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Retrospective Analysis of Forest Landscape Patterns in Western Oregon

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ABSTRACT: Using historical vegetation maps from the 1930s and a geographic information system, we quantified the spatial patterns of prelogging forest conditions in western Oregon. Specifically, we measured the composition and spatial distribution of forest patches and determined fire patch characteristics for three landscape study areas. The spatial coincidence between forest patches and topographic features was evaluated for slope gradient, aspect, elevation, and distance from streams. The prelogging landscapes of western Oregon were dominated by old-growth conifer with lesser amounts of mid- and early seral forest. Fire patches differed in size and shape between the Oregon Coast Range and the Oregon Cascades Range physiographic provinces. Fire patch size and variability were greater in the Cascades Range, with shorter mean distances between fire patches and smaller perimeter-to-area ratios compared to fire patches in the Coast Range. Forest patch types varied predictably by topographic feature. For instance, fewer fire patches occurred on cool, moist aspects, while more occurred on hot, dry, aspects. More burn area and less old-growth conifer than expected occurred within 4,000 m of major rivers. Assessing historical forest landscape patterns is useful for understanding disturbance regimes and the ecosystem processes that are associated with them.

Index terms: fire disturbance, historical forest conditions, landscape patterns, western Oregon

INTRODUCTION

Large-scale disturbances have been a prevalent force in natural landscapes for millennia. In the forests of Pacific northwestern North America, fire has been the dominant force creating, maintaining, and destroying the rich mosaic of disturbance patches that drape the landscape (Agee 1991). Where logging has not occurred, forest patch mosaics provide a record of a landscape's fire history. This fire history can be investigated by interpreting the age-class distributions of the disturbance patches within the landscape. Interpreting landscape patterns is not easy, however, because fire regimes vary in frequency, intensity, and extent across a wide range of environmental conditions. Recognizing the nature of disturbance, especially fire, is fundamental to understanding forest patch dynamics and to accurate interpretation of the patch mosaics that have historically characterized the landscape. This knowledge is important for being able to predict the role of future disturbances, including the effect of management activities, on terrestrial ecosystems in the forests of the Pacific Northwest.

Little is known about the historical spatial patterns of fire disturbances in western Oregon, especially at a landscape scale. Although there have been efforts to describe the forest conditions of Oregon for presettlement and settlement times (before and after the 1840s), these reports have been limited to per acre volume estimates of a few commercially important tree species over broad, nonspecific geographic areas (e.g., Gannet 1902, Langille et al. 1903, Franklin and Spies 1984, and Booth 1991). Except for the few fire history studies in the Western Cascades Range by Burke (1980), Teensma (1987), Morrison and Swanson (1990), Garza (1995), and Wallin et al (1996), and generalized reports by Teensma et al. (1991) and by Ripple (1994), spatial analyses of the historical forest conditions of western Oregon, and for natural fire disturbance patterns in particular, are lacking.

The availability of geographic information system (GIS) technology and remotely sensed data enabled us to characterize historical landscape patterns by examining various ecological data layers (e.g., topographic, hydrologic, vegetative, etc.). Once spatial and temporal patterns are identified, their interrelationships can be elucidated and inferences about the ecological processes that link them can be made. Management activities can focus on important natural landscape features in terms of composition, structure, and ecosystem function, by managing for a desirable range of landscape conditions.

The purpose of our research was to conduct a retrospective study of forest landscape patterns in western Oregon using spatial data from a U.S. Forest Service regional forest survey completed in the 1930s. The forest type maps from this survey were selected as our primary data source for two reasons: they provide detailed spatial information on the species composition and diameter size classes of forest patches across all ownerships, and they present spatial patterns of fire disturbance from a period before logging was a major factor on the landscape in most areas of the Pacific Northwest (Andrews and Cowlin 1940).

From their regional survey, Andrews and Cowlin (1940) determined that less than 12% of western Washington and Oregon was in a cutover condition in 1936. The majority of this harvest activity had occurred on private property in the fertile lowlands of western Washington and the extreme northwest portion of Oregon along the Columbia River. Because less than 5% of western Oregon had been logged at the time the source maps were created, we used the term "prelogging" to characterize the predominant forest conditions in western Oregon for this reference period.

We examined the patch mosaics of three large landscapes in western Oregon to answer three questions: (1) What was the prelogging forest patch type composition and corresponding spatial pattern of each landscape? (2) What was characteristic about the prelogging fire patches? (3) Was the spatial distribution of prelogging forest patch types associated with the topographic variables of slope gradient, aspect, elevation, and distance from streams?

In this paper, we describe the composition and distribution of prelogging forest cover types, including the size, shape, and configuration of disturbance patches and levels of forest fragmentation. We explore associations between topographic features and prelogging forest patch types. Finally, we discuss our observations in the context of fire disturbance ecology and suggest implications for ecosystem management.

STUDY AREAS

We analyzed the historical spatial data of three landscapes located in western Oregon. One study landscape occupies an area in the Coast Range province, and the other two are found in the Western Cascades mountain province as shown in Figure 1. A study size of 329,000 ha was chosen for each study area because it was the largest rectangular extent that would fit on the 1936 source maps without including any harvest patches. This individual study size falls within the meso-scale domain defined by Delcourt and Delcourt (1988), which is the appropriate spatial scale for observing changes in the landscape mosaic, especially those vegetative responses that are due to environmental gradients and predominant disturbance regimes.

The Coast Range and the Western Cascades provinces have a common maritime climate characterized by mild, wet winters and cool, relatively dry summers. Annual precipitation, mostly in the form of rain, or snow at higher elevations, ranges from 800 to 3,000 mm. Most precipitation, 75% to 85% of which occurs between October 1 and March 31, is the result of low-pressure systems that approach from the Pacific Ocean. The localized variations in climate that occur between the two provinces— local increases in precipitation (orographic effect) and in the proportion of precipitation that falls as snow—are associated with elevation and position of the mountain ranges.

North-south trending mountain ranges of plate tectonic origin dominate both provinces. This steep, deeply dissected terrain consists of mostly east-west trending ridges overlain by a dendritic network of perennial streams. Well-developed soils have formed from the weathered parent materials: Tertiary sedimentary rocks in the Coast Range and Tertiary basalt and andesites in the Western Cascades. Elevations range from sea level to 1,250 m in the Coast Range and from 100 to 2,100 m for the Western Cascades. Slope gradients range from 0% to 140%, with the majority falling in the 10% to 50% range.

Numerous conifer species that are the largest and longest-lived representatives of their genera dominate the forests within these two provinces. The hardwood species present are few in number and generally confined to specialized habitats such as riparian gallery forests and woodland savannas, or to early successional stages of the conifer-dominat-

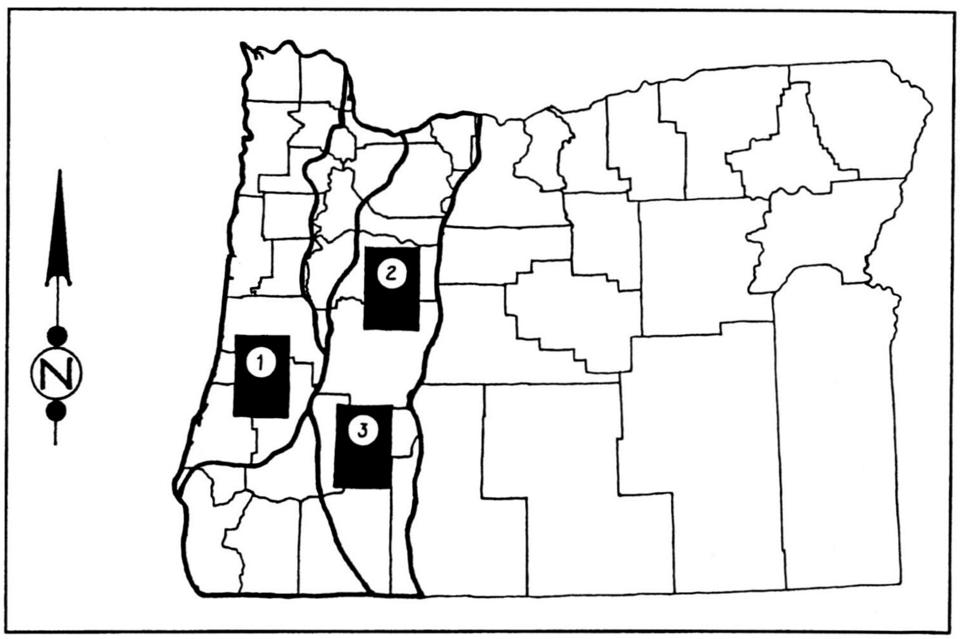

Figure 1. Location of landscape study areas: 1 = Oregon Coast Range; 2 = Central Oregon Cascades; 3 = Southern Oregon Cascades Range. Heavy lines denote physiographic province boundaries as described in Franklin and Dyrness (1988). Thin lines denote county boundaries for Oregon.

ed forest (Franklin 1988). The most common overstory tree species is Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco.), with western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), western redcedar (*Thuja plicata* Donn.), Pacific silver fir (*Abies amabilis* [Dougl.] Forbes.), and noble fir (*Abies procera* Rehd.) as associates. The understory consists usually of western hemlock, western redcedar, big leaf maple (*Acer macrophyllum* Pursh.), and red alder (*Alnus rubra* Bong.).

Wildfires during the past millennia have created a complex mosaic of variously aged forest patches throughout the two provinces (Hemstrom and Franklin 1982). Young forest patches originating from wildfires are typically densely stocked and dominated by Douglas-fir. During their first 100 years or so of growth, Pacific Northwest conifer forests are most susceptible to stand replacement fires (Franklin and Hemstrom 1981). By 200 years, many forest patches exhibit late-successional features, such as codominance of western hemlock in the overstory, diverse vertical foliage distribution, and large accumulations of woody debris (Franklin et al. 1981, Franklin and Spies 1984). True climax forests are rarely found because individual Douglas-fir trees can persist as overstory dominants for more than 1,000 years, and because wildfires have historically occurred more frequently than this on most sites in the Pacific Northwest (Spies et al. 1988).

METHODS

In this study, we examined the prelogging forest landscape patterns and topographic features for three study landscapes. Study area boundaries were identified on the forest survey maps, and the mapped locations of forest patches within the study landscapes were verified using aerial photos from the 1940s. We created digital maps of forest patch type, slope steepness, aspect, elevation, and stream network for each study area. With these data layers, we then quantified the composition and configuration of disturbance patches for each landscape, and determined the spatial coincidence of forest patches with the environmental variables of interest (e.g., slope, aspect, elevation, and distance from streams). Finally, we used Chi-square methods to compare observed versus expected spatial coincidence.

The 1936 Forest Survey Map

Source maps consisted of 1:253,440 scale color lithographed forest cover type maps of western Oregon, published in 1936 by the U.S. Forest Service. These maps were created from field examinations conducted between 1930 and 1934 by more than 20 field foresters employed by the Pacific Northwest Forest Experiment Station, Portland, Oregon. The objective of this regional inventory was to map areas of uniform type conditions (size-class and species composition) and to estimate the average volume per acre for each of these forest type patches. Forest type boundaries were determined by working along trails, roads, and ridges, and using high points for lookouts. Information was placed directly on 1:63,360 scale vellum base maps showing streams, road networks, and property boundaries and was augmented with information from aerial and oblique photos. The smallest patches mapped were 8 ha in size for hardwoods and 16 ha for conifers (Andrews and Cowlin 1940).

Before converting the historical maps into a digital format, we compared the location of the forest type patches portrayed on the 1936 source maps to their corresponding locations on 1940s-era 1:20,000 scale black and white aerial photos. Photos from randomly selected flight lines within each study area were used. The tree canopy sizes and shapes within the patches, and the patch extents that we observed on the photos, corresponded well with the patch types, shapes, and locations found on the 1936 maps. We also found that some of the mapped burn patches in both the Oregon Coast and Western Cascades provinces had, within their boundaries on their respective photos, residual live trees that were scattered on hill slopes and clumped near stream bottoms. This observation supports the finding that fires in the Cascades province do not destroy all remnants of the previous stand (Morrison and Swanson 1990) and that considerable variation in fire severity exists.

Spatial Data Layers

Five spatial data layers (prelogging forest patch type, slope gradient, aspect, elevation, and distance from streams) were created for each study area and analyzed using ERDAS GIS programs (ERDAS 1990). All data layers were geo-referenced using the UTM coordinate system and given a raster format with a common grid cell size of 1 ha (100 m x 100 m).

The original forest cover types from the 1936 Andrews and Cowlin maps were digitized and recoded into six categories to create the prelogging forest cover type data layer. This reclassification scheme is shown in Table 1. Because the three landscapes were mostly composed of forest patches dominated by Douglas-fir, we chose to lump the original Andrews and Cowlin (1940) cover types into general conifer size-class categories, ignoring species composition. Of the six categories we created, five reflect the process of ecological succession of a forested landscape through time: from disturbance (i.e., burn areas), through early and mid-succession (seedling-sapling, small conifer), to late-successional stages (large conifer, old-growth conifer). The sixth category (nonconifer) was used to classify the remaining areas that included hardwoods, nonforest land types, and water. The corresponding diameter size-class definitions for these six categories are listed in Table 1.

Old growth was defined on the 1936 maps as areas of forest where the majority of the volume (> 60%) was composed of Douglas-fir trees > 51 cm dbh, and of an age > 160 years. We retained this definition of old growth throughout our analysis, even though it differs from the structural and compositional features of more recent definitions of old growth (Franklin and Spies 1991), which use a standard of > 20 Douglas-fir trees per ha with > 81 cm dbh and > 200 years old. Although the Andrews and Cowlin (1940) forest survey initially collected site-specific information on old-growth patches of Douglas-fir trees > 100 cm dbh, this spatial information was not retained. For cartographic reasons, they combined this category with the 51–102 cm dbh old-growth category when the 1936 forest type maps were created.

Table 1. Reclassification scheme used in the landscape pattern analysis of the 1936 Andrews and Cowlin (1940) forest cover type maps of western Oregon. Definitions of categories are as follows: Burned Areas = conifer patches killed by fire and <10% restocked, Seedling-Sapling = conifer patches 0–15 cm dbh, Small Conifer = conifer patches 15–51 cm dbh, Large Conifer = conifer patches < 160 y old & 51–102 cm dbh, Old-Growth Conifer = conifer patches > 160 y old & > 51 cm dbh, Nonconifer = water, nonforest, and hardwood patches. (dbh = diameter at 1.4 m above ground level).

Original Cover Types from 1936 Andrews and Cowlin Map	Patch Types used for Prelogging Spatial Analysis	Percent of Area within each 329,000-ha Study Landscape		
		Oregon Coast Range	Central Oregon Cascades	Southern Oregon Cascades
1 Nonforest Land	Nonconifer	7.74	1.98	0.61
2 Agricultural Zones	Nonconifer	0.00	0.00	0.00
3 Subalpine Areas	Small Conifer	0.00	0.91	0.62
4 Lodgepole Pine	Small Conifer	0.00	0.09	0.87
5 Juniper	Small Conifer	0.00	0.00	0.00
Douglas-fir				
6 Old Growth	Old-Growth Conifer	39.10	51.17	62.84
7 Large	Large Conifer	32.92	8.65	7.56
8 Small	Small Conifer	15.71	17.72	5.39
9 Seedling/Sapling	Seedling-Sapling	1.81	2.86	5.17
Spruce/Hemlock/Cedar				
10 Large	Large Conifer	0.00	2.71	0.00
11 Small	Small Conifer	0.00	0.93	0.00
12 Cedar/Redwood Large	Large Conifer	0.00	0.00	0.00
Ponderosa Pine				
13 Large	Large Conifer	0.00	0.00	1.49
14 Pure Ponderosa Large	Large Conifer	0.00	0.00	0.00
15 Small	Small Conifer	0.00	0.00	0.51
16 Seedling/Sapling/Pole	Seedling-Sapling	0.00	0.00	0.09
Pine Mixture				
17 Large	Small Conifer	0.00	0.00	0.00
18 Small	Small Conifer	0.00	0.00	0.00
True Fir/Mtn. Hemlock				
19 Large	Large Conifer	0.00	7.86	9.43
20 Small	Small Conifer	0.00	1.64	0.83
21 Alder/Ash/Maple	Nonconifer	1.05	0.22	0.00
22 Oak/Madrone	Nonconifer	0.12	0.00	0.39
23 Recent Cut-Overs	N/A	0.00	0.00	0.00
24 Nonrestocked Cut-Overs	N/A	0.00	0.00	0.00
25 Deforested Burns	Burned Areas	1.49	3.25	4.20
Water Bodies	Nonconifer	0.06	0.00	0.02

Topographic feature maps of slope gradient, aspect, and elevation, were derived from 1:250,000 scale (1-degree) Digital Elevation Models (DEM) available in digital format from the U.S. Geological Survey (USGS). After subsetting and rectifying the DEM image for each study area, data reduction techniques were used to create meaningful map categories (e.g., 45-degree aspect classes and 10% slope gradient classes). As suggested by Isaacson and Ripple (1990), we retained the 16-bit format as far along in the chain of processing as possible, to minimize possible errors in the final image values of these digital terrain data sets.

The stream network maps were derived from 1:250,000 scale (1-degree) DEMs available from USGS. Each study area was subset from the DEM, and the vector data consisting of stream locations were then converted into raster format to perform the spatial adjacency analysis.

Spatial Analysis

The raster version of a spatial pattern analysis program, FRAGSTATS (McGarigal and Marks 1995), was used to quantify landscape structure of the prelogging forest cover type maps. This computer program calculates landscape metrics at user-defined patch, class, and landscape levels. The numerous indices available include descriptors of size, shape, and landscape configuration of vegetation patches; connectivity between patches; levels of forest fragmentation; and landscape heterogeneity. We chose to report only those metrics that were the most meaningful to our landscape-level analysis.

Fire patch characteristics were quantified from the prelogging forest patch type maps using the FRAGSTATS program after we first combined the burned areas with the seedling-sapling patches. These classes were combined because we could not determine with certainty that adjacent patches of recently burned areas and seedling-saplings were from separate fire events. We assumed that the seedling-sapling patches were the result of fire rather than wind, insects, pathogens, or other disturbance because of their extensive size and the predominance of fire as a disturbance factor on these landscapes.

Data for spatial adjacency analyses were obtained using the ERDAS SEARCH program. The variable, distance from streams, was measured using 25-m increments, which were subsequently aggregated into 100-m distance bands. A map portraying only major rivers and a second map including all perennial streams were created for each study landscape.

The ERDAS MATRIX program was used to determine how forest patch types coincided spatially with topographic and hydrologic variables. For each pair of input

Table 2. Prelogging landscape composition by study area. Definitions of patch types are in Table 1.

Patch Type	Oregon Coast Range % of landscape	Oregon Coast Range number of patches	Central Oregon Cascades % of landscape	Central Oregon Cascades number of patches	Southern Oregon Cascades % of landscape	Southern Oregon Cascades number of patches
Burned Areas	1.5	32	3.2	38	4.2	37
Seedling-Sapling	1.8	19	2.9	31	5.3	57
Small Conifer	15.7	71	21.3	61	8.2	69
Large Conifer	32.9	61	19.2	37	18.5	47
Old Growth	39.1	44	51.2	26	62.8	8
Non-conifer	9.0	51	2.2	32	1.0	23

files (e.g., forest patch type and elevation), a composite map was created containing class values that were coded to indicate how the class values from the original files overlapped.

RESULTS

Prelogging Forest Landscape Composition and Pattern

The prelogging landscape composition and distribution of forest patches are displayed in Table 2. Old-growth conifer (≥ 51 cm dbh) covered 39% of the Oregon Coast Range landscape, 51% of the Central Oregon Cascades landscape, and 63% of the Southern Oregon Cascades landscape. Among the three study areas, the quantity of old growth varied inversely with the number of old-growth patches. The early seral disturbance patches (burn areas and seedling-sapling categories) comprised less than 10% of each prelogging landscape. The Oregon Coast Range landscape had a substantially higher proportion of large conifer (33%) than the other study areas, while the Central Oregon Cascades landscape contained more small conifer (21%).

Even though composition varied between the three study areas, patch richness remained equal, with all six patch types present within each landscape. Furthermore, the number of patches per forest type were fairly evenly represented, with the exception of the old-growth class in the Southern Oregon Cascades landscape.

As depicted in Figure 2, the mean forest patch size for all three study areas increased along a patch type gradient representing time since disturbance. Early-seral patches (deforested burn areas and seedling-sapling categories) had small mean patch sizes (149–363 ha), while the mid-to late-seral patches (small and large conifer categories) had larger mean patch sizes (380–1,747 ha). The mean patch size for the old-growth matrix ranged from 2,679 ha for the Oregon Coast Range study area to 22,971 ha for the Southern Oregon Cascades study area. The most frequent

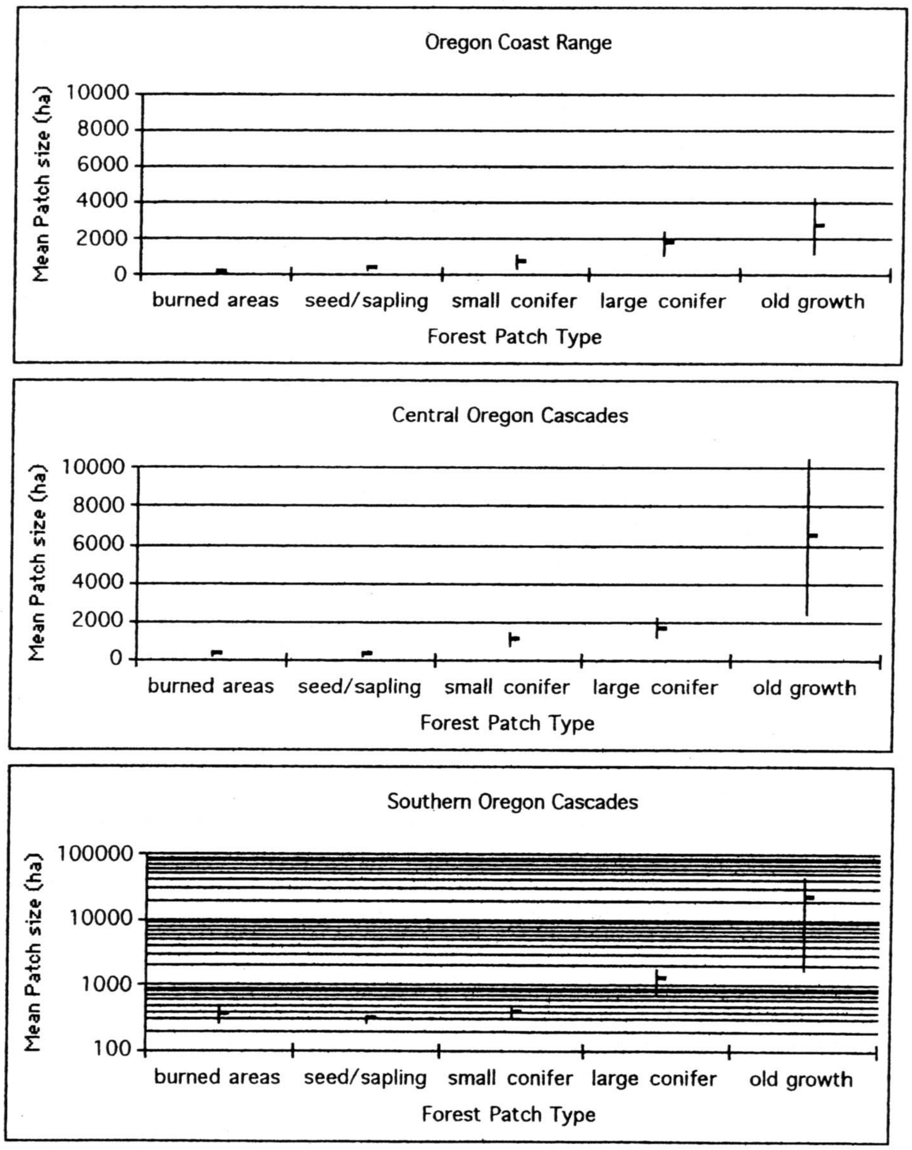

Figure 2. Comparison of prelogging mean patch sizes by forest patch type by landscape study area. Vertical bars represent standard errors.

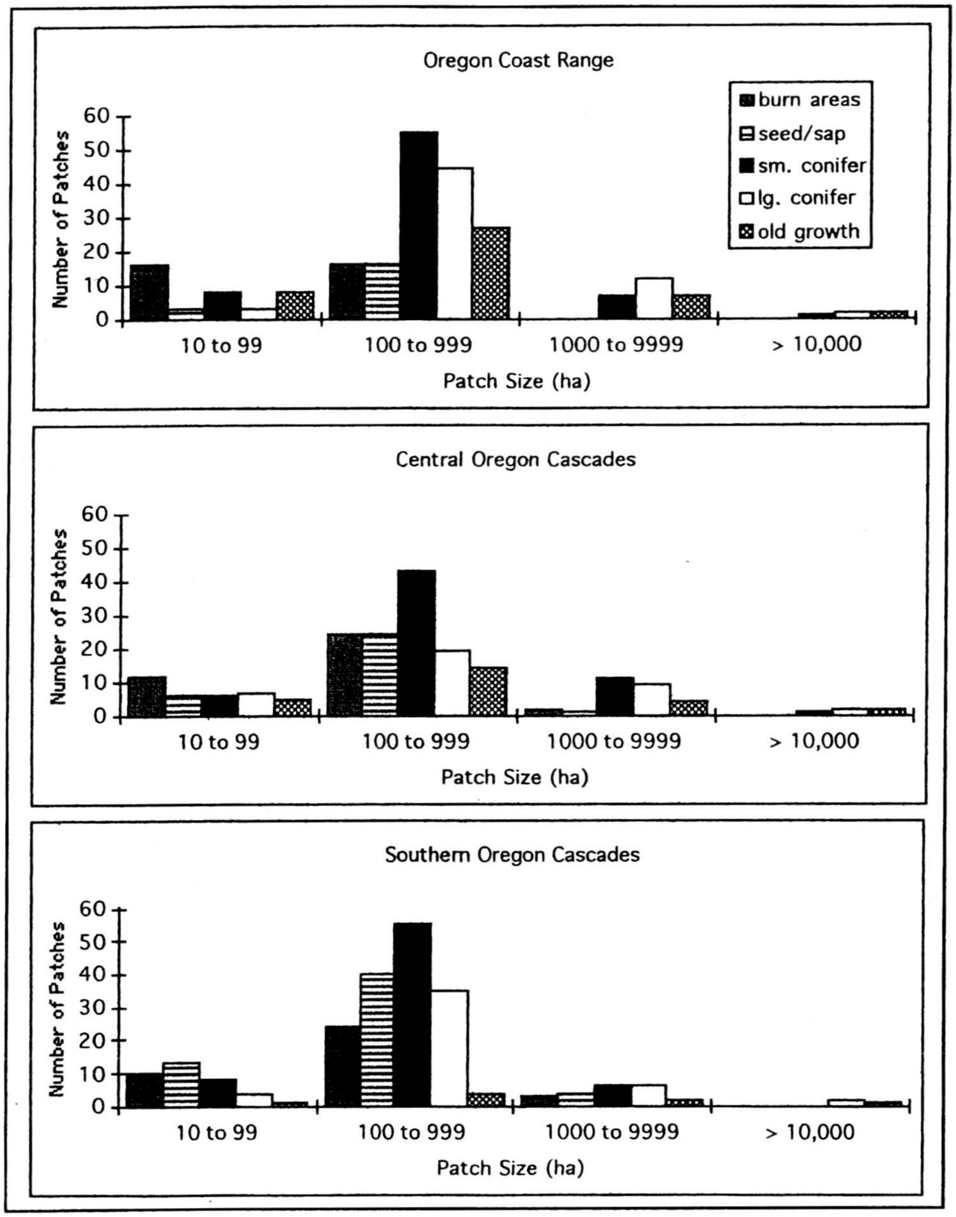

Figure 3. Frequency distribution of prelogging forest patches by size class.

patch size, regardless of forest patch type, fell in the 100–999 ha category for all three landscapes, as shown in Figure 3.

The prelogging spatial distributions for old-growth conifer and recent fire patches are shown in Figure 4. Old-growth conifer was the most extensive and connected cover type for all three study areas even though the distribution and composition varied by landscape. These large matrices of old growth enveloped the other disturbance patches and dominated the prelogging landscape. The Coast Range old-growth matrix was the most fragmented with 44 distinct patches, compared to 8 for the Southern Cascades landscape and 26 for the Central Cascades landscape.

Recent fire disturbance patches were evenly distributed across the two Cascade province landscapes, but were scattered away from large reforested areas in the Coast Range province landscape that burned as part of the Coos Bay fire of 1868 (Loy 1976).

A few large, contiguous patches dominated the Southern Oregon Cascades study area in contrast to the numerous small, dispersed patches of the Coast Range. The Central Oregon Cascades landscape had fewer total patches than its southern neighbor, but the average size of these patches was smaller.

Prelogging Fire Patch Characteristics

Prelogging fire disturbance patch characteristics varied more by physiographic province than by landscape study area. For example, mean fire patch size was 213 ha for the Coast Range area but 340 ha and 370 ha for the Central and Southern Cascades areas, respectively. The variability in patch size, as expressed by the coefficient of variation values shown in Table 3, was lower for the Coast Range (102%) compared to 161% for the Central Cascades and 149% for the Southern Cascades.

Perimeter/area ratios averaged 0.0051 for the Coast Range landscape compared to 0.0043 and 0.0045 for the Central and Southern Cascades landscapes, respectively (Table 3). The calculated values for this ratio range from zero to one, with complex patches having a higher value than patches of a more simple shape.

Mean nearest neighbor distance—the distance from one patch to the nearest patch of the same type— averaged over the landscape differed among the three landscapes: 2,370 m for the Coast Range area; 1,870 m and 1,222 m for the Central and Southern Cascades areas, respectively.

Spatial Coincidence of Forest Patch Types and Topographic Features

For the Central Oregon Cascades and Southern Oregon Cascades landscapes, the observed spatial coincidence of forest patch type to slope, aspect, elevation, and distance to streams differed significantly from that expected based on areal proportions of each variable on the mapped landscape ($p \leq 0.05$). For the Oregon Coast Range, there was no significant difference between observed and expected values for each patch type and aspect, slope, and elevation combination ($p \geq 0.05$).

The Central and Southern Oregon Cascades landscapes showed a trend of more

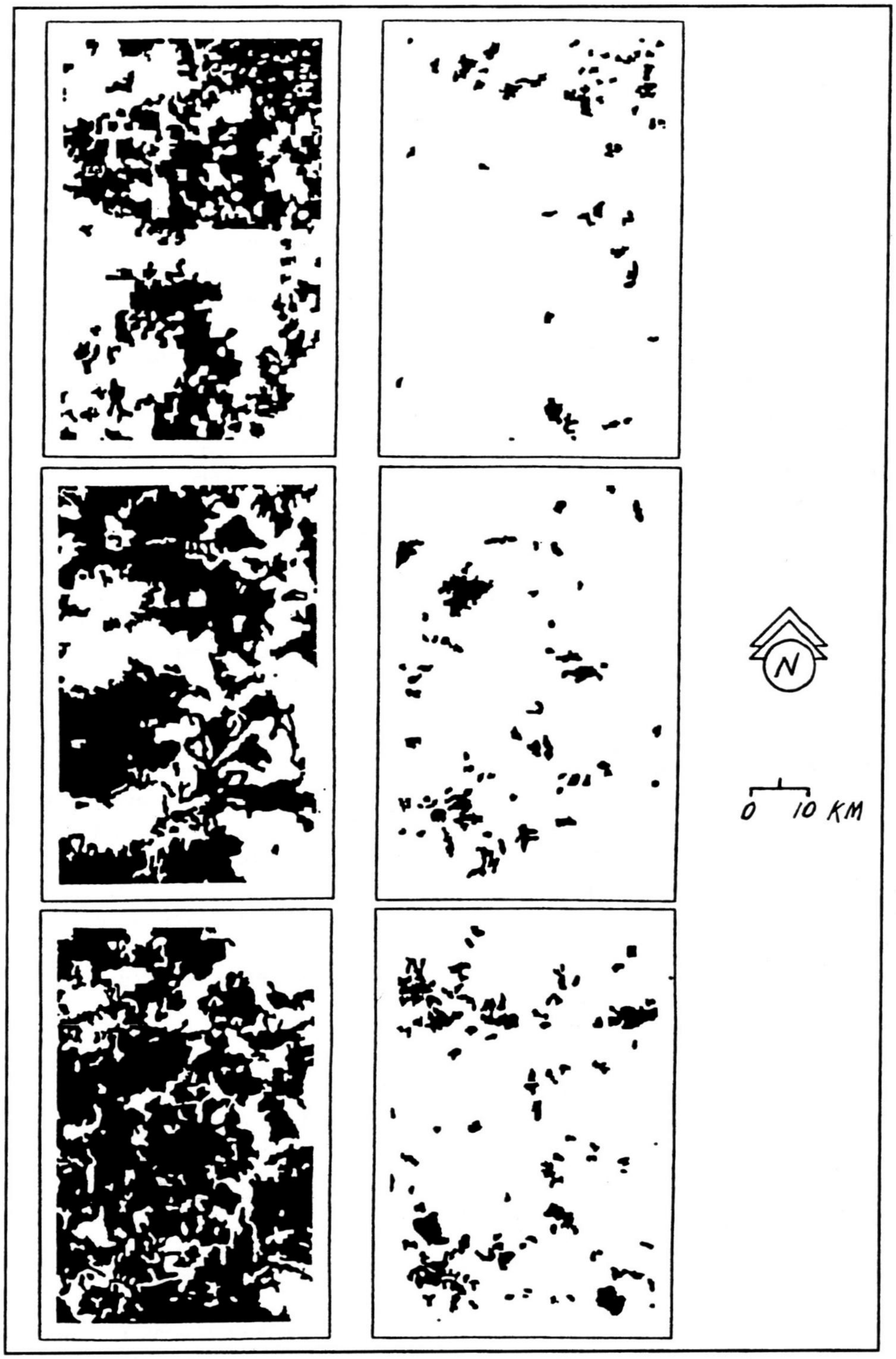

Figure 4. Prelogging spatial pattern of old-growth conifer (black patches on left images) and recent fire patches (black patches on right images). Oregon Coast Range study area is shown at top; Central Oregon Cascades study area is at middle; and Southern Oregon Cascades study area is at bottom.

of the seedling-sapling and small conifer patch types and less old-growth conifer than expected on slopes greater than 40% (Table 4a). Fewer small conifer and seedling-sapling patch types than expected were observed on slopes less than 40%.

Fewer burned areas than expected occurred on east and northeast aspects and more than expected occurred on south aspects (Table 4b), for both the Central and Southern Oregon Cascades landscapes. More large conifer than expected was observed on north, east, and northeast aspects, whereas less than expected occurred on south and southwest aspects.

The two Cascades landscapes showed changes in patch composition along an elevation gradient where less than expected amount of early disturbance area (burned areas and seedling-sapling categories combined) was found above 900 m, and more than expected was found below 900 m (Table 4c). More of the large conifer and less of the old-growth conifer than expected were observed above 1,200 m, as well as more old-growth conifer and less large conifer below 1,200 m.

For all three landscapes, the spatial coincidence analysis revealed a trend of more burned area than expected within 4,000 m of major rivers and less than expected beyond 4000 m (Table 4d). Less old-growth conifer than expected was observed within 4,000 m of major rivers for the Oregon Coast Range and the Central Oregon Cascades landscapes. When distance from all perennial streams was considered, no distinct association with forest type was discernible.

DISCUSSION

Prelogging Landscape Patterns

Before the period of major timber removal, the majority of western Oregon was composed of postfire forests less than 750 years of age (Agee 1991). In the Cascades, forests were established after cataclysmic fires that occurred during the relatively warm and dry sixteenth century, with some activity in the latter part of the nineteenth century. In the Coast Range, forests regenerated after large fires in the 1850s to early 1900s (Teensma et al. 1991) Within the extensive matrix of old-growth forest were patches of various age classes resulting from an extended period of tree establishment following the severe weather fire events and a history of less intense disturbances following the original burns (Teensma 1987, Morrison and Swanson 1990, Perry 1994). Many types of disturbance are responsible for these forest patches, including fire, wind, disease, insects, small-scale floods, and landslides. Of these, fire

Table 3. Prelogging fire patch characteristics by landscape study area. C.V. = coefficient of variation.

Patch Descriptor	Oregon Coast Range	Central Oregon Cascades	Southern Oregon Cascades
Number of Fire Patches Observed	50	59	83
Landscape Composition (%)	3.3	6.1	9.5
Range of Patch Sizes (ha)	14–968	49–3,636	14–2,523
Mean Patch Size (ha)	213	340	370
Patch Size C.V. (%)	102	161	149
Range of Perimeter/Area Ratios (m/m^2)	0.0019–0.0157	0.0015–0.0068	0.0013–0.0214
Mean Perimeter/Area Ratio (m/m^2)	0.0051	0.0043	0.0045
Perimeter/Area Ratio C.V. (%)	41	30	51
Range of Nearest Neighbor Distances (m)	100–21,966	100–7,900	100–6,476
Mean Nearest Neighbor Distance(m)	2,370	1,870	1,222
Nearest Neighbor Distance C.V.(%)	175	104	116

appears to be the primary landscape-level disturbance factor (Agee 1991).

The several large disturbance patches found in the western portion of the Coast Range landscape accounted for this study area's relatively high proportion of large and small conifer categories, and corresponded with the locations of several extensive stand-replacing fires (Loy 1976). Morris (1934a) reported that several fires occurred in the Coast Range during the late 1840s and 1860s, including the Coos Bay fire of 1868 that burned approximately 120,000 ha in the area now known as the Elliot State Forest. In the Central Oregon Cascades study area, several of the extensive patches of small conifer coincided with areas of burnt timber mapped by Plummer (1902) and with descriptive notes from cadastral surveys completed before 1900 (Burke 1980). The high proportion of old growth observed in the Southern Oregon Cascades study area may be due to a combination of factors: a preponderance of underburns or partial stand-replacing fires, and potentially less disturbance by European settlers until the latter part of the nineteenth and the early twentieth centuries (Ripple 1994).

We found that estimates for historical levels of old growth in the region vary considerably. At the turn of the century, 90% of western Oregon forests and 85% of western Washington forests were reported to be in old-growth condition (Gannett 1902, Plummer 1902, Langille et al. 1903). More recently, Franklin and Spies (1984) estimated that old-growth Douglas-fir covered 60% to 70% of the commercial forest land in the region during the early 1800s. Booth (1991) used the forest survey summary data from the 1930s to conclude that before logging occurred, 63% of western Washington and 61% of western Oregon were covered by old-growth forest. Our calculations show that 53% of the three western Oregon landscapes were in an old-growth condition in 1936, using the map-based prelogging estimates from Table 2 and excluding nonconifer areas. Our estimate of prelogging old growth for the Coast Range study area, 39%, closely agreed with the Teensma et al. (1991) estimate that 40% of the Coast Range forests were in a late-seral condition in 1850.

The variation among these old-growth estimates is due, in part, to the use of differing definitions, areal extents, and time periods. It is unclear what parameters were used to define old growth at the turn of the century, but Franklin and Spies (1991) and Booth (1991) used an age criterion (> 200 years). One limitation of the 1936 forest type maps was the generalization of the "large" old-growth patches (diameter > 102 cm) with the "small" old-growth patches (diameter = 51–102 cm) during map compilation. Because the 1936 Andrews and Cowlin (1940) estimates of old growth were based on the amount of forest having Douglas-fir trees with a diameter greater than 51 cm and older than 160 years, their results may overestimate old growth according to more recent definitions that use a minimum tree diameter of 81 cm (Franklin and Spies 1991). These current definitions also constrain estimates of old growth by specifying a range of species, sizes, and ages of trees for multiple canopy layers. These attributes are important, however, in recognizing the inherent structural and functional variability found within these complex ecosystems.

The integrated processes of disturbance (old-growth matrix perforated by fire) and succession (disturbance patch nucleation and coalescence through time) are intimately linked to the spatial patterns observed on the landscape. As disturbance events occur over time, varying in location, frequency, and severity, a mosaic of vegetation in different stages of succession results. Such mosaics are evident in the prelogging compositional data of Table 2 and in the spatial data of Figure 4. The spatial heterogeneity generated from these vegetation mosaics greatly enhances landscape diversity and provides an array of habitats for different organisms over time.

Fire Disturbance

The many combinations of fire regimes and forest types in the Pacific Northwest are a product of repeated fires having variable frequencies, extents, and intensities (Agee 1993). For the moist Douglas-fir forests found in the Coast Range of Washington and Oregon, a regional average fire-return interval has been estimated at 230 years by Fahnstock and Agee (1983). For the Oregon Coast Range alone, Ripple (1994) reported similar fire return intervals (237–242 years). Teensma et al. (1991) described the fire regime of the Oregon Coast Range as being characterized by high-intensity, stand-replacement fires occurring at intervals from 150 to 350 years. In a fire history study examing the charcoal distribution within lake sediments of Little Lake (Coast Range), Oregon, Long

Table 4. Spatial coincidence trends between prelogging forest patch types and topographic features.

Symbols used to show the spatial coincidence trends between prelogging forest patch types and topographic features are as follows:

O	=	Oregon Coast Range study area
C	=	Central Oregon Cascades study area
S	=	Southern Oregon Cascades study area
+	=	values that are higher than expected at the $p = 0.05$ level
++	=	values that are higher than expected at the $p = 0.001$ level
-	=	values that are lower than expected at the $p = 0.05$ level
--	=	values that are lower than expected at the $p = 0.001$ level
	=	no significance

TABLE 4A

	Slope Gradient						
Patch Type	**1–19%**	**20–39%**	**40–59%**	**60–79%**	**80–99%**	**100–119%**	**120–139%**
Burned Areas	C++						
Seedling-Sapling	C--		C++	C++	C+		
	S--	S--	S++	S++	S++	S++	
Small Conifer	C--	C--	C++	C++	C++		
	S--		S+	S++			
Large Conifer	C++			C--			
	S--		S+				
Old Growth		C+		C--	C--		
	S++		S--	S--	S-		

TABLE 4B

	45-Degree Aspect Classes							
Patch Type	**E**	**NE**	**N**	**NW**	**W**	**SW**	**S**	**SE**
Burned Areas	C--	C--					C++	
	S-	S--					S+	
Seedling-Sapling	C--				C++	C++	C--	
								S-
Small Conifer							C++	
	S--	S--	S--				S++	S++
Large Conifer	C++	C++	C++			C--	C--	
	S++	S++		S--			S--	
Old Growth			C-					

TABLE 4C

	Elevation (m)						
Patch Type	**1–299**	**300–599**	**600–899**	**900–1,199**	**1,200–1,499**	**1,500–1,799**	**1,800–2,099**
Burned Areas		C++	C--	C--	C--	C-	
				S++	S--	S--	S-
Seedling-Sapling		C++	C++	C--	C--	C--	
		S++	S++			S--	S--
Small Conifer	C++	C++	C--	C--	C+	C++	
		S-				S++	
Large Conifer	C++	C--	C--	C++	C++	C++	
		S--	S--	S--	S+	S++	S++
Old Growth	C--	C--	C++	C++	C--	C--	
		S++	S++	S++		S--	S--

TABLE 4D

Patch Type	Distance from Major Rivers (m) 1–999	1,000–1,999	2,000–2,999	3,000–3,999	4,000–4,999	5,000–5,999	6,000–6,999	7,000–7,999	8,000–8,999	9,000–9,999
Burned	O++				O--	O--	O+			O-
Areas	C++	C++	C++	C++			C--	C--	C--	C--
	S++	S++		S--	S--			S++	S+	S--
Seedling-	O--	O--	O++	O++	O++		O--		O++	
Sapling	C++		C++					C--	C--	C--
	S--	S++		S--	S--			S++	S+	S++
Small	O++	O+			O-	O--		O--	O--	O--
Conifer		C++	C++	C++		C--	C--	C--	C--	
	S--			S++		S--			S+	S++
Large	O+	O++	O++	O-	O--	O--	O--		O--	
Conifer		C++		C++	C++	C-	C--	C--		C--
	S--	S--		S++	S++	S++			S++	S++
Old	O--	O--	O--		O++	O++	O++	O++	O++	O+
Growth	C--	C--	C--	C--		C++	C++	C++	C++	C++
	S++				S-				S--	

(1995) estimated a local fire-return interval of approxiamtely 175 years. Because they experience irregularly timed, high-intensity burns, Coast Range forests have patches that are more even-aged compared to those of the central Oregon Cascades, where underburning and variable-intensity fires were historically prevalent (Stewart 1989).

Compared to the moist Douglas-fir forests of the Coast Range, the mesic-to-dry Douglas-fir forests of the Oregon Cascades experience a variable fire regime with much higher frequency. Morrison and Swanson (1990) measured a natural fire rotation of 95 to 145 years, with varying intensities, over the last five centuries. A similar fire regime was noted by Means (1982). Teensma (1987) estimated an average of 100 years between fires when only stand-replacement-intensity fires were considered.

At the landscape level, we know that topographic differences exist between the Coast Range and Western Cascades provinces. These large-scale landforms have not changed significantly since the end of the last ice age and do affect vegetation, fuel, micro-climate, and wind patterns, which in turn influence fire behavior and frequency. Therefore, we expect that the strength of association between topographic features and disturbance regimes would vary with topographic complexity.

Agee (1993) asserts that fires are oriented by wind direction, wind speed, and major topographic features. The large extents (100,000–400,00 ha) of the mid-1800s fires in the Coast Range may have been due to the topographic character of this mountain range. In general, it has gentler, more rounded terrain and less topographic relief than the Western Cascades; this could result in fewer natural fire/fuel breaks, and there are numerous drainage networks that might channel off-shore east winds during the summer dry season. We did not find significant differences between observed and expected amounts of forest patch types related to aspect, slope, and elevation in the Coast Range (See Table 4). These observations affirm our hypothesis that at a landscape level, weather and fuels have more influence on the fire regimes of this province than topography.

In our assessment of prelogging fire patch characteristics, we found that size and shape of the recently burned patches also varied by physiographic province. We observed that both the mean and the range of fire patch sizes (Table 3) were smaller in the Coast Range compared to the two Cascades study areas. The proportion of the landscape in a burned condition was also less for the Coast Range. The small patches of recent burns were located in the drier eastern portion of the Coast Range, away from where the extensive, nineteenth-century fires had occurred. Many of these small fire patches may have been ignited intentionally by humans (to reduce vegetative competition for grazing or farming) or could have been the result of fire suppression efforts that became effective in the early 1900s (Burke 1980).

As shown in Figure 3, we found 100–999 ha to be the most common range of forest patch sizes for all three landscapes regardless of patch type. This result was unexpected for two reasons: (1) the minimum mapping unit for the 1936 forest survey was 8 ha, and our assessment of the map indicated that these smaller patches (10–99 ha) were identified and recorded; (2) these findings contradict the observed frequency distributions for many natural phenomena (including lakes, soil units, tree gaps, and forest fires), which show an inverse relationship between size and abundance of patches (Harris 1984, Hunter 1990).

Instead of observing a log normal distribution of many small fire patches (10-99 ha) and fewer and fewer large fire patches (> 99 ha), we found fire patch sizes that averaged more than 200 ha for the Oregon Coast Range and more than 340 ha for the Central and Southern Oregon Cascades study areas (Table 3). Similarly, Garza (1995) studied the fire history of a 3,540-ha area north of our Central Oregon Cascades landscape study area. He mapped 11 fire episodes that occurred between the years 1666 and 1918, and found fire patch sizes that averaged 654 ha (range 26–1,787 ha). Connelly and Kertis identified 17 fire episodes in the western Cascades between 1469 and 1920, where the fire patches ranged from 380 to 5000 ha in size (Wallin et al. 1996).

These findings may indicate that the natural range of fire sizes for stand-replacing fire events in western Oregon, prior to logging and the initiation of fire suppression policies in the late 1910s, is bimodal in character. We think it is probable that very large cataclysmic fires occur irregularly, creating extensive forest patches that dominate the landscape mosaic. Agee (1993) noted that over the past millenia, several large-fire episodes in the Coast Range of Washington have been associated with sunspot minima and global cooling. Between these periods of severe fire weather, smaller and less significant fires (averaging several hundred hectares in extent) occur over the landscape. We may be experiencing, currently, a relatively severe-fire-free period, and when the next pulse of extensive fires occurs, the landscape mosaic could be reshaped.

Topographic Effects on Forest Patch Distribution

Disturbance patterns often are strongly influenced by topography and by the vegetation mosaic itself. For example, the intensity of fires tends to vary with factors such as slope steepness and aspect. Aspect and slope steepness combine to influence vegetation patterns through effects on the amount of solar radiation that is received. Differences in radiation received by different aspects vary with slope steepness, latitude, and season. In mid-latitudes, the influence of temperature on vegetation usually manifests over elevation gradients, while aspect and slope steepness primarily influence water balance (Perry 1994). This process is evident in the landscape patterns of the Cascades study areas where we observed more burn patches on the hotter, drier aspects and steeper slopes and more large conifer on the cooler, moister slopes. Our findings agree with Morrison and Swanson (1990), who found that steeper and more highly dissected areas burned more frequently than areas with gentler topography.

In mountainous terrain, landscape patterns reflect changes in vegetative composition along an elevation gradient (Zobel et al. 1976). We observed a change in patch type composition from mostly old-growth conifer to predominantly large conifer around 1,200 m. This elevation in the Cascades corresponds to a zone of transition in winter precipitation from rain to snow, and from Douglas-fir dominated communities to cold-tolerant true-fir-dominated communities. Above 1,200 m, the number of frost-free growing days is less and the trees grow more slowly. As elevation increases, average annual temperatures decrease while precipitation increases. The combination of declining temperatures and increasing precipitation influences the moisture holding capability of forest fuels and effectively shortens the length of the fire season, especially at high elevations (Agee 1993). This concept of environmental gradients affecting the distribution of major vegetation zones was reinforced by our observation of the absence of such a pattern in the Coast Range, which has less topographic relief, lower elevations, and fewer major vegetative zones than the Cascades.

Our spatial analysis shows a strong association between fire disturbance and the location of major rivers. Within 4,000 m of major rivers, we observed more burned area and less old-growth conifer than expected. This is similar to the direct relationship between distance from western Oregon rivers and percentage of large-class conifers that Ripple (1994) found. Agee (1988) noted that fire behavior is influenced by the shape of the landscape. For instance, winds in small, narrow drainages may increase fire intensity near the heads of canyons, and riparian areas may burn with higher intensities than the surrounding landscape because of this channeling effect.

The association between burn areas and rivers may be the result of anthropogenic activity. Burke (1980) observed a strong association between fire frequency and human activity when she mapped fires in the central Oregon Cascades between 1910 and 1977. A study of western Oregon and Washington forest fires by Morris (1934b) for the years 1925 to 1930 revealed that the majority of human-caused fires occurred at elevations below 600 m, while most lightning-caused fires occurred at elevations between 1,200 and 1,800 m. Since most major rivers occupy the lower elevations within their basins, and both European settlers and Native Americans were associated with river corridors for travel and settlement purposes (Boyd 1986, Boag 1992), it is reasonable to conclude that an anthropogenic influence on fire disturbance patterns in western Oregon may have existed around major rivers.

Management Implications

The effects of current management practices on today's landscape patterns are dramatically different from the landscape patterns created by historical disturbance regimes (Wallin et al. 1996). For example, timber harvest activities and land use conversion resulted in a two- to three-fold reduction in late-seral forest conditions and a concurrent three- to six-fold increase in early seral forest between 1936 and 1988 for our three western Oregon study areas (Rasmussen 1996). Compared to the coarse-scale patterns created by historical fire disturbances, forest cutting practices in the Pacific Northwest have created relatively fine-grained, highly fragmented landscape patterns (Harris 1984, Franklin and Forman 1987). This increased fragmentation, relative to prelogging conditions, could be significant. The increasingly smaller size of the remaining old-growth patches will create drier, windier microclimates along patch edges, accelerating both windthrow and potential fire behavior (Agee 1993).

Species loss and ecosystem change have been observed in areas of the Pacific Northwest where historical disturbance regimes and habitats have been substantially altered. Examples include the decline of forest health in Oregon, the buildup of fuels in areas where fire has been suppressed, forest regeneration failures, and the actual or potential listing as threatened or endangered of species such as the northern spotted owl *(Strix occidentalis caurina)*, the marbled murrelet *(Brachyramphus marmoratus)*, and many stocks of salmon (Swanson et al. 1993).

We recommend that managers assess historical forest landscape patterns and conditions as a starting point for understanding disturbance regimes and ecosystem processes operating at the landscape level. Because this study assessed landscape patterns over a large geographic area (ca. 1,000,000 ha combined), we were able to substitute space for time to help understand temporal ecological processes. This type of analysis can lead to estimates of the range of natural conditions for a given landscape. Managers need to assess the range of natural conditions of landscapes so that management objectives and activities can be evaluated for effectiveness in relation to overall ecosystem health and resiliency.

We also recommend that managers develop dynamic, adaptive strategies that are sensitive not only to historic fire regimes, but also to the new fire regimes expected with global climate change. Such approaches should identify and retain a distribution of vegetation seral classes (hence wildlife habitats) that are within the range of natural conditions and that also take into consideration the effects of natural disturbances that will interact with managed landscapes over time. In addition, such strategies should allow for the retention of stand conditions in topographic positions where they occurred naturally, so that they will have a higher probability of being sustained in the face of natural disturbance (Swanson et al. 1993).

The forest landscape patterns that we observed on the 1936 forest maps primarily reflect disturbance events that occurred during the nineteenth and early twentieth centuries. Analyzing older maps (compiled from the federal General Land Office surveys for instance) would be beneficial for discerning pre-European settlement landscape patterns. Such research has already begun in the Great Lakes region (e.g., Leitner et al. 1991, White and Mladenoff 1994, Frelich 1995). This type of spatial information would broaden our understanding of the natural variability of landscape patterns in the Pacific Northwest and would provide reasonable estimates for creating a desirable range of landscape conditions through selected management activities.

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