

FIRE SEVERITY PATTERNS IN THE WATERSHEDS OF INTERMITTENT STREAMS
FOLLOWING THE WARNER CREEK FIRE
WESTERN CASCADE RANGE, OREGON

A Final Project Presented

by

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to

The Faculty of the Graduate College

of

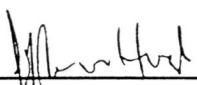
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Field Naturalist Program
Department of Botany
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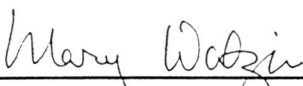
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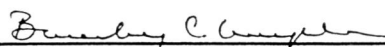
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I. SCIENTIFIC MANUSCRIPT

For submission to *Forest Ecology and Management*

**FIRE SEVERITY PATTERNS IN THE WATERSHEDS OF INTERMITTENT STREAMS
FOLLOWING THE WARNER CREEK FIRE
WESTERN CASCADE RANGE, OREGON**

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Abstract: Patterns of fire severity within the watersheds of 34 intermittent streams were analyzed in a portion of the Warner Creek Fire area in the central western Cascades of Oregon. Aerial photographs were used to measure differences in live canopy cover between streamside and upland zones and between the east and west-facing sides of the watersheds. Relationships between mean live canopy cover and four topographic variables were also examined among the watersheds. In a regression analysis, live canopy cover data estimated from aerial photographs and field survey data from six watersheds were positively and significantly correlated, validating the accuracy of the aerial photograph method used in this study. Analysis of aerial photographs revealed no significant differences in live canopy cover within watersheds. Analysis of field data from six watersheds, however, showed a significant and positive correlation between live canopy cover and distance from the stream. These results suggest that, in the steep, south-facing watersheds of intermittent streams in the Warner Creek Fire study area, a fire burning in the upland zone is likely to burn in the streamside zone with equal or greater severity. Stepwise multiple regression analysis of four topographic variables identified topographic complexity and maximum watershed elevation as significant predictors of live canopy cover within 33 watersheds, suggesting that fire severity was lower in topographically complex watersheds situated at lower elevations. These two topographic factors explained 21% of the variation in live canopy cover. This study provides preliminary insight into the role of fire in the watersheds of intermittent streams. Fire regime information such as this may be useful to managers attempting to use natural disturbance regimes as a guide for forest management or to those wishing to understand forest and landscape responses to fire.

1. Introduction

The role of natural disturbance processes in ecosystems has been widely discussed in recent decades (Rowe and Scotter, 1973; Sprugel, 1976; Heinzelman, 1978; White, 1979; Pickett and White, 1985; Sprugel, 1991). Contemporary ecologists agree that disturbance events occurring over various spatial and temporal scales can prevent ecosystems from reaching the stable, self-sustaining, climax state lauded by early ecologists (Weaver and Clements, 1938). In the Douglas-fir (*Pseudotsuga menziesii*) dominated forests of the central western Cascades of Oregon, fire is a dominant natural disturbance agent and is the primary determinant of forest structure and composition. Variation in fire severity can contribute significantly to remnant tree densities and overall habitat heterogeneity (Romme, 1982; Teensma, 1987; Morrison and Swanson, 1990; Taylor and Skinner, 1998; Weisberg, 1998; Keeton, 2000).

Information about natural disturbance regimes, including their historic frequency, severity, and spatial extent, can be applied to landscape management (Agee, 1993). If the assumption that species have adapted to a certain range of ecosystem conditions brought about by natural disturbance regimes is valid, then human activities that take ecosystems outside of this range may lead to species loss and ecological decline. Managing an ecosystem within its range of natural variability may increase the potential for sustaining native species in a broad range of habitat types (Swanson et al., 1994). For Douglas-fir dominated forests, understanding the range of natural variability depends on identification of fire regime characteristics.

Several studies have quantified historic fire regime characteristics in the central western Cascades (Teensma, 1987; Morrison and Swanson, 1990; Weisberg, 1998). Because fire regimes in this region are highly variable, however, fire effects studied at a regional scale may not be specific enough to effectively guide management decisions at any one site (Camp et al., 1997). Fire effects can vary widely according to such factors as topography, microclimate, soils, and vegetation. Managers may therefore benefit from “place-based” knowledge of fire regimes and fire effects (Taylor and Skinner, 1998). Small watersheds are a useful context for studying how fire patterns vary on a local scale.

Of the three components of the fire regime, fire severity is the least well known (Weisberg, 1998). While fire frequency and spatial extent can be quantified with a reasonable degree of accuracy, fire severity is often inferred rather than directly quantified for historic fires. Because evidence of fire severity is often obscured by repeated fire events, it is most easily quantified for the most recent fire event in an area (Swanson et al., 1994; Weisberg, 1998). A detailed understanding of fire severity patterns for recent fires can complement fire regime information obtained over broader temporal scales and can be applied directly to management activities.

The central objectives of this study were to develop and evaluate a method for quantifying the severity of recent fires using aerial photographs, and to apply this method to an analysis of fire severity patterns within the watersheds of intermittent streams. I hypothesized (1) that fire severity differed both between streamside and upland zones and between east and west-facing slopes within watersheds, and (2) that topographic variables including slope, topographic complexity, elevation, and drainage incision influenced patterns of fire severity in the watersheds of intermittent streams.

2. Study Area Description

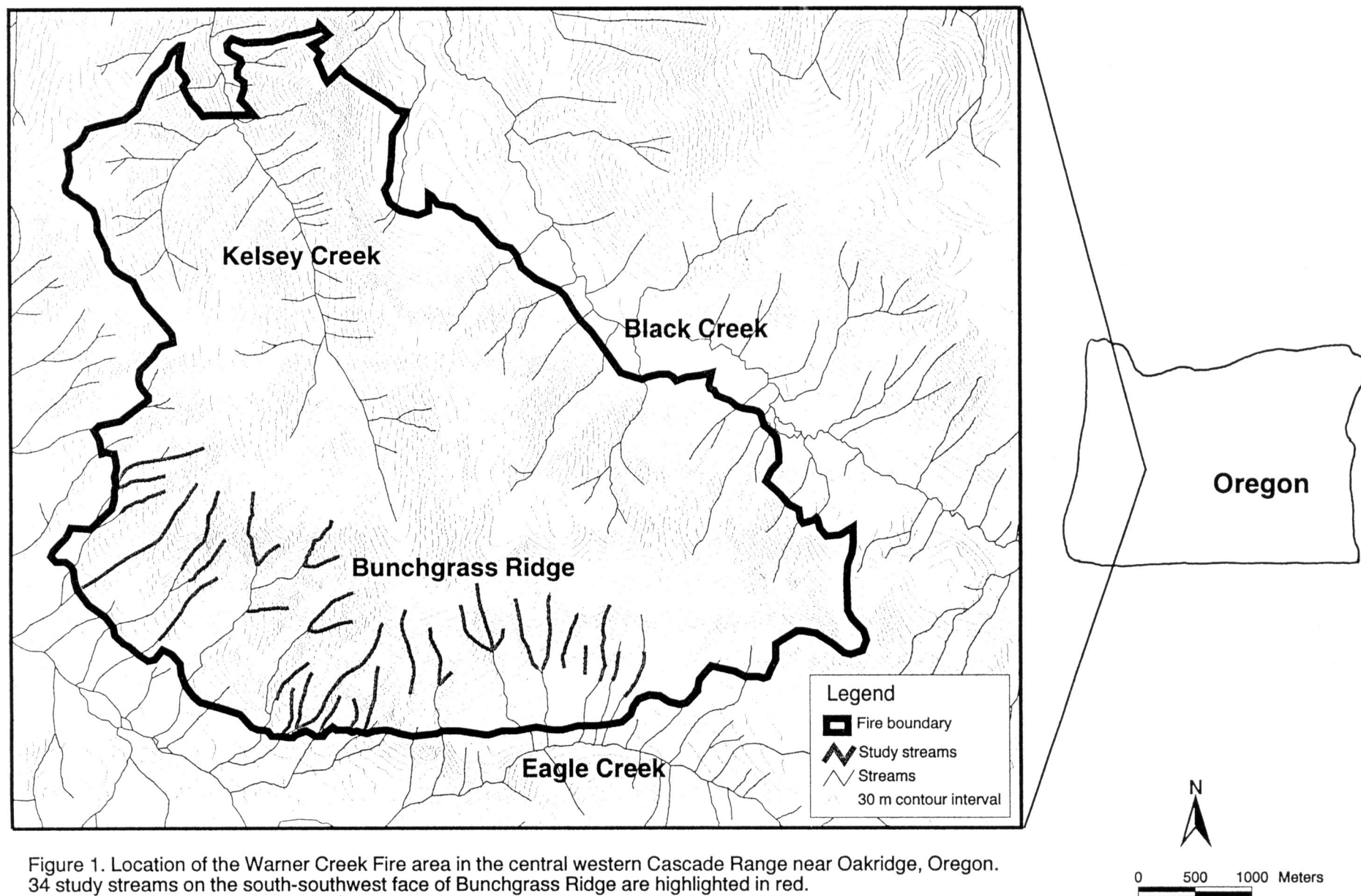
2.1. Location and physiography

This study was conducted on the 1991 Warner Creek Burn in the Willamette National Forest 19 km east of Oakridge, Oregon in the central western Cascade Range. The fire area encompasses 3630 ha on the north and south sides of Bunchgrass Ridge. The study area includes the watersheds of 34 intermittent streams incised into the steep, south-southwest face of Bunchgrass Ridge (Figure 1). The average watershed size is 16.2 ha, and the average slope within each watershed ranges from 16 to 40 degrees. Elevation ranges from 800-1750 m above sea level.

The bedrock consists of older pyroclastic rocks of Oligocene and Miocene origin overlain by andesitic flows and ridge-capping basalt flows (Franklin and Dyrness, 1973). Small, north-flowing Pleistocene glaciers carved broad, U-shaped valleys with steep side slopes and headwall cirques in the major drainages. Fluvial erosion has created a deeply dissected terrain, especially on more southerly aspects. Soils in the study area are derived mainly from basalt and andesitic flows, and in part from pyroclastic parent material (tuffs and breccias). In places, poorly drained clay-loam soils are subject to mass movement processes. Over much of the study area, soils are thin and susceptible to summer drought, making the site prone to fire.

2.2. Vegetation and climate

Three major forest zones are represented in the Warner Creek Fire area: the western hemlock (*Tsuga heterophylla*) zone (~800-1050 m), the Pacific silver-fir (*Abies amabilis*)



zone (~1050-1700 m), and the mountain hemlock (*Tsuga mertensiana*) zone (above ~1700 m) (Franklin and Dyrness, 1973). The Douglas-fir-dominated western hemlock zone is the most extensive vegetation zone in western Washington and Oregon, and is the most important for timber production (Franklin and Dyrness, 1973). Although western hemlock and western redcedar (*Thuja plicata*) are the climax species in this vegetation zone, Douglas-fir maintains dominance in many stands as a result of its longevity and fires that continually reset the successional clock (Franklin and Hemstrom, 1981). The Pacific silver-fir zone is wetter and cooler than the western hemlock zone, and Pacific silver fir, Douglas-fir, noble fir (*Abies procera*), and western hemlock are the dominant trees. The mountain hemlock zone is the highest forested zone in the western Cascades and generally occurs on the wettest, coldest sites where deep snow accumulates in the winter (Franklin and Dyrness, 1973). High elevation meadows are interspersed within the mountain hemlock zone (USDA Forest Service, 1993).

The maritime climate in the study area is characterized by cool, wet winters and warm, dry summers. Average annual temperature is 10.8 °C (US NRCS, 2000). Moisture-laden air masses moving east from the Pacific Ocean bring the most abundant precipitation between October and May. A precipitation monitoring site at Railroad Overpass (elevation 838 m) approximately one mile from the study area recorded a 30-year (1961-1990) annual precipitation average of 1450 mm. Over the 30-year period, the highest mean monthly precipitation was recorded in November (230 mm) and the lowest in August (38 mm) (US NRCS, 2000). Reduced rainfall, desiccating easterly winds, and lightning-associated storms in late summer and early fall create conditions ideal for wildfire.

2.3. Fire regime

A synthesis of fire history studies in the Cascade Range reveals a general pattern of increased fire frequency and decreased fire severity from Mt. Rainier in Washington to the Klamath Mountains in southwest Oregon (Morrison and Swanson, 1990). Lightning ignitions also occur with greater frequency along this north-south gradient (Agee, 1993). Large, infrequent, stand-replacement fires with a mean return interval on the order of 465 years characterize the wetter portions of the Pacific Northwest region (Hemstrom and Franklin, 1982; Agee, 1993). On the opposite extreme, smaller, less intense, and more frequent fires with a mean return interval between 15 and 50 years occur in the drier forests of southern Oregon (Atzet et al., 1988).

The Warner Creek Fire area lies in the middle of this gradient and, correspondingly, experiences fires of variable severity and frequency including stand-replacing crown fires, partial stand-replacing fires, and non-lethal underburns (Morrison and Swanson, 1990). To the north of Warner Creek, in the Blue River study area, mean fire return intervals range from 95-145 years (Teensma, 1987; Morrison and Swanson, 1990; Weisberg, 1998). To the south, in the northern Klamath Mountains, the estimated mean fire return interval is 19.5 years (Skinner and Taylor, 1998). A fire history reconstructed for the Warner Creek Fire area using tree ring counts, fire scars, and stand delineation from aerial photographs suggests that fires of intermediate frequency kill most of the trees on southerly aspects, leaving a few surviving Douglas-fir trees to re-seed the area (USDA Forest Service, 1993). South-facing slopes are more susceptible to fire due to intense solar heating and rapid depletion of fuel moisture. Fires are less frequent on northerly aspects, and may alternate between low-intensity under-burns and infrequent stand replacing fires (Morrison and Swanson, 1990).

This highly variable fire intensity and frequency generates a combination of complete canopy-killed, partial canopy-killed, and underburned forest depending on fuels, weather, and topography (Agee, 1993). Post-fire forests are a mosaic of even and multi-aged stands.

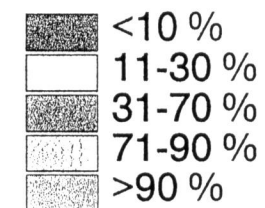
2.4. Warner Creek Fire event

The Warner Creek Fire was ignited by an arsonist on 10 October 1991 after a prolonged period of hot, dry weather and desiccating winds. Driven by a southwest wind, the fire burned east along the south face of Bunchgrass Ridge into the Eagle Creek drainage, and north into the Kelsey and Black Creek drainages. In total, 3630 ha burned on the north and south sides of Bunchgrass Ridge. Fire severity varied widely throughout the burn area (Figure 2). Within the study area, fire severity was most variable on the southwest face of Bunchgrass Ridge where the terrain was steep, rocky, and deeply dissected. Fire severity was highest on the south face and on the crest of Bunchgrass Ridge, where dry fuels and southwest winds carried an intense crown fire along the less rocky and less dissected terrain. By the time cold air and rain showers extinguished the Warner Creek Fire on 22-23 October, approximately 40% of the canopy had been completely killed, 28% was partially killed, and 32% was either underburned or unburned (USDA Forest Service, 1993).



Figure 2. Generalized map of fire severity resulting from the 1991 Warner Creek Fire near Oakridge, Oregon. (GIS coverage courtesy of the Willamette National Forest).

Live Canopy Cover



0 500 1000 Meters

3. Methods

3.1. *Sample watershed selection*

Thirty-four small watersheds on the south-southwest face of Bunchgrass Ridge were included in the study (Figure 1). The watersheds were selected based on three criteria: stream size, aspect, and pre-fire vegetation.

Stream size. All 34 watersheds surrounded intermittent streams. Despite some documentation of fire regime characteristics for the watersheds of perennial streams (e.g. Skinner, 1997; Olson, 2000; Wimberly and Spies, 2000), the role of fire in the watersheds of intermittent streams remains poorly understood. Of the 34 streams selected, 23 were already mapped as Class 4 intermittent, non-fish-bearing streams by the U.S. Forest Service (USFS). These streams were identified using a Geographic Information System (GIS) stream layer provided by the Willamette National Forest and a 30 meter contour map overlaid on a digital orthophoto mosaic of the Warner Creek Fire area. The contour map was created from a digital elevation model (DEM) for the Warner Creek Fire area. The remaining 11 intermittent streams, which were not mapped by the USFS, were identified from aerial photographs and field surveys. All 34 streams were on-screen digitized in ArcView GIS using digital orthophotos and a 30 m contour map as a guide.

Aspect. Fire suppression efforts were less intensive on the south side of Bunchgrass Ridge than on the north side (D. Gardner, per. comm.). To minimize the confounding effects of suppression activities on natural fire patterns, such as the effect of fire retardant drops on fire severity, sampling of watersheds was limited to the south-southwest face of Bunchgrass Ridge.

Pre-fire vegetation. Because a fire of a particular intensity (e.g., energy released per unit of fire line length) can have different severities (e.g., mortality) for different plant species (Agee, 1993), fire severity was quantified in terms of its effect on a single species: Douglas-fir. High elevation meadow, true-fir/mountain hemlock stands, and young Douglas-fir plantations were eliminated from the study since these vegetation types are likely to have higher mortality for a given fire intensity (Franklin and Dyrness, 1973; Agee, 1993; Kushla, 1996). A GIS map of pre-fire forest vegetation produced by the Willamette National Forest (Figure 3) was used to select watersheds dominated by either mature (80-200 years) or old-growth (200+ years) Douglas-fir stands before the fire (Franklin et al., 1986; USDA Forest Service, 1993).

3.2. Fire severity within watersheds

The 34 sample streams and their watershed boundaries were drawn on acetate that overlaid 1:12,000 color aerial photographs taken in 1998. Each watershed was divided into four zones: west-facing streamside, west-facing upland, east-facing streamside, and east-facing upland (Figure 4). The division between the streamside and upland zone was drawn halfway between the stream channel and the ridgeline to make the zones large enough to visually estimate live canopy cover. This method was selected after finding that neither a plot-scale analysis nor an analysis of change in live canopy cover along a stream-ridgeline gradient was feasible at the 1:12,000 aerial photograph scale.

Aerial photographs of the Warner Creek Fire area taken in 1990, one year before the fire, indicate that the study watersheds were nearly 100% forested before the burn. Fire severity was defined as the percentage of overstory trees that survived the fire (Agee, 1993). Using a

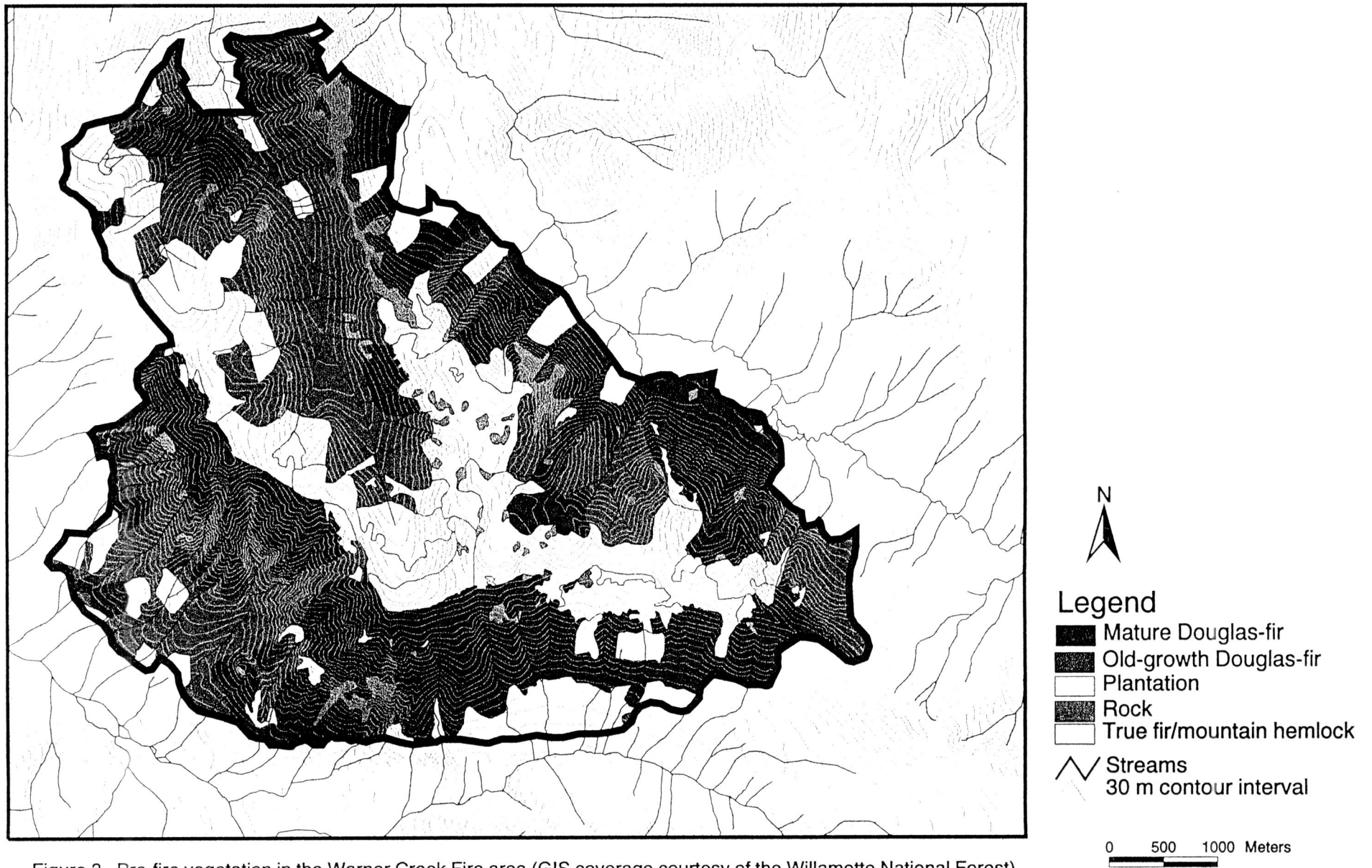


Figure 3. Pre-fire vegetation in the Warner Creek Fire area (GIS coverage courtesy of the Willamette National Forest).

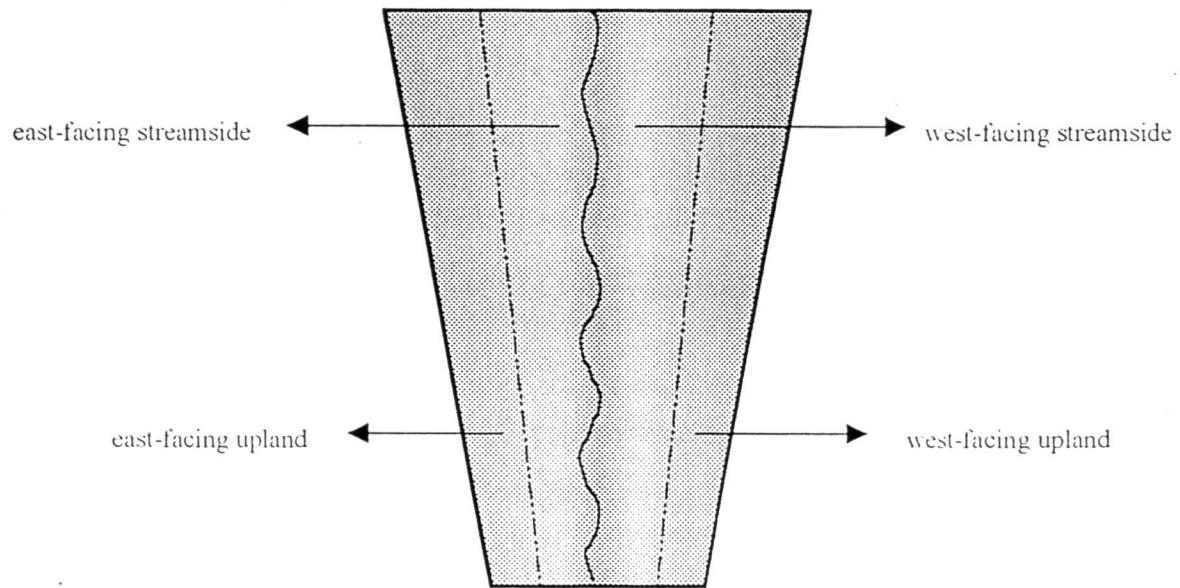


Figure 4. Schematic diagram of a watershed divided into the four zones used for quantifying live canopy cover from aerial photographs in the Warner Creek Fire study area.

Stratex-prism mirror stereoscope with 4x binoculars, percent live canopy cover in each of the four watershed zones was visually estimated from the aerial photographs within 10 equal intervals ranging from 0-100% (e.g., 0-10%, 10-20%, 20-30%, etc.). The mid-point of each interval was used in statistical analyses (e.g., 0-10% = 5%, 10-20% = 15%, etc.).

Differences in live canopy cover between streamside and upland zones and between east and west-facing slopes were tested using repeated measures analysis on the arcsine square-root transformed data (Sokal and Rohlf, 1987; SPSS Inc., 1999).

3.3. Evaluation of aerial photograph method

To assess the accuracy of live canopy cover values estimated from aerial photographs, six watersheds (approximately 103 ha, or 19% of the total area sampled) were randomly selected for ground-truthing. Percent live canopy cover was calculated in the field using a Moosehorn densiometer (Garrison, 1949; Mueller-Dombois and Ellenburg, 1974). Each watershed was divided into a 10 x 10 meter grid, and a canopy reading was taken every 10 meters while walking along the grid lines. The canopy was “open” if live canopy filled less than half of the Moosehorn grids, and “closed” if live canopy filled half or more of the grids. The percentage of closed canopy points was calculated to obtain an estimate of live canopy cover in each of the four watershed zones. All estimates were based on a minimum of 200 points and yielded a 95% confidence interval between +/-4.3 percent and +/-7.1 percent cover (Geographic Resources Solutions, 1995). The relationship between live canopy cover estimated from aerial photographs and live canopy cover calculated from field data was tested using regression analysis (SAS Institute, 1995).

An additional analysis was conducted to test for an effect of distance from the stream on live canopy cover that may have been masked by the coarse scale of the aerial photograph analysis described above. Field data were averaged at 10-meter intervals between the stream channel and 40 meters upslope. Change in live canopy cover along a stream-upland gradient was tested using regression analysis.

3.4. Topography and fire severity

While collecting the aerial photograph and field data described above, conspicuous differences in both live canopy cover and topography were observed between the watersheds. To examine the relationships between mean live canopy cover and topography in the study area, the following four variables were analyzed.

3.4.1. Topographic variables

Mean watershed slope. A slope map of the study area was derived from the 30 m DEM of the Warner Creek Fire area, and slopes for each watershed were extracted by overlaying watershed masks with the slope map using the ArcInfo/Grid combine function. Mean slope was computed for each watershed (SAS Institute, 1995). Steeper slopes have been associated with higher fire severity due to preheating of upslope fuels, convective winds, and, for drier aspects, greater exposure to solar radiation (Brown and Davis, 1973; Swanson, 1978; Agee, 1993; Weisberg, 1997). On the very steep slopes in the study area, however, patchier distribution of fuels and more exposed bedrock may actually restrict fire spread and reduce fire severity (Swanson, 1978).

Topographic complexity. Topographic complexity was quantified by computing the variance of the slope values for each watershed. Because complex topography can disrupt fire intensity and spread (Morrison and Swanson, 1990), I predicted that fire severity would be lower in watersheds with more variable slopes.

Drainage incision. Degree of drainage incision was quantified by a width-depth ratio calculated in ArcView GIS (modified from Rosgen, 1996). Drainage width and depth were measured along the contour lines every 100 meters within the watershed, then averaged to obtain a single width-depth ratio for each watershed. I predicted that the effect of drainage incision on fire severity would depend on the depth of drainage incision and which direction the fire burned relative to the drainage orientation (Figure 5). In a deeply incised drainage, a fire burning upslope may be channeled by the drainage and burn more intensely (Agee, 1994; Taylor and Skinner, 1998). A crown fire burning perpendicular to the drainage, on the other hand, may skip from one side of the drainage to the other due to the discontinuity of horizontal fuels (Brown and Davis, 1973). Where a fire burns perpendicular to a less deeply incised drainage, horizontal fuels are more continuous, allowing a crown fire to travel down one side and up the other (Brown and Davis, 1973).

Maximum watershed elevation. The maximum elevation of each watershed was obtained from the DEM in ArcView GIS. In the central western Cascade Range, higher elevations are associated with lower fire frequency due to cooler temperatures and to increased fuel moisture content that persists later into the fire season (e.g., Weisberg, 1998). Because low fire frequency is generally associated with higher fire severity (Agee, 1993), I predicted that fire severity would be higher in watersheds situated at higher elevations.

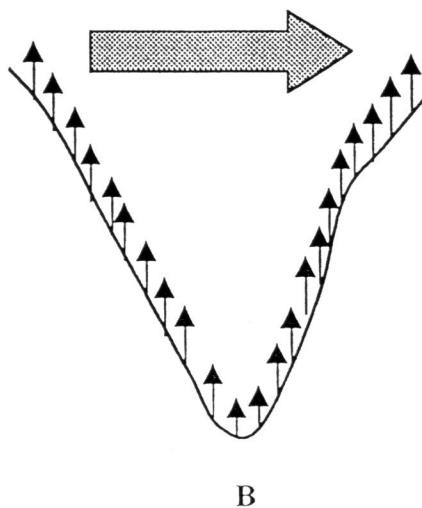
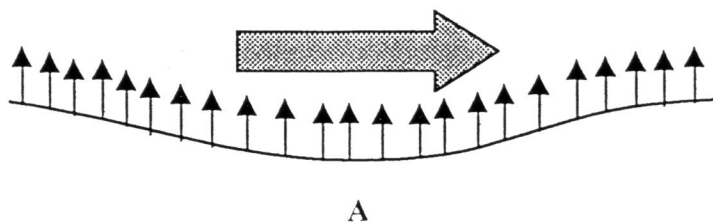


Figure 5. Potential effect of drainage incision on crown fire behavior and fire effects. In a shallow drainage (A), fuels are continuous, resulting in higher fire severity. In a deeply incised drainage (B,) discontinuity of horizontal fuels may cause flames to skip from one side of the valley to the other, resulting in lower fire severity at lower hillslope positions.

3.4.2. Statistical analysis of topographic variables

Because of insufficient topographic data, watershed #9 was eliminated from the analysis. Mean live canopy cover in each watershed was calculated by averaging live canopy cover estimates from the four watershed zones obtained in the aerial photograph analysis. Pairwise correlation analyses of all continuous topographic variables were conducted using Pearson product-moment correlation analysis (Sokal and Rohlf, 1987; SAS Institute, 1995). Stepwise multiple regression analysis with a p value to enter and remove variables of 0.10 (Kleinbaum et al., 1998) was used to identify the most predictive multivariate model of fire severity (SAS Institute, 1995). To test for significant interactive effects among the key predictors identified in the initial stepwise regression procedure, a second stepwise analysis was performed on a model including the key predictors and all two-way interactions among these predictors. The residuals of all regression models were analyzed to confirm normality and constant variance (Kleinbaum et al., 1998). Univariate regressions were examined to determine the relationships between fire severity and individual topographic variables included in the model.

4. Results

A significant and positive correlation ($p < 0.05$) was found between live canopy cover estimated from aerial photographs and live canopy cover calculated from field data in all four watershed zones (Figure 6). There was no significant difference in live canopy cover estimated from aerial photographs between streamside and upland zones on either side of the watersheds ($p > 0.05$), although live canopy cover appeared to be slightly higher in the upland zones on both the west and east-facing sides of the watersheds (Figure 7). Analysis of field data from six watersheds revealed a significant and positive correlation between live canopy cover and distance from the stream channel on both the east and west-facing sides of the watershed ($p = 0.03$; $p = 0.04$, respectively) (Figure 8).

Of the six pairwise correlations between topographic variables, only drainage incision and topographic complexity were significantly correlated (Table 1). Stepwise multiple regression analysis of mean slope, topographic complexity, maximum watershed elevation, and drainage incision resulted in a multivariate model that included both topographic complexity and maximum watershed elevation as predictors of live canopy cover (Table 2). These two topographic factors explained 21% of the variation in live canopy cover. No significant interactions were found between topographic complexity and maximum watershed elevation. Univariate regressions indicated a significant, positive relationship between live canopy cover and topographic complexity ($p = 0.02$) and a negative relationship between live canopy cover and maximum watershed elevation ($p = 0.06$), suggesting that fire severity was lower in watersheds that had more complex topography (e.g. more variable slopes) and that were situated at lower elevations (Figure 9).

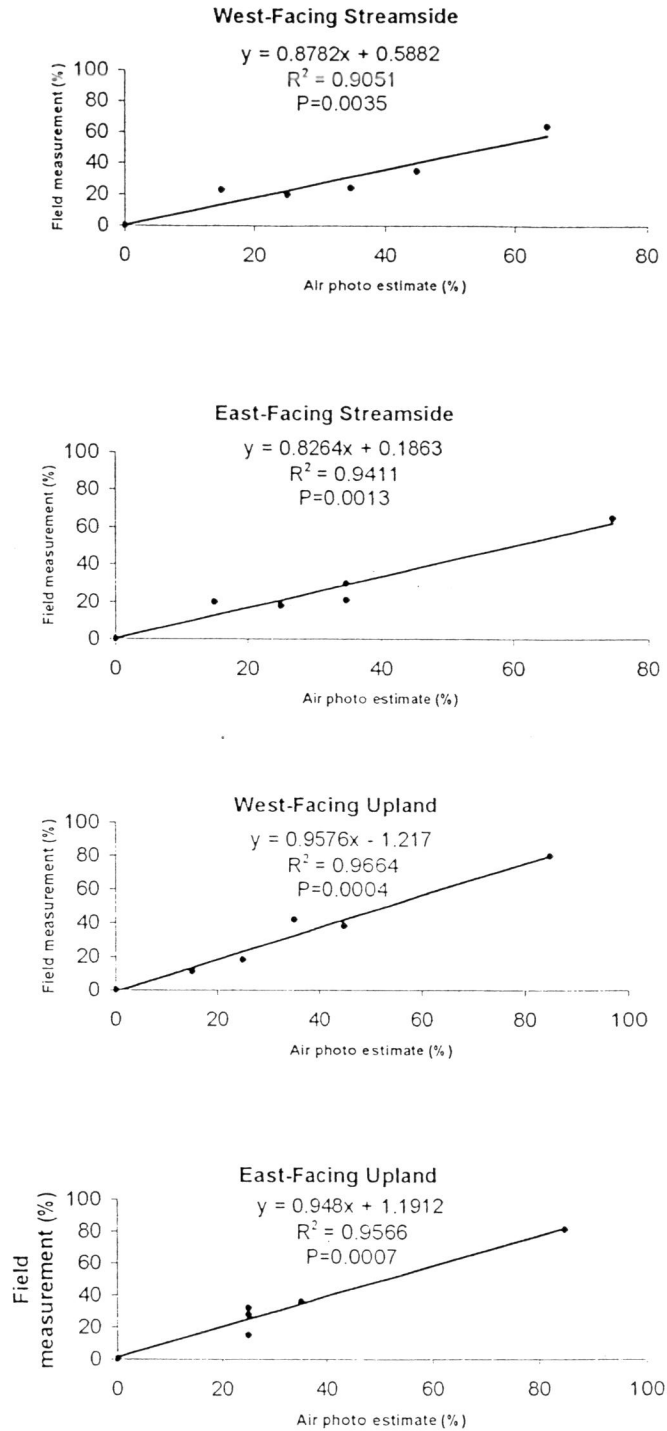


Figure 6. Correlations between live canopy cover estimated from 1:12,000 aerial photographs and live canopy cover calculated from field data in six watersheds in the Warner Creek Fire study area, July 2000.

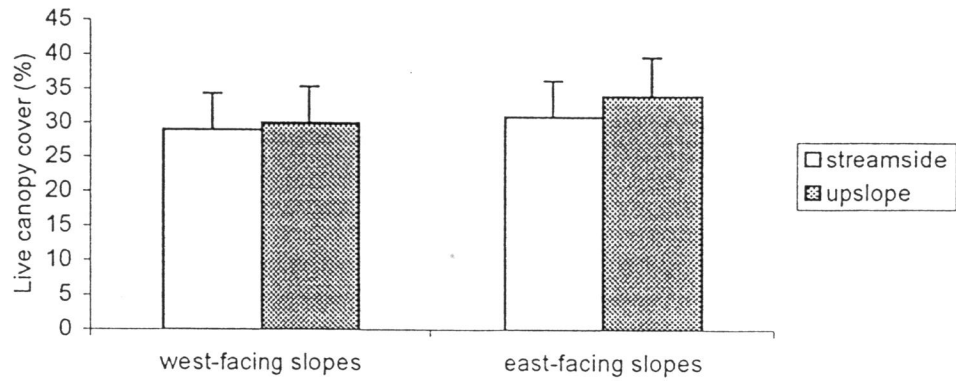


Figure 7. Live canopy cover estimated from aerial photographs in streamside and adjacent upland zones on east and west-facing slopes within the watersheds of 34 intermittent streams in the Warner Creek Fire study area, July 2000.

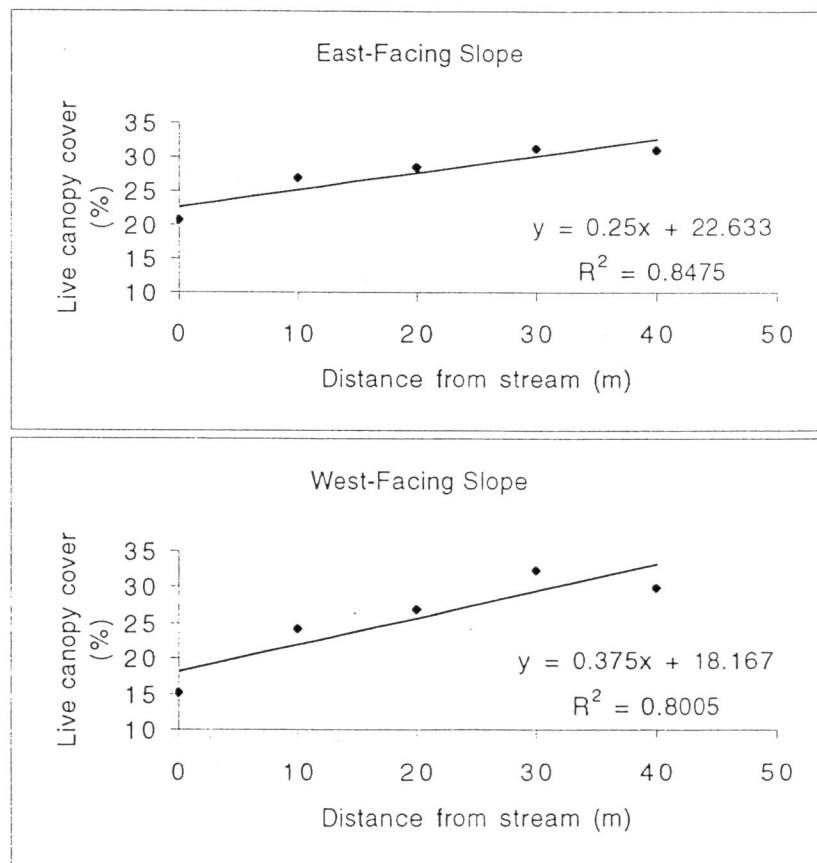


Figure 8. Live canopy cover calculated from field data along a gradient from the stream channel to 40 meters upslope on the east-facing ($p = 0.03$) and west-facing ($p = 0.04$) slopes of six watersheds in the Warner Creek Fire study area, July 2000.

Table 1. Pairwise correlation analyses of continuous topographic variables measured in the watersheds of 33 intermittent streams in the Warner Creek Fire study area, July 2000.

<i>Variable</i>	<i>by</i>	<i>Variable</i>	<i>Correlation</i>	<i>p</i>
slope variance		mean slope	0.251	0.16
drainage incision		mean slope	-0.265	0.14
drainage incision		slope variance	-0.387	0.03
maximum elevation		mean slope	0.314	0.07
maximum elevation		slope variance	-0.039	0.83
maximum elevation		drainage incision	-0.036	0.84

Table 2. Summary step history from the stepwise multiple regression analysis of live canopy cover in the watersheds of 33 intermittent streams in the Warner Creek Fire study area, July 2000.

<i>Step</i>	<i>Model Variables</i>	<i>b</i> ^a	partial <i>p</i>	<i>r</i> ² (adjusted)	<i>p</i>
1	topographic complexity	+	-	0.14	0.02
2	topographic complexity, maximum watershed elevation	+,-	0.02, 0.06	0.21	0.009

^a Indicates whether regression correlation was positive or negative.

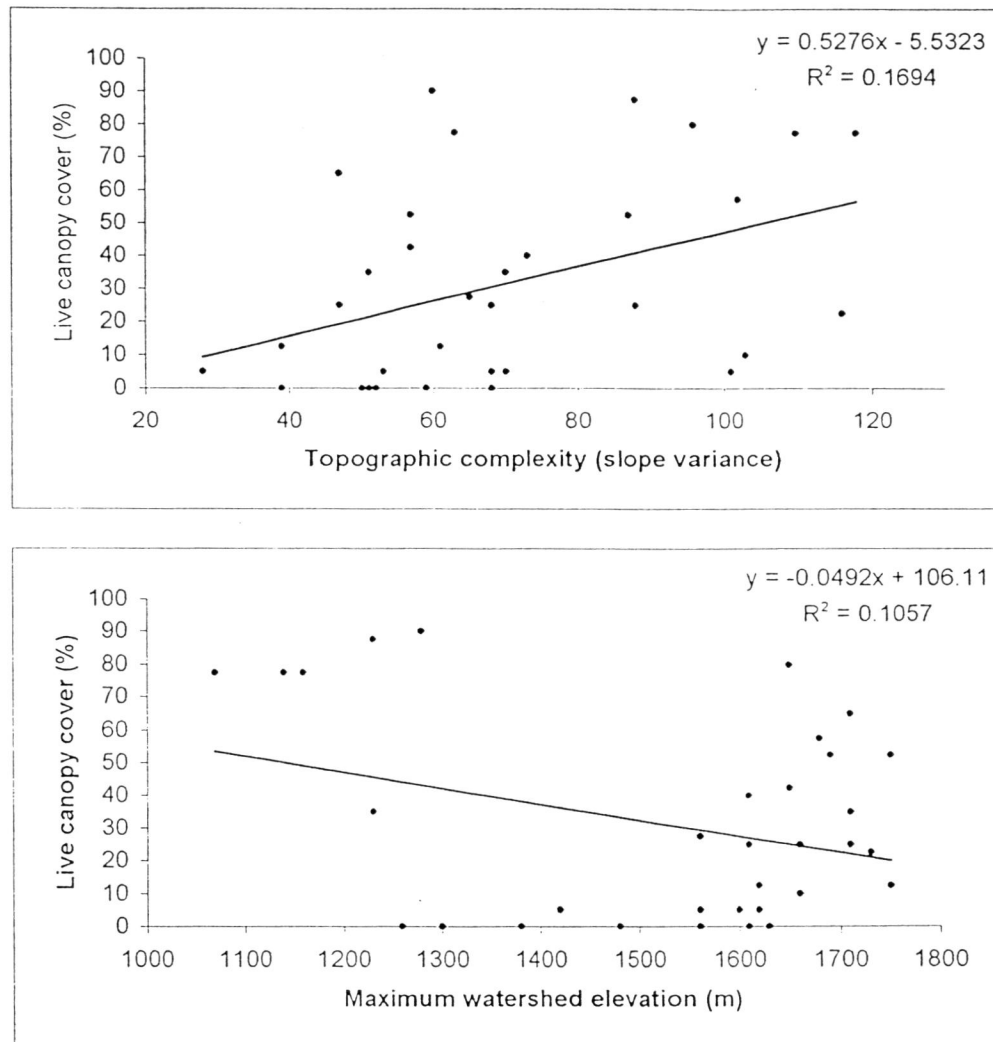


Figure 9. Univariate regressions showing the relationship between live canopy cover and topographic complexity ($p = 0.02$) and live canopy cover and maximum watershed elevation ($p = 0.06$) in the watersheds of 33 intermittent streams in the Warner Creek Fire study area, July 2000.

5. Discussion

5.1. *Evaluation of aerial photograph method*

A strong correlation between live canopy cover estimated from aerial photographs and live canopy cover calculated from field data provided a measure of confidence that estimates of live canopy cover taken from aerial photographs reflected actual conditions on the ground. Kushla (1996) notes that, although satellite-born sensors have been used in fire research for over two decades, aerial photography remains an effective tool for observing and quantifying fire effects. Remotely sensed data are particularly useful in analyses of fire severity over large, rugged, or remote landscapes, and an aerial photograph analysis can be accomplished with a fraction of the investment that a field-based analysis would require. Still, remotely sensed data should be ground-truthed to control for observer bias. Live canopy cover estimates are quite subjective and may need to be calibrated if there are consistent discrepancies between remote and field-based estimates.

Scale is an important consideration in aerial photograph analyses. At the coarse-scale of the aerial photograph analysis in this study, a statistically significant difference in live canopy cover between the streamside and upland zones was not detected, although live canopy cover tended to be slightly higher in the upland zone. When a finer-scale analysis was performed using detailed field data from six watersheds, this pattern strengthened and became significant. These results suggest that, while 1:12,000 scale aerial photographs are useful for mapping polygons of fire severity at a coarser scale, finer scale photographs (e.g., 1:4,000) may be more effective for quantifying change in fire severity along a stream to upslope gradient within small watersheds.

5.2. Fire severity within watersheds

In the aerial photograph analysis of 34 watersheds, fire severity did not differ significantly between streamside and upland zones, indicating that intermittent stream channels in the study area did not mitigate the severity of the Warner Creek Fire. Although intermittent stream channels have been associated with reduced fire severity (Keeton, 2000), the potential for intermittent streams to mitigate fire severity may depend largely on specific site and fuel moisture conditions (Camp et al., 1997; Skinner, 1997).

A number of studies suggest that riparian-associated landforms mitigate fire severity (Kushla, 1996; Impara, 1997; Camp et al., 1997; Skinner, 1997; Keeton, 2000; Olson, 2000; Wimberly and Spies, 2000). Higher humidity, reduced solar heating, the effects of cold air drainage, hydric soils, abundant herbaceous vegetation, and higher moisture content in both living and dead woody fuels may all contribute to reduced fire severity in these areas (Romme 1977; Romme and Knight 1981). The watersheds included in this study, however, are located in steep, south-facing, dissected terrain where vegetation composition and environmental conditions are similar along the stream and on the adjacent uplands. Solar radiation is high in the study area and, by late summer, site and fuel moisture is at a premium. The results of this study suggest that, when the humid characteristics of riparian-associated landforms are lacking, fire severity is likely to be similar adjacent to and upslope from intermittent stream channels.

Analysis of field data from six watersheds revealed a significant and positive correlation between live canopy cover and distance from the stream channel, supporting the finding that proximity to intermittent stream channels does not necessarily mitigate fire severity. Depending on the direction of the burn and the topography of the drainage, fires may even burn more

intensely along intermittent streams than on the surrounding uplands. Winds channeled by small, narrow drainages may increase fire intensity, causing the bottom of valleys to burn with greater severity than the surrounding uplands (Agee, 1994; Taylor and Skinner, 1998). Camp (personal obs., 1994) witnessed this pattern in the Rat Creek Fire on the Wenatchee National Forest where mortality was higher in valley bottoms than on the adjacent ridges. It is difficult to know whether this result is an artifact of a small sample size ($n = 6$) or an indication that the coarse scale of the aerial photograph analysis masked these finer scale patterns of fire severity.

Although there was no statistically significant difference detected in live canopy cover between east and west-facing slopes within the watersheds, live canopy cover appeared to be slightly higher on the east-facing side. This may be related to burning patterns of the fire. As the fire burned from west to east across the south face of Bunchgrass Ridge, it likely burned downslope on the east-facing side of many drainages and upslope on the west-facing side. Fires moving downslope tend to burn slower and less intensely due to backing and flanking behavior, while fires moving upslope spread faster and burn more intensely due to the preheating of surface fuels (Agee, 1993).

5.3. Topography and fire severity

In addition to site and fuel moisture conditions, topography may influence the mosaic of post-fire vegetation (Kilgore, 1978; Swanson et al., 1988; Heyerdahl, 2001). The severity of a fire, for example, may vary depending on aspect, slope, elevation, or degree of drainage incision. In this study, stepwise regression analysis identified topographic complexity and maximum watershed elevation as predictors of live canopy cover following the Warner Creek Fire.

Fire severity was highly variable and lower overall in watersheds with more complex topography, which included many of the watersheds on the southwest-facing section of Bunchgrass Ridge. Morrison and Swanson (1990) found a similar relationship between variable topography and fire severity in the central western Cascades. Changes in topography can cause dramatic changes in fire behavior as the fire moves across the landscape (Pyne et al., 1996). Complex topography affects wind patterns, resulting in more variable fire severity patterns (Morrison and Swanson, 1990). Steep, complex, irregular landscapes are more likely to disrupt the intensity of a fire, producing a more complex mosaic of fire severity patterns (Kilgore, 1978; Swanson, 1978).

Fire severity was higher in watersheds situated at higher elevations. Higher elevations are generally cooler and retain more moisture from a deeper snowpack that persists longer into the growing season (Franklin and Dyrness, 1973). Under very dry conditions late in the season, however, these factors may be less pronounced and less influential in controlling fire severity. Fuel accumulation at higher elevations, where fires are less frequent, may also result in higher fire severity (Agee, 1993). In addition, the thin-barked tree species found at higher elevations (e.g., Pacific silver fir) are less resistant to fire (Agee, 1993). The study area was dominated by Douglas-fir forests, but fire severity may have been higher in the upper reaches of drainages where Douglas-fir graded into Pacific silver fir.

Despite the significance of the regression model, slope variance and maximum watershed elevation explained a relatively small amount of the variability in fire severity among watersheds in the study area ($r^2 = 0.21$). This may be an indication that other variables not quantified in this study contributed to patterns of fire severity in the study watersheds. Cliffs and large rock outcrops, for example, which were much more common on the

southwest-facing section of Bunchgrass Ridge, may have acted as natural fuel breaks interrupting the severity of the fire (Swanson, 1978; Pyne et al., 1996; Keeton, 2000). Pre-fire stand age and structure may also have affected fire severity patterns (Keeton, 2000). A higher proportion of old-growth relative to mature Douglas-fir stands in watersheds on the southwest face of Bunchgrass Ridge may have mitigated the severity of the fire there. Watersheds on the south face of Bunchgrass Ridge, on the other hand, were dominated by a mature, even-aged stand of Douglas-fir that, in its smaller size and greater uniformity, may have been more susceptible to fire. Differences in fuel moisture and degree of exposure to desiccating easterly winds prior to the fire may have affected fire severity patterns, as may have watershed size, effectiveness of suppression efforts, and the time of day the fire reached each portion of the study area. Places the fire burned at night, for example, when higher humidity and cooler air would have reduced the intensity of the fire, may have burned less severely than places that burned during the day (Brown and Davis, 1973; Pyne et al., 1996).

6. Potential Management Implications

Managers in the central western Cascades may benefit from the kind of detailed fire regime information presented in this and related studies. In the Pacific Northwest, forest management objectives include both ecosystem protection and timber production. The Northwest Forest Plan employs a system of static reserves, corridors, and standard matrix prescriptions to protect an array of species thought to be dependent upon late successional forest, to protect aquatic ecosystems, and to provide a sustainable supply of timber (USDA and USDI, 1994; Cissel et al., 1999). Riparian reserves, which consist of buffers placed along all streams of all sizes, are an integral component of the Northwest Forest Plan. While this extensive reserve system boosts short-term ecosystem protection considerably, it also shifts intensive timber management to the upland areas between buffers. It is likely that, over the long term, harvesting timber under this system will create landscape structures unlike those found historically, resulting in compromised integrity of the matrix forest and increased forest fragmentation and forest edge (Cissel et al., 1999).

An alternative strategy for meeting the broad objectives of the Northwest Forest Plan involves the use of historic fire regime information as a guide for forest management (Cissel et al., 1999). In contrast to the static management prescriptions put forth in the Northwest Forest Plan, this approach takes the dynamic nature of ecosystems into account. Managers can gain insight from the landscape patterns created by historic wildfires and design management regimes that create similar landscape patterns.

Where timber harvest is an objective, cutting practices can lead to more natural landscape patterns than do either past practices or those prescribed currently under the Northwest

Forest Plan. Understanding how fire affects the forest at lower and upper slope positions within watersheds of different sizes and different landscape positions, for example, may help managers weigh the costs and benefits of varying management intensities in near-stream areas. The results of this study suggest that lower slope positions in small watersheds likely contain a diversity of disturbance-created stand structures. Alternative strategies that seek to create more natural landscape patterns may include less intensive timber management upslope and allow some level of infrequent, partial cutting on the lower slopes where management activities are currently prohibited or strictly limited (J. Cissel, per. comm.).

Spatial and temporal variability in fire severity creates a highly complex forest structure and composition in the central western Cascades, and detailed fire regime information is needed to complement information obtained at larger scales. Landscape-specific studies such as this one provide managers with insight necessary to tailor management strategies to local landscapes.

7. Conclusions

Aerial photograph analysis was shown to be an accurate method for quantifying fire severity in a recently burned area. The scale of the aerial photographs, however, must be well-matched with the study objectives. For quantifying fire severity along a stream-ridgeline gradient in small watersheds, aerial photographs of a finer scale (e.g., 1:4,000) may be most useful.

In the Warner Creek Fire study area, lower slopes burned with equal or greater severity than the adjacent upper slopes within the watersheds of intermittent streams. Although reduced fire severity has been associated with proximity to streams of various sizes, including intermittent streams (Keeton, 2000), under certain conditions the opposite may be true. On steep, south-facing slopes, site and fuel moisture may be depleted enough by late summer to overrule any potential mitigating effect of the stream on fire severity. Narrow, deeply-dissected drainages may actually act as chimneys, resulting in higher fire severity in the drainage bottom than on the adjacent uplands.

Fire severity varied significantly relative to differences in topographic complexity and elevation among watersheds. Fire severity was lower in watersheds with more variable slopes, where the intensity of the fire may have been interrupted. Fire severity was higher in watersheds situated at higher elevations where greater fuel accumulation and the presence of tree species with lower fire resistance may have been important influences. Still, topographic variables explained only 21% of the variability in fire severity patterns. Numerous other factors may obscure the relationships between fire severity and topography, making it challenging to reliably predict patterns of fire severity across heterogeneous

landscapes with complex climatic influences. The extent to which fire severity is mitigated by topographic features of the watershed may ultimately depend on the intensity of the fire. While low to medium-intensity fires may respond to topographic heterogeneity, in a high-intensity fire all but the most protected areas may burn (Rowe and Scotter, 1973; Swanson, 1978; Wimberly and Spies, 2001).

The variability in fire severity patterns in the Warner Creek Fire study area reflects the inherently variable nature of fire. No two fires are alike (Pyne et al., 1996), and even our best attempts to quantify and describe patterns of fire severity will be obscured to some degree by the idiosyncratic nature of fire as it responds to short-term changes in fuel conditions and weather patterns (Weisberg, 1998). Knowing this, explaining patterns of fire severity based on watershed characteristics or topographic variables poses a considerable challenge.

Still, local fire regime information couched within a broad, regional context may be useful to managers interested in using the range of natural ecosystem variability as a guide for forest management. Detailed fire regime information can be used to adapt management practices that are intended to sustain native species and maintain ecosystem productivity (Swanson et al., 1994). The search for a sustainable approach to ecosystem management is long-term. With a refined understanding of how natural disturbance processes affect forest ecosystems on a variety of spatial and temporal scales, managers may be better poised to design management strategies that balance ecological and economic objectives in Pacific Northwest forest management.

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Date:

Stream #	
Photo ID/#	
Area (m ²)	
Length (m)	
Elev. Range (ft)	
Pre-fire Stand	
Stream Class	
Channel Width (field)	

Notes:

Aspect		
Stream Channel	Slope A	Slope B

Channel Dissection ()			
Lower	Middle	Upper	Average

Slope (%) (field)		
Stream Channel	Slope A	Slope B

Live Canopy (%) (air photo)			
Stream A	Upslope A	Stream B	Upslope B

Live Canopy (%) (moosehorn)			
Stream A	Upslope A	Stream B	Upslope B

Date:

Stream #	
Photo ID/#	
Area (m ²)	
Length (m)	
Elev. Range (ft)	
Pre-fire Stand	
Stream Class	
Channel Width (field)	

Notes:

Aspect		
Stream Channel	Slope A	Slope B

Channel Dissection ()			
Lower	Middle	Upper	Average

Slope (%) (field)		
Stream Channel	Slope A	Slope B

Live Canopy (%) (air photo)			
Stream A	Upslope A	Stream B	Upslope B

Live Canopy (%) (moosehorn)			
Stream A	Upslope A	Stream B	Upslope B

PROJECT PRESENTATIONS

April 10, 2001 Fire Ecology seminar at Plattsburgh State University, Plattsburgh,
New York

"Fire ecology, fire regimes, and forest management in the Pacific Northwest."

April 12, 2001 Marvin Lecture Series, Botany Department, University of Vermont

"Analysis of fire severity patterns in the watersheds of intermittent streams, Warner Creek Fire, Oregon."

II. FEATURE ARTICLE

For submission to *High Country News*

IN THE WESTERN OREGON CASCADES, MANAGERS TAKE LESSONS FROM WILDFIRE

BLUE RIVER, OREGON. Imagine reading a 500-year history of wildfires on a tree stump. In their search for stumps, researchers in the western Oregon Cascades endure steep slopes, poison oak, blackberry brambles, and 98-degree days. But there is a reward: fire scars etched in the tree rings tell them about the historic frequency and severity of fires in the region. In a watershed 60 miles east of Eugene, Oregon, this information is being used to guide an alternative approach to forest management.

A forest made for fire

In the Blue River Watershed, wildfires have produced a complex mosaic of even and multi-aged forest stands. Looking down on the forest canopy from above, you can guess the age of a stand by the texture of the tree crowns. The patches with uneven crowns are old-growth, where the biggest trees have survived repeated fires for hundreds of years. The patches with smooth crowns are younger stands that probably initiated all at once after a stand-replacement fire.

It may seem counterintuitive, considering that it rains steadily for eight months out of the year, but fire is the dominant natural disturbance agent in the forests of the western Oregon Cascades. Rainfall drops off by mid-June, and the beginning of the fire season coincides with the arrival of lightning-associated thunderstorms in late summer and early fall.

To a large extent, fire also determines the structure and composition of the forest. Although western hemlock and western redcedar are the climax species here, they dominate the forest canopy only when stand-replacement fires are absent for centuries at a time. Otherwise, Douglas-fir maintains dominance for hundreds of years due to its longevity and to fires that continually reset the successional clock. Protected by thick bark, deep roots, and a high crown, mature Douglas-fir trees can escape low and medium-intensity fires unscathed. In high-intensity crown fires entire stands may die, but are quickly replaced by vigorous seedlings. A single fire can destroy one Douglas-fir forest and create another in its place.

Ecology vs. economics

The frequency of wildfire increases from north to south in the western Cascade Range, due to a decline in summer precipitation and an increase in lightning strikes along that gradient. In the driest parts of the region, where a forest might burn naturally once every 15 years, decades of fire suppression have caused fuels to accumulate to potentially disastrous levels. Concerns about public safety and forest health have spurred land managers to bring fire back, hoping to return these ecosystems to some semblance of their former selves.

In the central Oregon Cascades, managers have other reasons for turning back to fire. Here, because a forest might burn naturally only once every 90-150 years, the tinderbox situation is not nearly so dire. "The trigger here," says Fred Swanson, Ecosystem Team Leader at the Forestry Sciences Lab in Corvallis, Oregon, "was the approach to forest management. People didn't like clearcuts, and forest fragmentation was an emerging concern."

In the 1950s, clearcutting fed the nation's growing need for timber efficiently, and the Pacific Northwest quickly became one of the most productive timber-growing regions in the world. Some have defended the practice by claiming that clearcutting mimics the effects of a catastrophic wildfire.

Swanson disagrees. "Logging using dispersed and aggregated clearcuts created landscape structures that were much simpler than wild disturbance patches," he says. The Douglas-fir plantations that grew back in clearcuts in no way resembled the complex mosaic of even and multi-aged forest stands produced by wildfire. Instead of mimicking nature, clearcutting caused forests in the western Oregon Cascades to deviate from their natural condition.

Growing concern over the impact of clearcut logging on old-growth forests in the early 1990s led to a court-ordered injunction banning all timber sales on federal forest lands in the Pacific Northwest. In response, the Clinton Administration drafted the Northwest Forest Plan—an attempt to balance ecosystem protection and timber production on 24 million acres of federal forest lands across western Washington, Oregon, and northern California.

The objectives of the Northwest Forest Plan are ambitious: to sustain species associated with old-growth forests, to maintain and restore aquatic ecosystems, *and* to provide a sustainable supply of timber. It looks great on paper, but striking a balance between ecological and resource objectives has not been easy. While short-term ecosystem protection is significantly bolstered through the generous use of forest and aquatic reserves, timber harvest has been shifted to the fingers of matrix forest between reserves. Over the long-term, harvesting timber under this system is likely to compromise ecosystem health by fragmenting the forest and creating landscape patterns unlike natural patterns created by fire. Additional challenges are likely to arise when the lands open to timber harvest are too small or too inaccessible to make logging logistically or economically feasible. Timber sales have already dropped precipitously since the late 1980s, when timber harvested on the Willamette National Forest brought in \$200 million/year on a \$30-40 million budget. Today, timber sales account for almost nothing.

Lessons from fire

Recognizing that a sustainable balance between ecosystem protection and timber production on public forests has yet to be found, scientists and managers based at the H.J. Andrews Experimental Forest and the Blue River Ranger District of the Willamette National Forest have turned to wildfire for guidance. "We are trying to figure out the best way to meet the expectations we have of the forest landscape," explains Swanson.

Their project, called the Blue River Landscape Plan, attempts to match timber harvest prescriptions with key elements of the historic fire regime. The logic goes something like this: wildfire has 'managed' forests in the western Cascades for thousands of years. Understanding the range of landscape patterns brought about under a natural fire regime can provide clues about how to employ cutting practices that can lead to more natural landscape patterns.

Information about the historic frequency, severity, and size of fires in the Blue River Watershed serves a kind of roadmap for timber harvest. Fire frequency, for example, informs the rate of timber harvest. Fire severity, or the level of fire-induced tree mortality, is represented by the number and type of trees left standing following timber harvest. In a low-medium severity fire regime, post-harvest tree retention may range from 15-50%. Keeping in mind that disturbance frequency and severity are often inversely related, timber harvests that remove more trees will occur less frequently, leaving more time for recovery before the next harvest. In theory, these practices should result in a more heterogeneous forest mosaic than has existed on managed lands in the last 50 years, ranging from small gaps to large patches distributed across the landscape in a pattern that approximates what a fire might produce.

Dampening the disturbance regime

Like any idea outside the mainstream, the Blue River Landscape Plan has received some criticism. There are those, for example, who would rather not see any timber taken from the public forests. They see it as just another excuse to "get the cut out."

"Another misinterpretation," says John Cissel, Research Coordinator at the Blue River Ranger District, "is that we are substituting timber harvest for fire. But we know that these are completely different processes, and that timber harvest cannot replace the process of fire."

"A lot of carbon leaves the landscape on those logging trucks," he points out. Most of the wood that remains standing or on the ground following a wildfire is removed from the forest during logging. That has significant implications for ecosystem processes like nutrient cycling and the input of wood into streams. Furthermore, a wildfire varies in intensity based on weather patterns and microclimatic conditions, creating an unpredictable mosaic of fire severity that puts even the most sophisticated logging operation to shame.

Logging may never mimic fire, but it can approximate some of the structural patterns that fire creates on the landscape. And prescribed fire can be employed as a complement to logging to accomplish other important functions, like creating the soil and nutrient conditions necessary for tree regeneration.

Still, the ecological effects of dampening the natural disturbance regime to meet diverse forest management objectives are unknown. It may turn out that sustaining healthy ecosystems and producing timber are incompatible objectives. "We're not doing this because we think it's what the ecosystem needs," says Cissel. "We're trying to meet the diverse objectives of the Northwest Forest Plan in a way that minimizes risk to ecosystem health."