about 900 ybp to about 60 ybp. Median fire return intervals for plant associations range from a low of 26 years for the TSHE/RHMA3-BENE2 plant association, to a high of 85 years for the TSHE/VAOV2/POMU association *(table 3)*, The confidence intervals are wide, reflecting a high degree of variability.

Table 3—*Weibull medians and confidence intervals for the plant associations in the Western Hemlock Series.*

Plant association	Weibull median (years)	80 percent CI
TSHE/RHMA-BENE2	26	12-165
TSHE-PSME/GASH-SWO	34	15-164
TSHE-CACH6/GASH-RHMA3	43	19-147
TSHE/ACCI-GASH-SWO	43	14-151
TSHE/ACCI-RHMA3	48	15-145
TSHE-ABCO/BENE2	53	17-156
TSHE-ABCO/ACCI-BENE2	59	21-192
TSHE/RHMA3-GASH-SWO	61	14-265
TSHE/GASH-BENE2-SWO	67	20-188
TSHE-THPL/RHMA3	67	20-251
TSHE/POMU-SWO	69	33-297
TSHE/GASH-RHMA3-SWO	81	26-190
TSHE/GASH/POMU-SWO	81	26-275
TSHE/VAOV2/POMU	85	30-243

Snags or down wood alone showed poor correlations with fire and environmental variables when compared with total dead wood density.

Percent slope explained 68 percent of the variation in total dead wood *(table 4)*. The highest densities of dead wood occurred on the gentlest slopes and the lowest on slopes over 50 percent. Elevation explained 41 percent of the variation in total dead wood density. The highest amounts were at elevations less than 689 m and densities decreased as the elevation increased. Sites on gentle slopes and lower elevations often correspond to riparian areas in the Western Hemlock Series and are areas where fires are often less severe. Aspect explained a little over 28 percent of the variation, though the equation was not significant, and microposition explained virtually none of the variation in total dead wood density *(table 4)*. Because elevation and slope are highly correlated in our data, it is not appropriate to use them together in a multiple regression.

Table 4—*Regression analyses of environmental variables and total dead wood densities.*

	RSQ	df	sigf	b0	b1	b2
Total dead wood						
Elevation	0.410	11	0.055	78.90	-0.026	2.9E-06
Slope	0.680	11	0.002	-19.27	1.264	0.0006
Microposition	0.063	11	0.699			
Median aspect	0.283	11	0.160	19.15	0.028	0.0001

The variables mean fire severity, severity of the last fire, and length of the last fire interval were all highly correlated, and as such, were not appropriate for use together in multiple regression. When density of snags and density of down wood were combined into a total dead wood pool, regression showed that the length of the last fire interval explained over 27 percent of the variation (R-squared = 0.274), and fire severity explained slightly less *(table 5)*. Median fire return interval (FRI) explained over 42 percent of the variation with a quadratic function. In all cases except median FRI, nonlinear regression did not improve the fit of the data. The large amount of variation made it difficult to detect a difference between linear and nonlinear relationships. Fire severity was negatively related to total dead wood, and length of the last fire interval was positively related.

Table 5—*Regression analyses of mean fire severity, last fire severity, last fire interval length, and Weibull median fire return interval as predictors of total dead wood densities. Equations are shown for all data, and data with two outliers removed.*

	R-SQ	df	sigf	b0	b1	b2
Total dead						
Mean fire severity	0.221	12	0.090	111.43	-40.99	
Last fire severity	0.201	12	0.108	51.68	-19.93	
Last fire interval	0.274	12	0.055	1.75	0.22	
Median FRI	0.422	11	0.049	33.96	- 0.76	0.011
Total dead–no outliers						
Mean fire severity	0.637	9	0.010	406.27	-323.83	66.31
Last fire severity	0.609	9	0.015	97.56	- 86.01	20.92
Last fire interval	0.422	9	0.085	12.56	- 0.12	0.002

Interestingly, when the two outliers with the highest total dead wood values are removed from the data set, and nonlinear analyses are used, the R-squared values increase dramatically. Mean fire severity has an R-squared value of 0.637 (p=0.01), and length of time between the last two fires has an R-squared of 0.422 (p=0.085). These two outlier data points represent the warmest, driest plant associations, which may follow a different pattern than the warm, moist western hemlock areas.

Multiple regression with elevation and median FRI was highly significant in explaining the densities of dead wood, where density = -27.023 + 0.245 (median FRI) + 1.116 (slope). (R-squared = 0.76).

Overall, the length of the last fire interval is positively correlated with total dead wood. This suggests that for 50 cm+ dead material, fire suppression has likely caused an increase in material, and plant associations with longer fire return intervals are capable of carrying more dead wood. Average fire severity and severity of the last event are negatively correlated with total dead material; that is, the more severe the event, the less 50 cm+ material remains. This may seem counter-intuitive, because high severity fires generally correspond to stand replacement fire, which may yield high levels of dead wood. In southwestern Oregon, in the mature stands we sampled, multiple intervening low intensity fires likely consumed a great deal of the dead wood generated by stand-replacing events. The median FRI data show an inflection point around 50 years, after which the amount of dead wood increases sharply.

Our data show levels of snags and down wood are highly variable over the landscape. This variability should be retained, and stratification by plant association will aid prescriptions. Some portion of the landscape will have little or no dead wood, while other portions will have a great deal. The distribution should be based on an integration of desired conditions. For example, fire and wildlife managers may suggest leaving most in riparian areas, a prescription that is supported by the data on elevation and percent slope. If the management objective is to remove dead material, leave some part of the landscape with the extremes and remove wood from areas with median amounts.

Fire return intervals in Western Hemlock Plant Associations in southwestern Oregon are shorter than those further north. They are variable, as are the severities. This chaotic nature of fire across the landscape is the primary means of creating diversity in composition and structure for which the southwestern Oregon forests are known. Fire should be returned to the forest with landscape level planning and allowed to burn in non-uniform, chaotic patterns.

Our data indicate, the higher the severity the fire, the less large material will remain. Attempting to retain too much coarse wood will have an effect similar to fire control. Over the long run, the proportion of high intensity fire will increase. Consequently, the potential for soil damage and reduction of late seral conditions will increase. This "boom-and-bust" cycle is more characteristic of the temperate forests to the north. It may have negative effects on local species that evolved with frequent, but low intensity fire.

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