AN ABSTRACT OF THE THESIS OF

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William J. Ripple

Using historical maps and tools provided by GIS, the spatial patterns of pre-logging forest conditions were quantified for three landscapes in western Oregon. The spatial coincidence between forest patches and topographic features was determined for slope gradient, aspect, elevation, and distance from streams. Pre-logging and current forest compositions were compared.

The pre-logging landscape was dominated by old growth conifer with less than 10% consisting of early seral disturbance patches. Fire patches differed in size and shape between the Oregon Coast Range and the Oregon Cascade Range provinces. The size and variability of fire patches was larger in the Cascades, with shorter mean distances between fire patches and smaller perimeter to area ratios compared to fire patches in the Coast Range. Mean fire return intervals ranged from 170 to 292 years for the Oregon Coast Range. The most frequent patch size, regardless of patch type and study area, ranged from 100 to 999 ha. 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 4000 m of major rivers. Late seral forest cover has declined dramatically across all three landscapes since 1933.

Landscape Patterns of Pre-logging Forest Conditions in Western Oregon

by

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Mary C. Rasmussen, Author

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Landscape Patterns of Pre-logging Forest Conditions in Western Oregon

1. Introduction

Large-scale disturbances have been a prevalent force in natural landscapes for millennia. In the forests of the Pacific Northwest, 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 draped the landscape. This knowledge is, in turn, important for predicting 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. While there have been efforts to describe the general forest conditions of Oregon for pre-settlement and settlement times (before and after 1840's), these reports provided only limited tree volume estimates based on a few commercially important species linked to broad, non-specific geographic areas (e.g., Gannet

1902, Langille et al. 1903, Franklin and Spies 1984, and Booth 1991). Except for a few fire history studies in the Western Cascades Range by Burke (1980), Teensma (1987), Morrison and Swanson (1990), and Garza (1995); and generalized reports by Teensma et al. (1991) and Ripple (1994), spatial data for historical forest conditions of western Oregon, and for natural fire disturbance patterns in particular, are lacking.

Fortunately, advances in computer software technology have provided new techniques for conducting effective, retrospective landscape studies. These spatial analysis techniques allow scientists to identify and measure natural landscape patterns from historical maps by manipulating various data layers (climatic, topographic, edaphic, hydrologic, and vegetative) in a geographic information system (GIS). As spatial and temporal patterns are identified, their inter-relationships can be elucidated and inferences about the ecological processes that link them can be made. Resource managers can then use this information to retain important natural landscape features in terms of composition, structure, and ecosystem function, as they attempt to create and manage a desirable range of landscape conditions through selected management activities.

The purpose of this research was to conduct a retrospective landscape study of the "pre-logging" forest conditions in western Oregon using the first regional forest survey completed by the USDA Forest Service. The spatial information on the survey maps was selected as the primary data source because it provided detailed information on the species composition and diameter size-classes of forest patches across all ownership's in western Oregon and Washington, including the locations of recent harvest activity.

From the survey data, Andrews and Cowlin (1940) determined that less than 12% of the two-state Douglas-fir region was in a cut-over condition in 1933. The majority of this logging 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 was cut-over at the time the source maps were created, I used the term "pre-logging" to describe the predominant forest conditions of western Oregon for this study.

Digitally-mapped patch mosaics of three pre-logging landscapes in western Oregon were studied to answer four questions: (1) What was the pre-logging forest patch type composition and corresponding spatial pattern of each landscape? (2) What was the stand-replacement fire return interval for the Oregon Coast Range landscape? (3) Was the spatial distribution of forest patch types associated with the topographic variables of slope gradient, aspect, elevation, and distance from streams? (4) How much change in landscape composition has occurred between pre-logging times (1933) and now (1988)?

In this paper, I describe the composition and distribution of forest cover types; and size, shape and configuration of disturbance patches, including levels of forest fragmentation. Associations between topographic features and forest patch types are explored and results between pre-logging and current forest conditions are compared. Finally, I discuss my observations in context to fire disturbance ecology and suggest possible implications for ecosystem management.

2. Methods

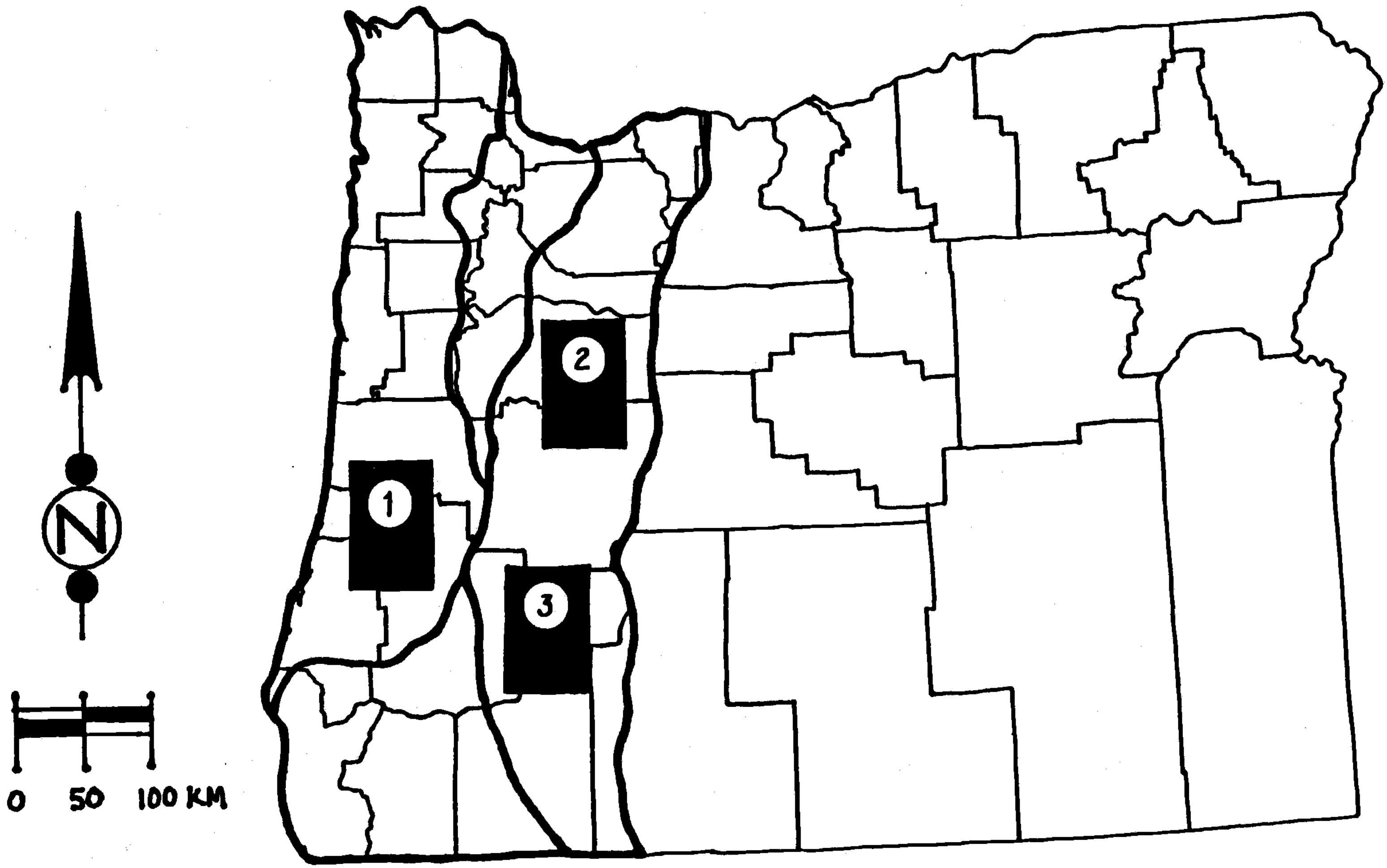
2.1 Study Areas

This analysis used historical spatial data from three landscapes located in western Oregon. One study landscape occupies an area in the Coast Range province while the other two are found in the Western Cascades mountain province as shown in Figure 2.1.

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 3000 mm. Most precipitation, 75-85 % of which occurs between October 1 and March 31, is the result of low-pressure systems that approach from the Pacific Ocean.

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 0-140 %, with the majority falling in the 10-50 % range.

Figure 2.1 Location of landscape study areas: 1 = Oregon Coast Range; 2 = Central Oregon Cascades; 3 = Southern Oregon Cascades Range. Heavy lines denote physiographic province boundaries of interest and thin lines denote county boundaries for Oregon.



Numerous conifer species that are the largest and longest-lived representatives of their genera dominate the forests within these two provinces. Hardwood species are few and generally confined to specialized habitats such as riparian gallery forests and woodland savannas or to early successional stages of the conifer-dominated forest (Franklin 1988). The most common overstory tree species is Douglas-fir *(Pseudotsuga menziesii)*, with western hemlock *(Tsuga heterophylla)*, western red cedar *(Thuja plicata)*, Pacific silver fir *(Abies amabilis)*, and noble fir *(Abies procera)* as associates. The understory consists usually of western hemlock, western red cedar, big leaf maple *(Acer macrophyla)*, and red alder *(Alnus rubra)*.

The landscape areas examined in this study fall within two major vegetation zones described by Franklin and Dyrness (1988): the Western Hemlock Zone and the lower elevations of the Pacific Silver Fir Zone. Within these zones, western hemlock and Pacific silver fir are the climax species on most sites except for dry areas, where Douglas-fir may be climax.

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. 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 1000 years, and wildfires have historically occurred more frequently than this on most sites in the Pacific Northwest (Spies et al. 1988).

2.2 General Study Design

In this study, I examined the pre-logging forest landscape patterns and topographic features for three 329,000 ha study areas. First, a pilot study was conducted to determine the appropriate grain and extent of investigation. Next, the study areas were identified on the forest survey maps and the mapped forest patches were examined for accuracy using aerial photos from the 1940's. Then, I created digital maps of forest patch type, slope steepness, aspect, elevation, and stream network for each study area. With these data and tools provided by GIS, I quantified landscape patterns of the pre-logging forest conditions and determined the spatial coincidence of forest patches with the environmental variables of interest (e.g., slope, aspect, elevation, and distance from streams). Chi-squared methods were used to compare observed versus expected spatial coincidence. A comparison between pre-logging and current forest conditions was conducted for each study landscape. Finally, a range of fire return intervals was calculated for the Oregon Coast Range landscape using a method developed by Van Wagner (1978).

2.3 Determining Grain and Extent

Landscape patterns are generated by ecological processes operating at various spatial and temporal scales. For example, forest cover type is positively correlated in time and space to the disturbance process of wildfire (Urban et al. 1987). The ability to detect any given landscape pattern is a function of both the grain and extent of an investigation, where "grain" refers to the size of the individual units of observation and "extent" refers to the overall area encompassed by the study (Wiens 1989). These factors establish the lower and upper limits of resolution for the analysis of landscape composition and pattern. To gain meaningful results, it is necessary to identify the nature and scale of the process of interest, and then select a grain and extent that allows the resulting landscape patterns to be revealed and measured.

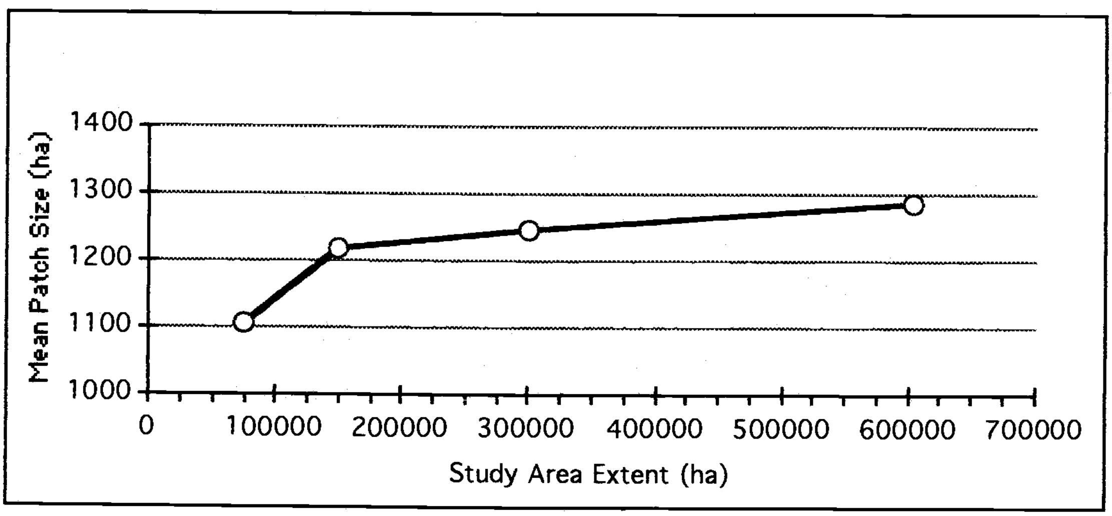
For this research effort, it was essential to select a grain and extent that would capture the spatial patterns of the forest patch mosaics created by fire. To determine grain size, I measured the smallest patch on the 1936 Forest Type map (8 ha) using a dot grid and selected a grain size of 100 m^2 or 1 ha, such that the shape of the smallest patch would be represented in a GIS data layer by approximately eight grid cells. At this selected resolution, all patterns occurring on the source map would be detectable (i.e., fire disturbance events but not individual tree fall gaps).

To select an extent large enough to measure the typical sizes and shapes of fire disturbance patches without truncating those patches with the study area boundaries, I first digitized a region (600,000 ha) of the 1936 forest survey map that captured representative fire disturbance patches within the western Cascades province. I chose this region for the pilot study after observing that the disturbance patches in the Coast Range province were relatively smaller. Then I divided the digitized forest patch map into successively smaller maps. For each set of map extents, I calculated several landscape pattern indices and explored the results.

My results showed that mean patch size was the most helpful index for selecting an appropriate study area extent. The response of mean patch size to changing spatial extent appeared asymptotic as shown in Figure 2.2. As study area extent increased, mean patch size also increased, but at a declining rate. In their research on habitat patterns near northern spotted owl nests, Lehmkuhl and Raphael (1993) also found an asymptotic response between mean patch area and study size.

Using this information on the response of mean patch size, I focused on the values corresponding to a study extent greater than 300,000 ha. This range of values corresponded to mean patch sizes that approached the asymptote. This range also avoided the region of the response curve where the rate of increase in mean patch size per unit increase in extent was greatest. I chose the value of 329,000 ha as my study area size because it was the largest rectangular extent that would fit on the maps without including any harvest patches. This selected study extent gave me confidence that the study area maps were large enough to detect the approximate size and shape of the fire disturbance patches with little patch truncation.

Figure 2.2 Response of mean patch size to changing spatial extent.



2.4 Accuracy Assessment of the 1936 Forest Survey Map

After determining the grain, extent and location of the study areas, I compared the accuracy of the forest type patches portrayed on the 1936 source maps to available 1940's era 1:20,000 black and white aerial photos from randomly selected flight lines within each study area. The cover type definitions corresponded well with the canopy characteristics of size, shape, and texture that I observed on the photos. It was not possible to distinguish tree species beyond conifer and hardwood categories. Some of the mapped burn patches in the western Cascades province, had on their respective photos, residual live trees that were scattered on hill slopes and clumped near stream bottoms. This observation supports the idea that severe stand-replacing fires do not destroy all remnants of the previous stand (Morrison and Swanson 1990).

2.5 Creating Spatial Data Layers

Six spatial data layers (pre-logging forest patch type, current forest patch type, slope gradient, aspect, elevation, and distance from streams) were created for each study area and analyzed using a microcomputer version of the GIS program ERDAS (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 one hectare (100m x 100m).

Pre-logging Forest Cover Type Layer

The original forest cover types from the 1936 Andrews and Cowlin maps were digitized and recoded into six categories to create the pre-logging forest cover type data layers (Refer to Table 2.1 for the reclassification scheme used). Of the six categories that I created, five reflect the process of ecological succession 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 (non-conifer) was used to classify the remaining areas that included hardwoods, non-forest land types, and water.

Old growth was identified on the 1936 maps as areas of forest composed of more than 60% Douglas-fir of an age greater than 160 years, with the majority of the volume in trees 51 cm or larger in diameter. This definition of old growth is used throughout this analysis, even though it differs with the structural and compositional features of more recent old growth definitions (Franklin and Spies 1991) that have a standard of > 20 Douglas-fir trees per ha with > 81 cm diameter and > 200 years old. Even though the Andrews and Cowlin forest survey collected site specific information on old growth patches of Douglas-fir trees > 100 cm, this information was generalized with the "small" old growth category when the 1936 Forest Type maps were created.

Table 2.1 Reclassification scheme used in the landscape pattern analysis of the 1936 forest cover type maps of western Oregon.

Forest Cover Types from 1936 Map Legend	Pre-logging Forest Patch Type Classification	Percent composition within each landscape		
		Oregon Coast Range	Central Oregon Cascades	Southern Oregon Cascades
1 Non- Forest Land	Other	7.74	1.98	0.61
2 Agricultural Zones	Other	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	Other	1.05	0.22	0.00
22 Oak/Madrone	Other	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
26 Water Bodies	Other	0.06	0.00	0.02

Current Forest Cover Type Layer

The current forest cover type data layers were subset from a satellite-derived general vegetation map of western Oregon commissioned by the Oregon Department of Forestry (Schriever and Birch 1995). This map identified six vegetation classes reflecting critical stages of structural maturity based on an analysis of 1988 Landsat Thematic Mapper imagery and extensive field measurements. I used four of these categories (late-seral, mid-seral, early-seral, and other) to make comparisons with the pre-logging data layers (Table 2.2). The 53 cm diameter breakpoint between the late-seral and mid-seral categories was compatible with the 51 cm diameter breakpoint used to distinguish the large conifer and old growth classes from the smaller conifer classes. Only a tabular comparison between the two dates was attempted because the methods used to determine the cover type boundaries were different enough to render any spatial comparisons meaningless.

Table 2.2 Pre-logging and current forest patch type definitions.

Pre-Logging Forest Type Description	Pre-Logging Forest Type Definition	Current Forest Type Description	Current Forest Type Definition
Burned Areas	stands killed by fire and < 10% restocked	Early seral	< 70% total crown closure; > 30% conifer
Seedling-Sapling	conifer patches 0 - 15 cm DBH	Early seral	< 70% total crown closure; > 30% conifer
Small Conifer	conifer patches 15 - 51 cm DBH	Mid-seral	few or no conifer trees > 53 cm DBH
Large Conifer	conifers < 160 yr. old and 51 - 102 cm DBH	Late seral	few to many conifer trees > 53 cm DBH
Old-Growth Conifer	conifers >160 yr. old and > 51 cm DBH	Late seral	few to many conifer trees > 53 cm DBH
Non-Conifer	water and non-forest	Other	water and non-forest

DBH = Diameter at breast height (1.36 m)

Environmental Data Layers

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 United States 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). The 100 m elevation contour maps were created by converting and recoding the 16-bit DEM image file into an 8-bit GIS file.

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

2.6 Spatial Analysis

The raster version of a spatial pattern analysis program, FRAGSTATS (McGarigal and Marks 1994), was used to quantify landscape structure of the pre-logging forest cover type maps. This computer program calculates landscape metrics at user-defined patch, class and landscape levels. Landscape pattern indices were collected for pre-logging forest conditions only. These indices included descriptors of size, shape and landscape configuration of vegetation patches, connectivity between patches, levels of forest fragmentation, and landscape heterogeneity. Definitions of the landscape indices and measurements for each study area are listed in the Appendix.

Fire patch characteristics were determined from the pre-logging forest patch type maps using the FRAGSTATS program after first combining the burn areas with the seedling-sapling patches. These classes were combined because it could not be determined that adjacent patches of recently burned areas and seedling-saplings were separate fire events.

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 was 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 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. The ERDAS BSTATS program was then used to obtain frequency distributions of the observed forest patch type and environmental variable combinations.

2.7 Fire Return Interval Calculations

Observing that many North American forest types are dependent on periodic fire for their continued existence, Van Wagner (1978) developed a negative exponential model to deduce the fire history of a landscape from its present age-class distribution. The model assumes that the study area has a uniform fire regime through time and space of stand-replacement intensity, and that fire events occur randomly across the landscape regardless of forest patch age.

Fire return intervals for the Coast Range study area were determined in four steps: 1) calculating the proportion of the landscape (L) that met or exceeded a selected diameter class; 2) estimating the minimum age (A) in years for Douglas-fir trees to meet or exceed the selected diameter class; 3) calculating the annual fire probability (P) using the formula:

$$P = [-(\ln L)] / A$$

where ln is natural logarithm; and 4) calculating the fire return interval (C) as the reciprocal of the annual fire probability, P.

Standard Douglas-fir yield tables (Forbes 1955), provided estimates for determining the minimum age (96 yrs.) at which the average tree diameter equaled the selected diameter of 51 cm. Estimates from site classes I-III were used based on the Site Map for the Douglas-fir Region included in Isaac (1949). The diameter breakpoint of 51 cm was selected because it distinguished the old growth and large conifer classes from the smaller conifer categories. I combined the large conifer and old growth proportions for one calculation to represent late-successional forest conditions and because specific information on old growth diameter ranges (above and beyond 51 cm) was lacking.

A second fire return interval was calculated for just the old growth portion of the landscape using a minimum age estimate of 160 years (rather than 96 yrs.) based on observations reported by Andrews and Cowlin (1940) that closed stands of Douglas-fir did not obtain a 102 cm diameter before 160 years of age.

It should be noted that the use of minimum ages rather than mean ages to represent a forest type tends to reduce estimates of the mean fire return interval.

3. Results

3.1 Pre-logging Forest Landscape Composition and Pattern

The pre-logging landscape composition and distribution of forest patches are displayed in Table 3.1. Old growth conifer (≥ 51 cm) 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 pre-logging 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%).

Table 3.1 Pre-logging landscape composition by study area.

	Oregon Coast Range		Central Oregon Cascades		Southern Oregon Cascades	
Patch Type	% of landscape	number of patches	% of landscape	number of patches	% of landscape	number of patches
Non-Conifer	9.0 %	51	2.2 %	32	1.0 %	23
Burn 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

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

As depicted in Figure 3.1, mean forest patch size increased along a patch type gradient representing time since disturbance for all three study areas. 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 common patch size, regardless of forest patch type, fell in the 100-999 ha category for all three landscapes as shown in Figure 3.2.

The pre-logging spatial distributions for old growth conifer and recent fire patches are shown in Figure 3.3. It can be seen that 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 pre-logging 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 clumped 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.

Figure 3.1 Comparison of pre-logging mean patch sizes by forest patch type. Vertical bars represent standard errors.

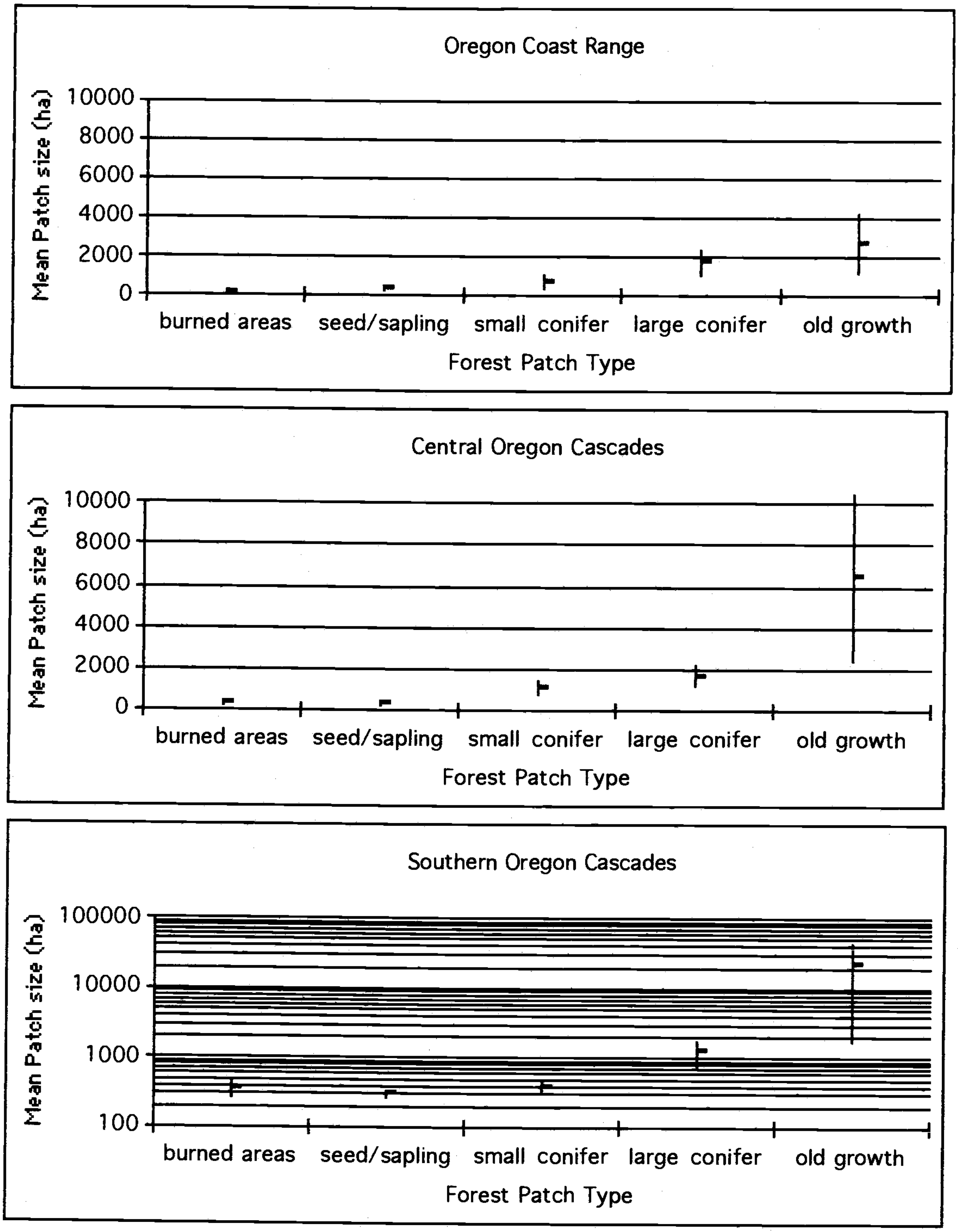


Figure 3.2 Frequency distribution of pre-logging forest patches by size class.

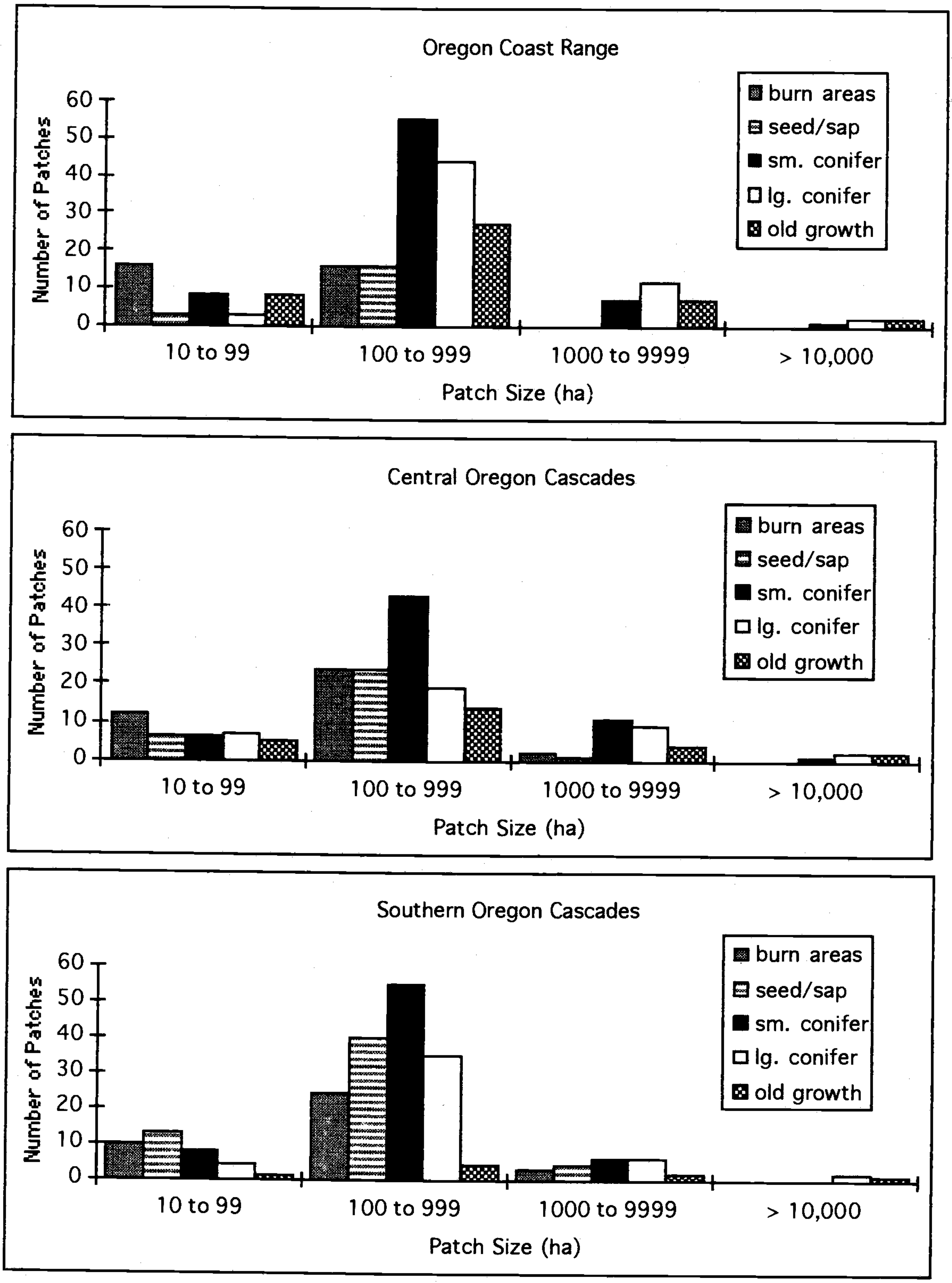
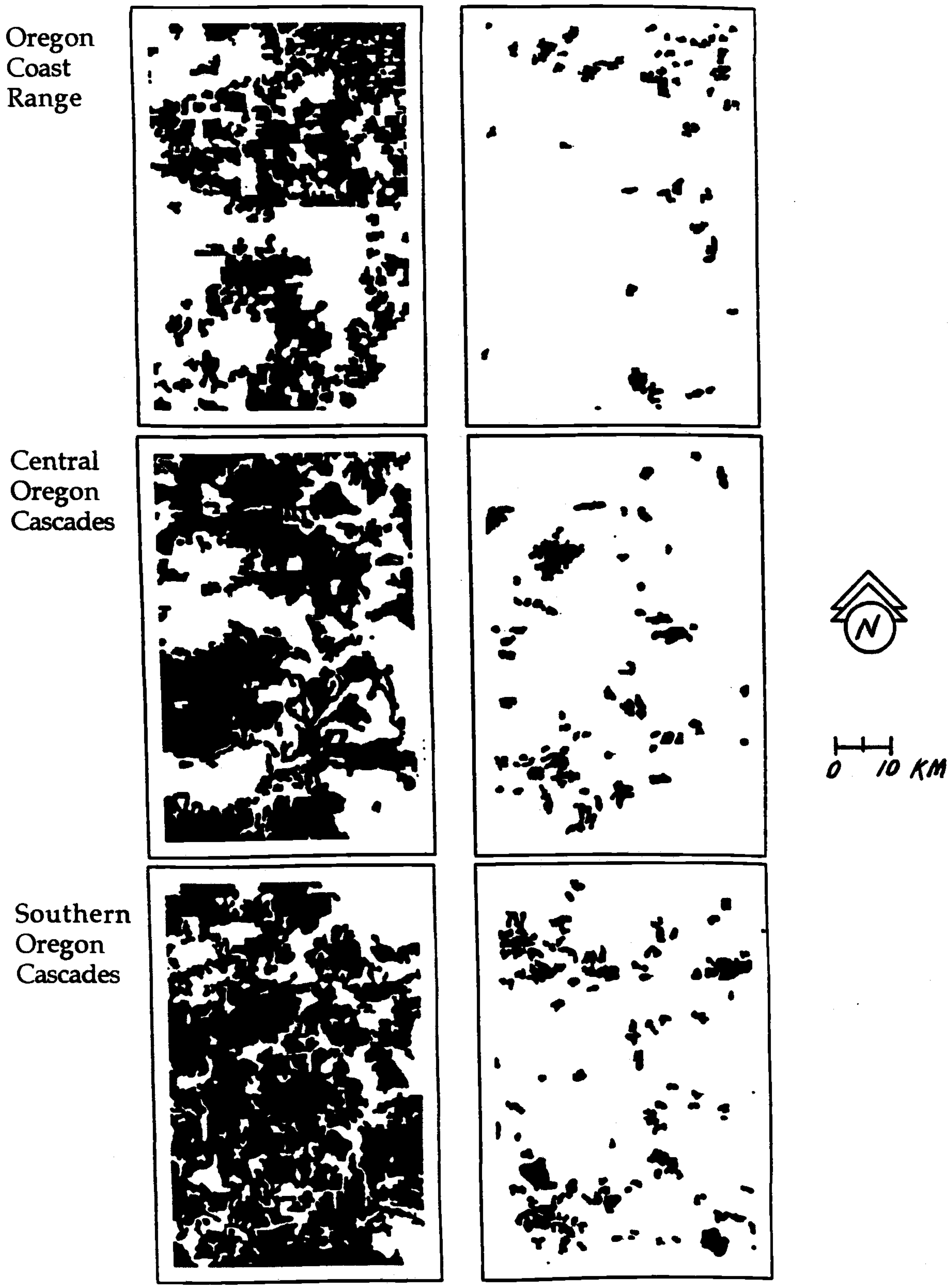


Figure 3.3 Pre-logging spatial pattern of old growth conifer (left in black) and recent fire patches (right in black).



3.2 Pre-logging Fire Disturbance Patterns

Pre-logging 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 standard deviation and coefficient of variation values shown in Table 3.2, was lower for the Coast Range (218 ha and 102% respectively) compared to 547 ha and 161% for the Central Cascades and 552 ha and 149% for the Southern Cascades.

To compare the relative shape complexity of fire patches from the three study areas, the mean perimeter/area ratio was calculated for each landscape. The calculated values for this ratio range from zero to one, with complex patches having a higher value than simply-shaped patches. The perimeter/area ratio averaged 0.0051 for the Coast Range landscape compared to 0.0043 and 0.0045 for the Central and Southern Cascades landscapes respectively.

Mean nearest neighbor distance, the distance from one patch to the nearest patch of the same type averaged over the landscape, was different for all 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.

Stand-replacing fire return intervals for the Coast Range study area were 170 and 292 years depending on the age used to estimate when trees would reach the 51-cm diameter size class and depending on the proportion of the landscape occupied by the selected forest type (i.e. old growth vs. late-succession). Table 3.3 shows that the 170-year fire return interval is from the proportion of old-growth Douglas-fir forest > 160 years old and that the 292-year return interval represents the more extensive late-successional forest type (a combination of both old growth and large conifer classes).

3.3 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 seedling-sapling and small conifers, and less old growth conifer than expected on slopes greater than 40% (Table 3.4a). Less small conifer and seedling-saplings than expected were observed on slopes less than 40%.

Fewer burn areas than expected occurred on east and northeast aspects and more than expected occurred on south aspects (Table 3.4b), for both the Central and Southern Oregon Cascades landscapes. More large conifer than expected was observed on north, east and northeast aspects, while less than expected occurred on south and southwest aspects.

The two Cascade landscapes showed elevation trends of less than expected early disturbance area (burn areas and seedling-sapling categories combined) above 900 m, and more than expected below 900 m (Table 3.4c).

More large conifer and less old-growth conifer than expected were observed above 1200 m, as well as more old growth conifer and less large conifer below 1200 m.

For all three landscapes, the spatial coincidence analysis revealed a trend of more burn area than expected within 4000 m of major rivers and less than expected beyond 4000 m (Table 3.4d). Less old growth conifer than expected was observed within 4000 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.

3.4 Changes in Landscape Composition Between 1933 and 1988

Figure 3.3 shows that the percentage of late-seral forest cover declined dramatically across all three western Oregon landscapes between 1933 and 1988. Late-seral forest has been reduced from a pre-logging level of 72% to a current level of 24% for the Oregon Coast Range study area; from 71% to 30% for the Central Oregon Cascades study area; and from 81% to 48% for the Southern Oregon Cascades study area. Concurrently, there was a three-to-six-fold increase in the amount of early-seral forest cover. The percentage of early-seral forest changed from a pre-logging level of 3% to a current level of 12% for the Oregon Coast range; from 6% to 37% for the Central Oregon Cascades; and from 10% to 30% of the landscape for the Southern Oregon Cascades.

Table 3.2 Pre-logging fire patch characteristics by landscape study area. S.D. = standard deviation. 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 S.D. (ha)	218	547	552
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 S.D. (m/m^2)	0.0021	0.0013	0.0023
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 S.D. (m)	4,155	1,955	1,425
Nearest Neighbor Distance C.V. (%)	175	104	116

Table 3.3 Fire return interval estimates for the Oregon Coast Range study area.

Forest Type	Minimum Age Estimate (yrs.)	Proportion of Landscape	Fire Return Interval (yrs.)
Late-successional	96	72 %	292
Old growth	160	39 %	170

Table 3.4a-d Spatial coincidence trends between pre-logging forest patch types and topographic features.

Legend: Symbols used to show the spatial coincidence trends between pre-logging forest patch types and topographic features:

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 3.4a

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

Table 3.4b

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

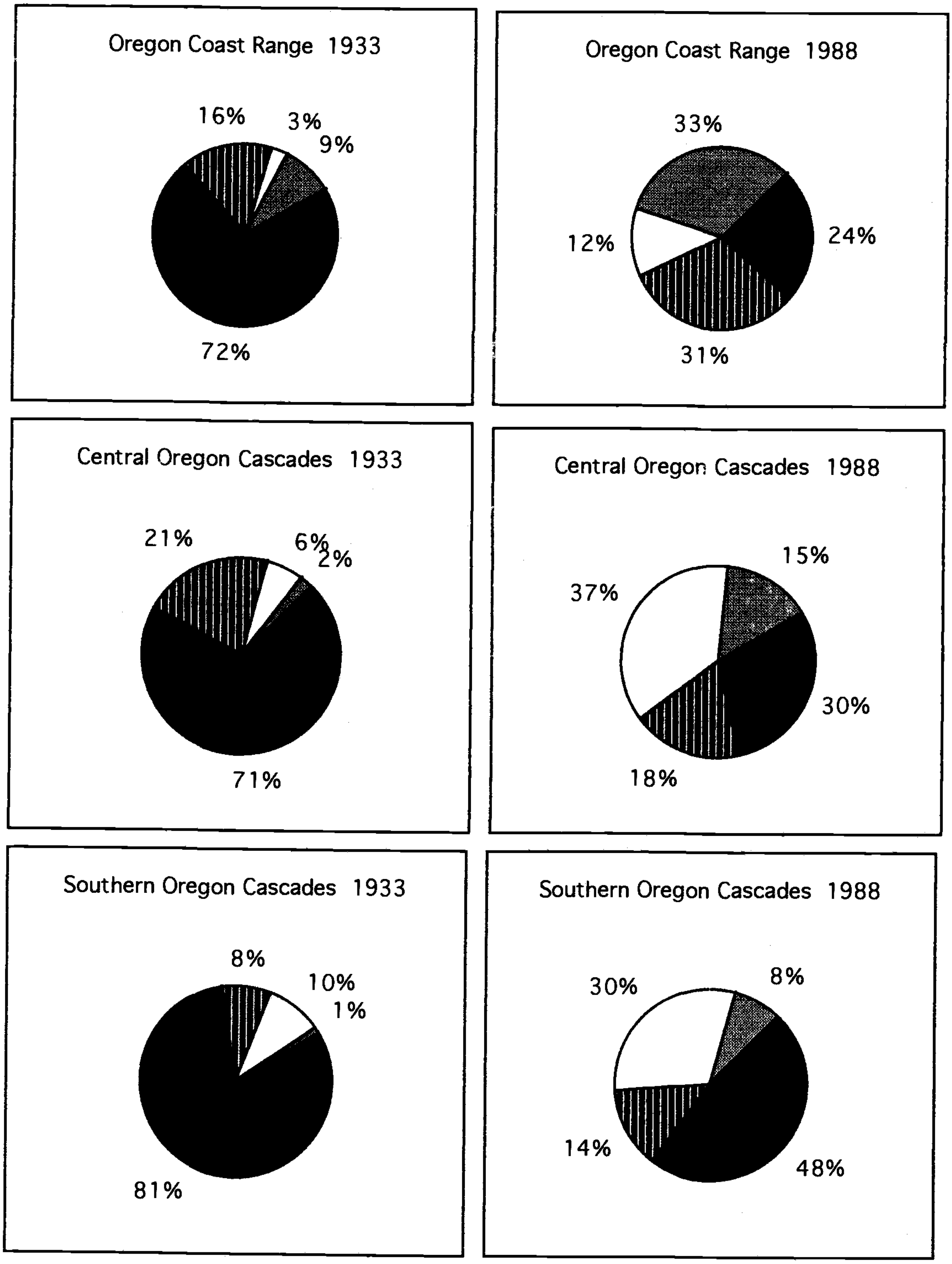
Table 3.4c

Patch Type	Elevation (m) 1-299	300-599	600-899	900-1199	1200-1499	1500-1799	1800-2099
Burn Areas		C++	C--	C-- S++	C-- S--	C- S--	S-
Seedling-Sapling		C++ S++	C++ S++	C--	C--	C-- S--	S--
Small Conifer	C++	C++ S-	C--	C--	C+	C++ S++	
Large Conifer	C++	C-- S--	C-- S--	C++ S--	C++ S+	C++ S++	S++
Old Growth	C--	C-- S++	C++ S++	C++ S++	C--	C-- S--	S--

Table 3.4d

Patch Type	Distance from Major Rivers (m)									
	1 - 999	1000 - 1999	2000 - 2999	3000 - 3999	4000 - 4999	5000 - 5999	6000 - 6999	7000 - 7999	8000 - 8999	9000 - 9999
Burn Areas	O++ C++ S++	C++	C++	C++ S++	O--	O--	O+ C-- S--	C-- S--	C-- S-	O- C--
Seedling-Sapling	O-- C++ S--	O-- S++	O++ C++	O++ S--	O++ S--		O--	C-- S++	O++ C-- S+	C-- S--
Small Conifer	O++ S--	O+ C++	C++	C++ S++	O-	O-- C-- S--	C--	O-- C--	O-- C-- S+	O- S++
Large Conifer	O+ S--	O++ C++ S--	O++	O- C++ S++	O-- C++ S++	O-- C- S++	O-- C--	C--	O-- S++	C-- S++
Old Growth	O-- C-- S++	O-- C--	O-- C--	C--	O++ S-	O++ C++	O++ C++	O++ C++	O++ C++ S--	O+ C++

Figure 3.4 Forest landscape compositions for 1933 and 1988. Legend: black = late seral class; stripes = mid-seral class; white = early seral class; and gray = other.



4. Discussion

4.1 Pre-logging Landscape Patterns

The pattern and distribution of forest patches observed on the pre-logging landscape maps of western Oregon reflect disturbance processes that have occurred throughout the previous several hundred years with the most distinct patterns traceable to events during the 19th century.

Forest patches located in the western portion of the Coast Range landscape accounted for this study area's relatively high proportion of large and small conifer category, and corresponded to extensive stand-replacing fires (Loy 1976). Morris (1934a) reports that several fires occurred in the Coast Range during the late 1840's and 1860's, 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 1979). The high proportion of old growth observed in the Southern Oregon Cascades study area may be due to a combination of factors: a lack of intense stand replacement fires, and isolation from disturbance by European settlers until the later part of the 19th and early-20th centuries (Ripple 1994).

Estimates of historical levels of old growth vary considerably. At the turn of the century, it was reported that 90% of western Oregon and 85% of western Washington forests were 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 60-70 % of the commercial forest land in the region during the early 1800's. Booth (1991) used the 1933 forest survey data to conclude that 63% of western Washington and 61% of western Oregon was covered with old growth forest before logging. My calculations show that 53% of the three western Oregon landscapes were in an old growth condition in 1933, using the map-based pre-logging estimates from Table 3.1, and excluding non-conifer areas. My pre-logging old growth estimate of 39% for the Coast Range study area closely agreed with the Teensma et al. (1991) estimate that 40% of the Coast Range forests were over 200 years old in 1850.

The variation between 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, and Booth 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 old growth estimates were based on areas of forest composed of more than 60% Douglas-fir of an age greater than 160 years, with the majority of the volume in trees 51 cm or larger in diameter, the Andrews and Cowlin estimates may over-estimate old growth according to more recent definitions that use a minimum tree diameter of 81 cm (Franklin and Spies 1991). Current definitions of old growth also recognize the inherent structural and functional variability of these complex forest systems by providing a range of species, sizes, and ages of trees for multiple canopy layers.

Old growth forests are part of a continuum in which many aspects of structure and function change. One can view the ecological processes of disturbance and succession in Douglas-fir forests as the waxing and waning of structural features related to the dominant trees in the forest patch.

Spies and Franklin (1988) have developed a theory that represents two general courses of change in ecosystem features after natural disturbance. The first course has a U-shaped pattern through time with high values of a given feature immediately after a catastrophic disturbance to old growth, declining to low values midway through succession, and then increasing to moderately high values again in late succession. The ecosystem features that follow this general course include amount of coarse woody debris, number of large snags, heterogeneity of understory plant species, and mammal species diversity.

The other course is more S-shaped and is related to growth and development of live trees; it has low values early in succession and increases to an asymptote in late succession or old growth and may stay high for several hundred years before declining. Features following this course include stand biomass, tree size, and diversity of tree sizes.

The change in mean patch size as displayed in Figure 3.1, may also be an ecosystem feature that follows one of these two courses, but at a landscape rather than patch level. I observed that the mean patch size was low for early and mid-successional patches, and higher for the late successional and old growth phases, similar to the S-shaped course. Additional data is needed to verify the mean patch size trends for very old, forest patches (300 - 700 years old) and to help determine the shape of the course.

Regardless of the course of change that ecosystem features such as mean patch size may follow, 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. It is important to understand that as disturbance events occur through time, varying in frequency and severity, a mosaic of vegetation in different stages of succession results. This spatial heterogeneity greatly enhances landscape diversity and provides an array of habitats for different plants, animals, and microbes.

The compositional data in Table 3.1 and the spatial data from Figure 3.3, demonstrates that the pre-logging landscapes of western Oregon contained a high degree of spatial heterogeneity and structural diversity.

4.2 Fire Disturbance

The many combinations of fire regimes and forest types in the Pacific Northwest are a product of repeated fires with variable spread rates and intensities. (Agee 1993). In my assessment of fire patch characteristics, I found that size and shape of patches differed by physiographic province. Because topographic and climatic differences exist between the Coast Range and Western Cascades provinces, and fire behavior is influenced by weather and topography, it is reasonable to conclude from the data that different fire regimes exist between the two mountain provinces.

The fire regime of the Coast Range has been described by Teensma et al. (1991) as being characterized by high-intensity, stand replacement fires occurring at intervals from 150 to 350 years. As a result of having irregularly timed, high intensity burns, Coast Range forest patches are more even-aged compared to those of the central Western Cascades, where under burning and variable intensity fires were historically prevalent (Stewart 1989, Agee 1991).

One of my fire return interval estimates for the Coast Range province (170 yrs.) was based on the Andrews and Cowlin definition of old growth. Because of existing disagreements over the historical levels and definitions of old growth I also included an estimate (292 yrs.) based on late-successional forest conditions. When considered as a range rather than two seperate observations, these return intervals for high intensity, stand replacing fires mimic Teensma's findings and bracket Ripple's estimates of 237-242 years. From a regional perspective, these Coast Range estimates are greater than the 200-year interval estimated by Morrison and Swanson (1990) for the Oregon Cascade Range, and less than the 450-year interval estimated for the late seral forests of Mt. Rainier National Park (Hemstrom and Franklin 1982).

As shown in Figure 3.2, I 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 a couple of reasons: 1) the minimum mapping unit for the 1933 forest survey was 8 ha and my assessment of the map (using aerial photos) indicated that these smaller patches (10-99 ha) were identified and recorded; 2) these findings contradict the observed frequency distributions (log-normal) for many natural phenomena (including lakes, soil units, tree gaps, and forest fires) which show an inverse relationship between size and abundance (Harris 1984, Hunter 1990).

It is unclear why a higher frequency of forest patches, especially fire patches, in the 10-99 ha size was not observed. Morrison and Swanson (1990) observed that 70-96% of fire patches in their two 1940 ha fire history study areas in the Oregon Cascades were less than 10 ha. In contrast, I found fire patch sizes that averaged 340 ha (range 49-3636 ha) for the 329,000 ha Central Oregon Cascades study area. Garza (1995) mapped 11 fire episodes that occurred between the years 1666 and 1918 with patch sizes that averaged 654 ha (range 26-1787 ha). His 3,540 ha fire history study area was located north of my Central Oregon Cascades study area.

These findings may indicate that 100-999 ha is a natural range for stand-replacing fire events before the initiation of fire suppression policies in the late 1910s, or it may indicate that despite detailed field observations, smaller disturbance patches (low intensity, non-stand replacing events) may not have been mapped. It is clear from the contradicting data that additional research is needed to determine the historic range of fire sizes for western Oregon.

4.3 Topographic Effects on Forest Patch Distribution

Disturbance patterns may be 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 borne out in the landscape patterns of the Cascades study areas where I observed more burn patches on the hotter, drier aspects and steeper slopes and more large conifer on the cooler, moister slopes. My findings agree with Morrison and Swanson (1990), who found that steeper and more highly dissected areas burned more frequently at a lower intensity than areas with gentler topography.

In mountainous terrain, landscape patterns reflect changes in vegetative composition along an elevation gradient. As elevation increases, average annual temperatures decrease while precipitation increases. I observed a change in patch type composition from mostly old growth conifer to predominantly large conifer around 1200 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 1200 m, the number of frost free growing days is less and the trees grow more slowly. This idea is reinforced by the absence of a similar pattern in the Coast Range, which has less topographic relief and lower overall elevations than the Cascades.

The spatial analysis shows a strong association between anthropogenic fire disturbance and the location of major rivers. Within 4000 m of major rivers, I 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. Burke (1979) 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 lightening-caused fires occurred at elevations between 1200 and 1800 m. Since most major rivers occupy the lower elevations within the basins, and both European settlers and Native Americans were associated with river corridors for travel and settlement purposes (Boag 1992, Boyd 1986), it is reasonable to conclude that an anthropogenic influence on fire disturbance patterns in western Oregon existed around major rivers.

4.4 Landscape Composition Change

Coarse-scale disturbances such as fire can leave a strong imprint on the landscape for many decades to centuries. Since the 1930's, another disturbance factor, timber harvesting, has left its mark on the Douglas-fir forests of the Pacific Northwest in the form of relatively fine-grained, highly fragmented landscape patterns (Harris 1984, Franklin and Forman 1987).

Timber harvest activities and land use conversion (forest to agriculture, forest to residential) have resulted in a two- to three-fold reduction in late-seral forest and a concurrent three- to six-fold increase in early-seral forest between 1933 and 1988 for the three western Oregon study areas. Only minor amounts of this change are attributed to fires because of the aggressive fire suppression policies that have been in effect since the 1910's.

The amount of change may be slightly effected by the diameter breakpoints used to define the 1933 and 1988 late-seral classes (51 cm versus 53 cm respectively). This discrepancy may slightly over-estimate the amount of late-seral forest observed in 1933, slightly over-estimate the amount of mid-seral forest in 1988, and slightly under-estimate the amount of late-seral forest measured in 1988. Some of the perceived change may be attributable to the differences between the source data for the maps - aerial photos versus satellite imagery. Even so, the magnitude and direction of change are clearly recognizable. There is less late-seral forest now than there was earlier this century and probably historically.

5. Conclusions

In this paper, landscape patterns of pre-logging forest conditions were identified, measured and described with the aid of historical forest survey maps and computerized spatial analysis techniques. This is the first time that the size and shape of historical forest patches for western Oregon have been reported. The methods used in this study, such as determining the grain and extent of investigation, and analyzing the various spatial data, provide a template for future retrospective landscape studies aimed at understanding landscape pattern-process relationships over broad geographic areas.

This research has shown that before logging was a common activity in western Oregon, high proportions of old growth conifer forest covered the landscape. These landscapes contained a high degree of spatial heterogeneity and structural diversity. During the last 60 years, the amount of late-seral forest habitat has declined by more than a factor of two and the amount of early-seral forest habitat has increased by more than a factor of four.

Terrain features and disturbance history have strongly influenced the Cascadian forest landscape patterns observed, while disturbance history alone has more strongly influenced the Coast Range landscapes displayed on these pre-logging maps of western Oregon. The most distinct landscape patterns have been associated with disturbance events of the 19th and early-20th centuries.

During the 19th century, anthropogenic fires were generated by both aboriginal and Euro-American cultural practices. The opportunity to analyze 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 information would broaden our understanding of the range of natural variability for landscape patterns of the Pacific Northwest and provide reasonable estimates for creating a desirable range of landscape conditions through selected management activities.

This study assessed landscape patterns over a large geographic area (≈ 1,000,000 ha combined), which allowed me to substitute space for time to help understand temporal ecological processes. But because the variability of ecosystem structure and function over space and time is extreme, future research should be directed towards identifying trends, processes, and rates of change, in addition to quantifying the variability in structure of forested landscapes.

Because coarse-scale disturbances such as fire leave a strong imprint on many North American landscapes, historic as well as current disturbances can and should be identified and monitored for their effects on ecosystem processes. Such a strategy would strengthen efforts to manage for the long-term health and functioning of our terrestrial ecosystems.

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APPENDIX

Definitions of Landscape Pattern Indices

A.1 Patch Level Indices

Patch Area Units: Hectares Range: AREA > 0, w/o limit

AREA equals the area (m^2) of the patch, divided by 10,000 (to convert to hectares).

A.2 Class Level Indices (Forest Patch Type Indices)

Percent of Landscape Units: Percent Range: 0 < %LAND <= 100

%LAND equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage).

Number of Patches Units: None Range: NP>= 1, w/o limit

NP equals the number of patches of the corresponding patch type (class).

Largest Patch Index Units: Percent Range: 0 < LPI < 10

LPI equals the area (m^2) of the largest patch of the corresponding patch type divided by total landscape area, multiplied by 100 (to convert to a percentage); in other words, LPI equals the percentage of the landscape comprised by the largest patch.

Patch Density Units: Number per 1000 ha. Range: PD > 0, w/o limit.

PD equals the number of patches of the corresponding patch type divided by total landscape area, multiplied by 10,000 and 1000 (to convert to 1000 hectares).

Mean Patch Size Units: Hectares Range: MPS > 0, w/o limit

MPS equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by the number of patches of the same type, divided by 10,000 (to convert to hectares).

Patch Size Coefficient of Variation Units: Percent Range: PSCV > 0

PSCV equals the standard deviation in patch size divided by the mean patch size of the corresponding patch type (MPS), multiplied by 100 (to convert to percent): that is, the variability in patch size relative to the mean patch size. Note, this is the population coefficient of variation, not the sample coefficient of variation.

Area-Weighted Mean Shape Index Units: None Range: AWMSI > 1

AWMSI equals the sum, across all patches of the corresponding patch type, of each patch perimeter (m) divided by the square root of patch area (m^2), adjusted by a constant to adjust for a square standard, multiplied by the patch area (m^2) divided by total class area (sum of patch area for each patch of the corresponding patch type). In other words, AWMSI equals the average shape index of patches of the corresponding patch type, weighted by patch area so that larger patches weigh more than smaller patches.

Area-Weighted Mean Patch Fractal Dimension Units: None
Range: 1 < AWMPFD < 2

AWMPFD equals the sum, across all patches of the corresponding patch type, of 2 times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m^2), multiplied by patch area (m^2) divided by total class area (sum of patch area for each patch of the corresponding patch type); adjusted to correct for the bias in perimeter. In other words, AWMFPD equals the average patch fractal dimension of patches of the corresponding patch type, weighted by patch area.

Mean Nearest-Neighbor Distance Units: Meters Range: MNN > 0

MNN equals the sum of the distance (m) to the nearest neighboring patch of the same type, based on nearest edge-to-edge distance, for each patch of the corresponding patch type, divided by the number of patches of the same type.

Nearest-Neighbor Coefficient of Variation Units: Percent
Range: NNCV > 0

NNCV equals the standard deviation in nearest-neighbor distance divided by the mean nearest-neighbor distance (MNN) of the corresponding patch type, multiplied by 100 (to convert to percent); that is, the variability in nearest neighbor distance relative to the mean nearest neighbor distance. Note, this is the population coefficient of variation, not the sample coefficient of variation.

A.3 Landscape Level Indices

Largest Patch Index Units: Percent Range: 0 < LPI < = 100

LPI equals the area (m^2) of the largest patch in the landscape divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage); in other words, LPI equals the percent of the landscape that the largest patch comprises.

Patch Density Units: Number per 1000 ha Range: PD > 0, w/o limit

PD equals the number of patches in the landscape divided by total landscape area, multiplied by 10,000 and 1000 (to convert to 1000 hectares).

Area-Weighted Mean Shape Index Units: None Range: AWMSI > 1

AWMSI equals the sum, across all patches, of each perimeter (m) divided by the square root of patch area (m^2), adjusted by a constant to adjust for a square standard, multiplied by the patch area (m^2) divided by total landscape area. In other words, AWMSI equals the average shape index of patches, weighted by patch area so that larger patches weigh more than smaller ones.

Area-Weighted Mean Patch Fractal Dimension Units: None
Range: 1< AWMPFD <2

AWMPFD equals the sum, across all patches, of 2 times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m^2), multiplied by the patch area (m^2) divided by total landscape area; adjusted to correct for the bias in perimeter. In other words, AWMFPD equals the average patch fractal dimension of patches in the landscape, weighted by patch area.

Simpson's Diversity Index Units: None Range: 0 < SIDI < 1

SIDI equals 1 minus the sum, across all patch types, of the proportional abundance of each patch type squared.

Simpson's Evenness Index Units: None Range: 0 < SIEI < 1

SIEI equals 1 minus the sum, across all patch types, of the proportional abundance of each patch type squared, divided by 1 minus 1 divided by the number of patch types. In other words, the observed Simpson's Diversity Index divided by the maximum Simpson's Diversity Index for that number of patch types.

Interspersion/Juxtaposition Index Units: Percent Range: 0 < IJI < 100

IJI equals minus the sum of the length (m) of each unique edge type divided by the total landscape edge (m), multiplied by the logarithm of the same quantity, summed over each unique edge type; divided by the logarithm of the number of patch types times the number of patch types minus 1 divided by 2; multiplied by 100 (to convert to a percentage). In other words, the observed interspersion over the maximum possible interspersion for the given number of patch types.

Contagion Index Units: Percent Range: 0 < CONTAG <= 100

CONTAG equals 1 minus the sum of the proportional abundance of each patch type multiplied by the number of adjacencies between cells of that patch type and all other patch types, multiplied by the logarithm of the same quantity, summed over each patch type; divided by 2 times the logarithm of the number of patch types; multiplied by 100 (to convert to a percentage). In other words, the observed contagion for the given number of patch types.

Table A.1 Pre-logging forest patch characteristics for the Oregon Coast Range study area.

Patch Type Characteristic	Burn Areas	Seedling/ Sapling	Small Conifer	Large Conifer	Old Growth
Largest Patch Index	0.3 %	0.3 %	6.8 %	9.6 %	21.1 %
Patch Density (#/1000 ha)	0.10	0.06	0.22	0.19	0.15
Mean Patch Size (ha)	149	314	708	1,747	2,679
Patch Size Coeff. of Var.	114 %	75 %	366 %	291 %	401 %
Mean Shape Index	1.67	1.65	2.95	3.91	9.63
Mean Fractal Dimension	1.07	1.06	1.11	1.14	1.18
Mean Nearest Neighbor Distance	2,844 m	5,283 m	1,155 m	895 m	834 m
Nearest Neighbor Coeff. of Var.	204 %	117 %	122 %	109 %	102 %

Table A.2 Pre-logging forest patch characteristics for the Central Oregon Cascades study area.

Patch Type Characteristic	Burn Areas	Seedling/ Sapling	Small Conifer	Large Conifer	Old Growth
Largest Patch Index	0.8 %	0.3 %	4.8 %	4.3 %	26.8 %
Patch Density (#/1000 ha)	0.12	0.09	0.19	0.12	0.08
Mean Patch Size (ha)	281	303	1,130	1,666	6,475
Patch Size Coeff. of Var.	158 %	80 %	230 %	188 %	318 %
Mean Shape Index	1.64	1.69	3.03	3.18	6.40
Mean Fractal Dimension	1.06	1.06	1.11	1.12	1.18
Mean Nearest Neighbor Distance	2,424 m	2,728 m	1,122 m	1,370 m	946 m
Nearest Neighbor Coeff. of Var.	121 %	138 %	127 %	114 %	117 %

Table A.3 Pre-logging forest patch characteristics for the Southern Oregon Cascades study area.

Patch Type Characteristic	Burn Areas	Seedling/ Sapling	Small Conifer	Large Conifer	Old Growth
Largest Patch Index	0.8 %	0.4 %	0.9 %	5.4 %	61.7 %
Patch Density (#/1000 ha)	0.12	0.17	0.22	0.15	0.03
Mean Patch Size (ha)	363	304	380	1,267	22,971
Patch Size Coeff. of Var.	168 %	99 %	128 %	276 %	277 %
Mean Shape Index	1.87	1.69	1.95	4.03	11.97
Mean Fractal Dimension	1.07	1.06	1.08	1.14	1.23
Mean Nearest Neighbor Distance	2,239 m	1,776 m	1,584 m	1,337 m	546 m
Nearest Neighbor Coeff. of Var.	97 %	112 %	72 %	123 %	33 %

Table A.4 Pre-logging landscape pattern indices by study area.

Landscape Characteristic	Oregon Coast Range	Central Oregon Cascades	Southern Oregon Cascades
Largest Patch Index	9.6 %	4.8 %	5.4 %
Patch Density (#/1000 ha)	0.87	0.70	0.75
Mean Shape Index	4.85	4.67	8.61
Mean Fractal Dimension	1.15	1.15	1.18
Simpson Diversity Index	0.71	0.65	0.56
Simpson Evenness Index	0.85	0.78	0.67
Interspersion/ Juxtaposition Index	74 %	78 %	72 %
Contagion Index	55 %	58 %	62 %