Snag Recruitment in Subalpine Forests of the North Cascades, Washington State[1]

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Abstract

We recorded snag species, locations, and causal agents of tree mortality, and estimated fire histories and standing dead and downed fuel abundance in polygons in subalpine forests in the Entiat watershed in Washington State. The overall snag density was 51 ± 5.2 snags per hectare. The density of dominant and codominant snags did not differ by aspect or slope categories ($p = 0.74$), but the density of intermediate and suppressed snags was highest on steep south-facing slopes ($p < 0.05$). Weather-related effects created more snags than any other disturbance in the period between stand-replacing fires. More weather-caused mortality occurred on northerly aspects than on southerly aspects ($p < 0.05$) and on mid-slopes than either upper or lower slopes ($p < 0.05$). Standing dead and downed fuel, and tree mortality caused by weather (snow, ice, and wind), root diseases, animals, and bark beetles were related to stand structural stage. We estimate the mean fire interval was 12 years for the 5,685 ha encompassed in the study area. The estimated mean size of stand-replacing fires was 146 ± 95 ha.

Introduction

Vegetation in subalpine forests is not distributed randomly but is closely tied to topography, climate, and the cumulative effects of disturbances at various scales. Disturbance regimes of subalpine forests differ considerably from those of forests at lower elevations where fire was historically a frequent visitor to all stand development stages, commonly burning large areas at low severity and selectively killing individuals and small groups of trees. In contrast, fires in subalpine forests are less common and are typically mixed-severity or stand-replacing (Covington and others 1994).

How a tree dies influences its longevity as a snag and its usefulness to wildlife (Bull and others 1997). Snag longevity is site-specific (Everett and others 1999, Keen 1929) and is enhanced by larger bole diameter, shorter height, and thinner bark (Raphael and Morrison 1987). When killed by fire, thin-barked species such as Engelmann spruce *(Picea engelmannii* Parry ex Engelm.), lodgepole *pine (Pinus contorta* var. *latifolia* Dougl. ex Loud.), and subalpine fir (*A. lasiocarpa* [Hook] Nutt.) dry quickly (Bull 1983), making them resistant to insects and decay fungi

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(Hadfield and Magelssen 1997, Parry and others 1996) and increasing their longevity as snags (Everett and others 1999).

Over the course of stand development, insects and pathogens kill far more trees and recycle more biomass in most forests than do fires (Hagle and others 1995). With the exception of large-scale outbreaks of the mountain pine beetle *(Dendroctonus ponderosae* Hopkins) and spruce beetle (*D. rufipennis* Kirby), most of the conifer mortality caused by biotic agents in subalpine forests occurs individually or in small groups. The slow accumulation of fuel beds and fuel ladders resulting from insect and pathogen activity, as well as by wind, snow, and animals, takes place over a long period of time but affects the behavior of subsequent fires.

Methods

The study site is located in subalpine forests of the Entiat Ranger District, Wenatchee National Forest, on the eastern slope of the Washington Cascade Range *(fig. 1)*. The study site was chosen because the range of climatic and vegetation conditions are representative of many other sites in the Cascade Mountains of eastern Washington State. Elevations in the study area range from 1,280 m to 2,150 m above sea level. Mean annual precipitation in the study area ranges from approximately 100 to 230 cm. Subalpine forests in the upper Entiat watershed are classified into five major plant series: whitebark pine (*Pinus albicaulis* Engelm.), subalpine larch (*Larix lyallii* Parl.), subalpine fir, mountain hemlock *(Tsuga mertensiana* [Bong] Carr.), and Pacific silver fir (*Abies amabilis* Dougl. ex Forbes) (Lillybridge and others 1995). The western-most forests in the study area are in the Glacier Peak Wilderness Area. Plummer (1902) commented on burns that occurred in the 1800s: “On the high divides between Entiat and Mad Rivers extensive burns occurred years ago, and the very life was burned out of the soil, leaving it poor indeed.”

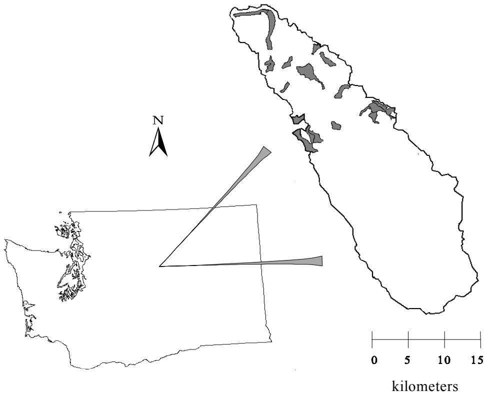

Figure 1—Location of study sites (shaded gray) in the Entiat watershed, Washington State.

Black and white aerial photographs taken in 1992 at a scale of 1:16,000 were used to delineate polygons. Eighteen polygons representing several predominant aspect and slope categories were randomly selected from a total of 93, allotting 3 polygons to each slope and aspect category. The total area encompassed by the 18 selected polygons was 5,685 ha; the average size was 316 ha ± 181 ha. Stand types within polygons were subjectively classified by crown density and whether crowns had single or multiple layers. Aerial photographs were also used to assign stand types to one of seven structural stages: stand initiation, open stem exclusion, closed stem exclusion, understory reinitiation, young multi-strata, old forest multi-strata, and old forest single-stratum (O'Hara and others 1996, Oliver 1981). Less than 1 ha in the study area was classified as old forest single-stratum. Therefore, data from old forest single-stratum and old forest multi-strata were combined. Polygon and stand type boundaries were drawn on 1:24,000 scale USDA Forest Service resource orthophotos then digitized into a geographic information system.

Fire histories, occurrences, and extents were estimated from a variety of sources. Ages of the oldest appearing conifers in each stand type were measured. Fire atlases, which are maps with boundaries of fires hand-drawn at the time of occurrence, historical panoramic photographs taken from fire lookouts, and aerial photographs supplemented stand age data and improved estimates of fire sizes. The most recent fires were mapped for each polygon. FHX2 fire history software (Grissino-Mayer 1995) was used in this study to calculate the Weibull median fire interval (*sensu* Johnson and Gutsell 1994) for the area encompassed by the 18 polygons.

Downed and dead woody fuel was measured in tones per ha using the planar intersect method (Brown 1974) at plot centers. Sampling plane lengths varied from 0.9 m for continuous heavy slash of 0 to 2.54 cm to 11 m for light slash larger than 15 cm.

Both belt transects and fixed area plots were used to collect data on conifer mortality. Five variable-length 9.1 m belt transects were systematically established in each polygon to cross all stand type, beginning and ending at polygon boundaries. The following data were recorded in each transect: extents of stand types encountered; conifer species and crown class for each dead tree. Crown classes were assigned to individual trees according to Oliver and Larson (1990). All agents potentially contributing to mortality were recorded for each dead tree, and a determination was made of the primary agent responsible. For example, the primary agent recorded for a tree with evidence of moderate to aggressive root disease and bark beetle galleries was root disease. Trees that were blown over were recorded as killed by weather. Some of these may have been infected by root disease. Trees with advanced root disease are more likely to fail than trees with intact root systems (Harvey and Hessburg 1992). Fixed circular 0.02 ha plots were established where a belt transect crossed closest to the center of each stand type. Diameter at 1.37 m, henceforth referred to as dbh (diameter at breast height), and crown position were recorded for every live and dead tree in each fixed plot. Statistical tests were performed using Statistical Analysis Systems software (SAS 1997).

Results and Discussion

Subjective data from fire atlases, historical panoramic photographs from fire lookouts, and aerial photographs were analyzed, as were 793 tree age cores. Forty-one fires were recorded, dating from 1505 to 1935. The most recent fire in 14 of the 18 polygons occurred between 127 and 102 years ago. Between 1880 and 1900, over half of the polygons had a fire that burned at least 25 percent of the area, equivalent to 2,126 ha. The Weibull mean fire interval was 12 years for the 5,685 ha encompassed in the study. Intervals between fires on the same polygon varied from

10 years to 291 years, and it is likely that fires did not overlap much in extent. The estimated mean size of stand-replacing fires was 146 ha (standard error [s.e.] = 95 ha). Lightning directly killed 4 trees, and small lightning-caused fires killed an additional 68 trees.

Downed and dead fuel weight from 116 planar transects were compared to stand structural stage *(fig. 2)*. Eight of the 15 possible two-way comparisons differed statistically (as indicated by standard error bars).

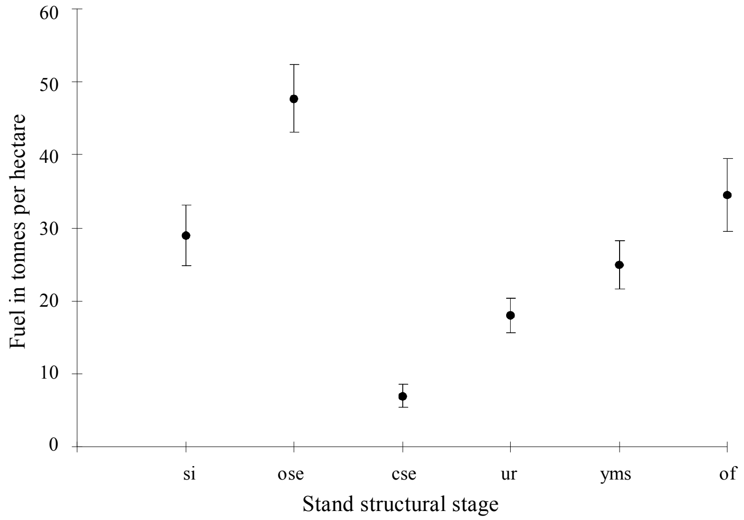

Figure 2—Dead and downed fuel by stand structural stage: si = stand initiation, ose = open stem exclusion, cse = closed stem exclusion, ur = understory reinitiation, yms = young multistory, of = single stratum and multi-stratum old forest. Vertical lines are standard errors of the mean.

A total of 6,629 snags (standing dead trees), were recorded along 142 km of belt transects, representing a 130 ha sample size. The overall snag density was 51 ± 5.2 snags per ha. An additional 329 snags were recorded in the 77 fixed plots in the 18 polygons. Snags were combined into two groups based on similarities in crown class: dominant and codominant snags, and intermediate and suppressed. The majority of the snags (83 percent) at one time occupied dominant or codominant crown positions relative to the surrounding trees. Mean dbh for dominant and codominant snags was 32.5 cm (s.e. = 17.6). Mean dbh for intermediate and suppressed snags was 14.1 cm (s.e. = 10.8).

The number of intermediate and suppressed snags per ha was significantly higher ($p < 0.05$) for steep (> 50 percent) south-facing slopes, which had a preponderance of relatively pure, dense lodgepole pine stands, than for other slope and aspect categories *(table 1)*. The number of dominant and codominant snags per ha did not differ significantly by aspect and slope categories ($p = 0.74$). Mean basal area in vegetation plots was 43 m^2 per ha (n = 115; s.e. = 98).

Table 1—*Snags per hectare by aspect and slope in two crown class categories.*

	Slope (percent)					
	10-30		30-50		50+	
Aspect	**DC**[1]	**IS**	**DC**	**IS**	**DC**	**IS**
North	36	5	36	7	47	7
South	47	3	48	9	51	37[2]

[1] DC = dominant + codominant, IS = intermediate + suppressed

[2] Significantly different than other aspect/slope combinations for intermediate and suppressed trees.

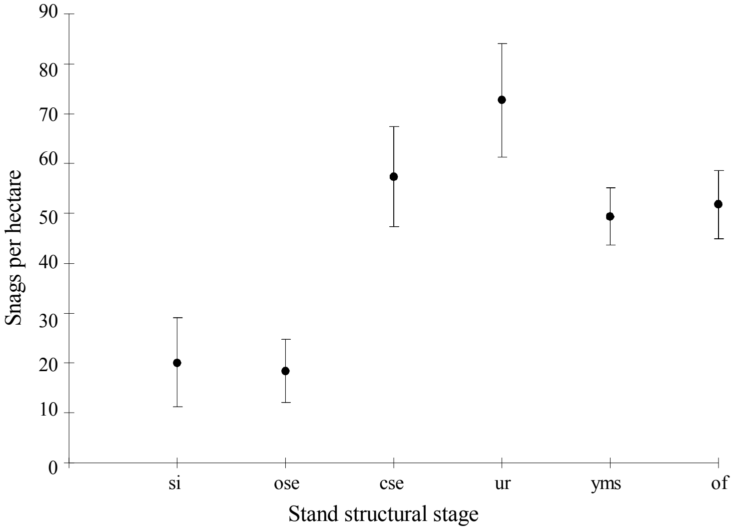

Figure 3—Snags per hectare by stand structural stage: si = stand initiation, ose = open stem exclusion, cse = closed stem exclusion, ur = understory reinitiation, yms = young multistory, of = single stratum and multi-stratum old forest. Vertical lines are standard errors of the mean.

Snag density was significantly different ($p < 0.01$) among the 6 structural stand stages for both the dominant and codominant snag category and the intermediate and suppressed snag category. A majority of the total snags (88 percent) were found in four structural stand stages: closed stem exclusion, understory reinitiation, young multi-story, and old forest *(fig. 3)*.

Conifer mortality by crown class was analyzed for Engelmann spruce, subalpine fir, whitebark pine, and lodgepole pine. Disturbance groups included in the analyses were weather, bark beetles, root diseases, animals, white pine blister rust (*Cronartium ribicola* Fisch.) in whitebark pine and lodgepole dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) in lodgepole pine. All four conifer species analyzed had the majority of mortality in dominant and codominant crown classes, regardless of the disturbance agent species or group ($p < 0.05$).

Snow, ice, and wind created significantly more snags than insects, pathogens, animals, or fire. A majority of these snags were subalpine fir and lodgepole pine broken off at, or near, the base of the live crown. Only weather-caused tree mortality showed a difference by aspect or slope categories. More weather-caused tree mortality occurred on northerly aspects than on southerly aspects ($p < 0.05$), and on mid slopes than on either upper or lower slopes ($p < 0.05$). The mid-slope on a mountain, also called the thermal belt, typically receives the least variation in diurnal temperature, has the highest average temperature, and the lowest average relative humidity (Anonymous 1981). Therefore, fuels in the study area were most likely to accumulate where they would dry quickest and have the lowest fuel moisture. The trend in old forest structures is for fewer weather-killed trees than in the intermediate structural stages. This might be attributable to the decreased number of trees overall in old forest.

The second and third most common disturbance agents were bark beetles and root diseases, respectively. Lodgepole pine was the tree species most commonly killed by bark beetles. In the study area, most stands of lodgepole pine were very dense, and were attacked not by mountain pine beetles but by secondary bark beetles such as *Pityogenes* spp. and *Pityophthorus* spp., sometimes in concert with Armillaria root disease. Armillaria root disease killed nine different conifer species in the study area, accounting for 88 percent of the mortality caused by identified root diseases. Fifteen percent of the subalpine fir, 41 percent of the Engelmann spruce, and 51 percent of the lodgepole pine infected with root disease were also attacked by bark beetles.

Stand replacement fires create pulses of snags on the landscape. The number of standing dead trees per ha was compared to the time since the last stand-replacing fire for four disturbance agent groups: weather, bark beetles, root disease, and animals. The correlation for each group was not significant, indicating that just using time since the last fire is inadequate in predicting conifer mortality from these disturbance agent groups. Structures and compositions of the previous stands are unknown, as are the intensities and severities of the last fires. These variables, if known, might result in better correlations with conifer mortality in the current stands. Also, in stands where the last fire date was estimated, the range in number of years (62 to 127) since the last fire may be inadequate to demonstrate consistent differences in insect- and pathogen-induced mortality.

The highest standing dead fuels were found in intermediate structural stages *(fig. 3),* and the highest downed and dead fuels are found in the earlier structural stages and in old forest structure *(fig. 2).* Perhaps this is carryover from stand replacement events. Conifer mortality begins to increase in intermediate structural stages, primarily from wind, snow, ice, root diseases, and bark beetles. Wood decay rates are relatively slow in the eastern Cascade Mountains due to climatic factors, and as a result fuels increase faster than they decompose.

In subalpine forests in Rocky Mountain National Park, Clagg (1975) found that total dead woody fuels increased immediately after a fire, quickly declined to a low point at about a stand age of 50 years, rapidly increased to a peak at 100 years, then gradually declined until about age 300 years, after which the fuel load remained almost constant. In a subalpine watershed in Yellowstone National Park, Romme (1982) found that heavy down fuel decreased during early successional stages between stand ages 70 and 200 years as large fire-killed stems decomposed, then fuels increased in later stages when natural mortality of mature trees began to occur. Maximum fuel loading was reached around 350 years.

The average fire size was 146 ha ± 95 ha. Current tree harvest units do not mimic these sizes or their variability. The legal limitations imposed on sizes of harvest units conflict with the size of inherent disturbance regimes, and with the intent of ecosystem management. By targeting mid-slopes where lodgepole pine is dominant and where subalpine fir is increasing in the understory, multiple-use goals can be achieved. On these sites, thinning lodgepole pine and cutting subalpine fir would produce larger trees for wildlife and eventual harvest, increase resistance to bark beetles and weather (e.g., wind), and decrease potential dead and down fuel. The tradeoff is a short-term increase in fuels from logging slash.

In the last half of this century, subalpine forests have become more uniform and dense (Covington and others 1994, Tande 1979), and have greater vulnerability to stand-replacing fire (Romme and Despain 1989). In the Northern Cascades Ecological Reporting Unit of the Columbia River Basin, there were no significant changes in fuel loading among fuel classes from the historical to the current period. Similarly, in the Wenatchee subwatershed, there were no significant changes in fuel loading from the historical to the current period (Huff 1995). However, in the Wenatchee subwatershed, there was a significant decrease in the number of forested stands with no dead trees, and a significant increase in the number of forested stands with from 1 to 10 percent dead trees (Lehmkuhl and others 1994). In this study, standing dead trees were more numerous than required for four species of woodpeckers, according to one study (Thomas and others 1979). Although some species of wildlife may currently benefit from the bounty, fuels and flammability of these forests are increasing, and the inevitable stand-replacing fires may be larger and more severe than were historical fires.

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