Emulating Natural Forest Landscape Disturbances

Concepts and Applications

Edited by

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Using Criteria Based on the Natural Fire Regime to Evaluate Forest Management in the Oregon Coast Range of the United States

MICHAEL C. WIMBERLY, THOMAS A. SPIES, and ETSUKO NONAKA

Forest landscapes in the Oregon Coast Range have changed considerably since settlers first arrived in the mid-nineteenth century. Clearing of forests for agriculture and development, ignition of extensive forest fires by settlers and loggers, and conversion of natural forests to managed plantations have all contributed to the fragmentation of late-successional forests (Ripple et al. 2000; Wimberly et al. 2000). These rapid and widespread changes have led to concern for populations of native species, particularly those associated with old-growth forests and aquatic habitats. Some threatened or endangered species such as the northern spotted owl (*Strix occidentalis caurina* [Merriam]) have been the subject of intensive research, resulting in the development of detailed conservation plans (Thomas et al. 1990). There are many other species, however, for which comprehensive information on habitat requirements and demography is not available. Because of limited knowledge and resources, developing and implementing individual management plans for every species is not feasible. Instead, the *coarse filter* approach has been proposed as an alternative for conserving native biodiversity at the landscape scale (Noss 1987). This method entails preserving ecological diversity at the community level based on the assumption that a representative array of habitats will be sufficient to meet the needs of most species (see Thompson and Harestad, this volume, chapter 3).

Studies of landscape dynamics under natural disturbance regimes can play a critical role in the development of coarse-filter conservation strategies (Landres et al. 1999; Swetnam et al. 1999). Disturbance-based ecological assessments are grounded on the assumption that historical landscapes were subjected to both natural and human disturbances for millennia prior to the arrival of Europeans and other nonindigenous settlers. Despite these perturbations, pre-European settlement landscapes sustained the native species that we currently wish to preserve. Comparisons between present-day and pre-European settlement disturbance regimes can therefore serve as indicators of the potential for conserving species and sustaining ecosystem processes in the modern landscape. Analyses of natural disturbance regimes and the forest patterns they generate can also provide targets for future landscape restoration efforts and can suggest approaches to maintaining habitat diversity in dynamic landscapes. Because landscapes influenced by natural disturbance regimes seldom approach a steady state equilibrium, historical patterns must be characterized as a distribution of possible system states rather than as an arbitrary "snapshot" taken at a single point in time (Sprugel 1991).

Fire was a ubiquitous landscape-scale disturbance in the Pacific Northwest for thousands of years prior to the arrival of settlers (Agee 1993; see also Hessburg et al., this volume, chapter 13). Because fire has been almost entirely suppressed in the Oregon Coast Range for the past 50 yr, our ability to observe and study such fundamental processes as fire ignition, fire spread, and fuel consumption is limited. However, paleoecological, dendroecological, and historical research has yielded considerable information about the frequencies, sizes, and severities of past fires (Teensma et al. 1991; Impara 1997; Long et al. 1998; Weisberg and Swanson 2003). Therefore, we have adopted a primarily historical and empirical approach to characterizing and modeling fire regimes in this chapter. For the purposes of our study, we assumed that the "natural" fire regime is equivalent to the historical fire regime that existed prior to settlement. Fires initiated by lightning, as well as those ignited by Native Americans, are all considered to be part of this natural fire regime (Suffling and Perera, this volume, chapter 4).

The goal of this research was to reexamine current forest management practices and landscape patterns in the Oregon Coast Range by considering them in the context of the natural fire regime. Specific objectives were to (1) contrast the frequencies, sizes, and effects of historical fires with those of forest management disturbances; (2) examine differences in the abundance and pattern of seral stages between pre-European settlement and present-day forest landscapes; and (3) assess the potential for applying management based on pre-European settlement fire regimes in the Oregon Coast Range within the framework of present-day forest conditions and socioeconomic constraints.

Study Area

The Oregon Coast Range encompasses more than 23,000 km^2 in western Oregon, bounded by the Pacific Ocean to the west, the Coquille River to the south, the Willamette Valley to the east, and the Columbia River to the north (figure 12.1). Elevations range from sea level to more than 1000 m at the highest peaks. The physiography is characterized by highly dissected terrain with steep slopes and high stream densities. Soils are predominantly well-drained Andisols and Inceptisols (based on the Soil Science Society of America Classification System). Parent materials are mostly marine sandstones and shales, along with some basaltic volcanics and related intrusives. The climate is generally wet and mild, with most precipitation falling between October and March. Precipitation is highest and summer temperatures are lowest near the coast, resulting in low moisture stress during the growing season and high forest productivity. Decreasing precipitation and increasing temperature with increasing distance from the coast create a predominantly west-to-east gradient of increasing moisture stress (color plate 16).

Major coniferous species include Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), with Sitka spruce (*Picea sitchensis* [Bong.] Carr.) prevalent along a narrow coastal strip. Hardwoods, including red alder (*Alnus rubra* Bong.) and bigleaf maple (*Acer macrophyllum* Pursh), are often found in mixed stands with young conifers and dominate many riparian areas. Long-lived conifers and a favorable climate combine to produce some of the largest accumulations of live-tree biomass in the world (Waring and Franklin 1979). The presence of large live and dead trees (often >100 cm in diameter at breast height [dbh]), along with a diverse multilayered canopy and spatial heterogeneity created by canopy gaps, are characteristics of Pacific Northwest old-growth forests (Franklin et al. 1981). These features typically require 200 yr or more to develop

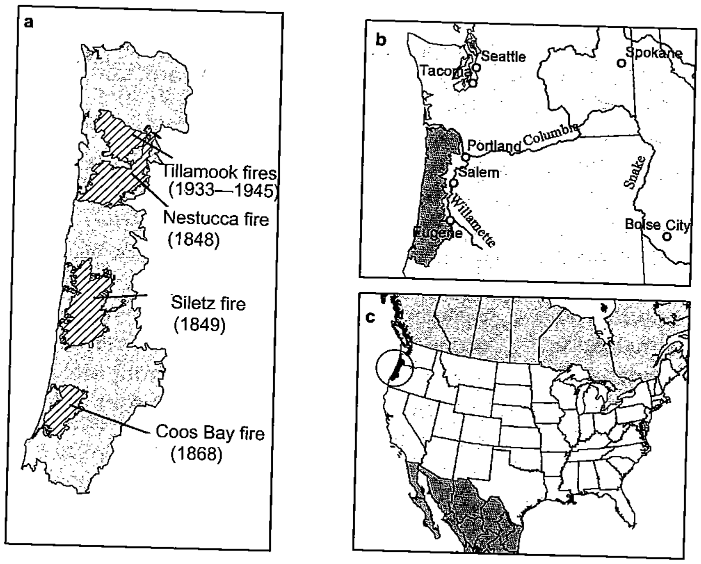

FIGURE 12.1. Maps of the Oregon Coast Range study area. (a) Boundary of the study area, with major historical fires of the past 200 yr. (b) Location of the study area within the Pacific Northwest region. (c) Location of the study area within North America.

following a stand-replacing disturbance, although old-growth structure may develop more quickly following partial disturbances that leave a cohort of live remnant trees.

Major groups of forest landowners in the Oregon Coast Range include private industry, private nonindustrial owners, the state of Oregon, and the federal government (the U.S. Department of Agriculture Forest Service and the Bureau of Land Management). Landowner goals, forest management strategies, and regulatory constraints vary considerably among these ownership classes. Private industrial ownerships comprise 38% of the study area, concentrated in blocks in the northern, central, and southern portions of the Coast Range (color plate 16b). Private industrial lands are managed primarily for wood production within the regulatory constraints imposed by the Oregon State Forest Practices Act (Oregon Department of Forestry 2002). The predominant management practice on private industrial land is clearcutting, with rotations of 30 to 50 yr. Private nonindustrial ownerships cover 24% of the study area, primarily along the Willamette Valley margin and in the large river valleys. Private nonindustrial owners operate within the same regulatory framework as private industry, but have a broader range of goals and use a wider variety of management practices.

Federal lands managed by the U.S. Department of Agriculture Forest Service and the Bureau of Land Management also occupy substantial areas of the Coast Range (11 and 14% of the study area, respectively). A significant portion of the land controlled by the Bureau of Land Management is interspersed with private industrial land in a checkerboard pattern (color plate 16b). The federal lands are presently managed under the Northwest Forest Plan for primarily ecological goals related to the preservation and restoration of old-growth forests, conservation of threatened and endangered species, and protection of aquatic ecosystems (Forest Ecosystem Management and Assessment Team 1993). Timber harvests are restricted in a large network of late-successional and riparian reserves, and harvests in the remaining matrix lands are required to leave residual live trees, snags, and downed trees. State forest lands cover 12% of the study area. Current plans for the state forests propose active management for timber production, protection of the forest's health, and species conservation by combining retention of large trees, snags, logs, and other habitat elements following timber harvests with long rotations to create a range of forest structures across the landscape (Oregon Department of Forestry 2001).

Methods

Comparison of Disturbance Regimes

Historical fire regimes in the Coast Range were characterized through a literature review and an analysis of published data. Paleoecological research based on high-resolution charcoal analyses provided long-term fire history information for the watersheds surrounding Little Lake (Long et al. 1998) in the central Coast Range and Taylor Lake (Long and Whitlock 2002) in the northwestern Coast Range. Fire frequency data from these studies were summarized for different time periods as mean fire-return intervals, defined as the mean number of years between fires at a particular location (Agee 1993). Dendroecological research based on tree-ring and fire-scar data from a 1375-km^2 study area in the central Coast Range provided a more detailed picture of rates and patterns of burning over the past 500 yr (Impara 1997). Using published data from Impara's study, we computed the natural fire rotation to serve as a metric of fire frequency for the coastal-interior and Willamette Valley margin portions of the study area. The natural fire rotation represents the total number of years required to burn a particular landscape (Heinselman 1973), and is computed as:

$$NFR = \frac{YEARS}{\sum_{i=1}^{NFIRES} FSIZE_i / TAREA}, \qquad (12.1)$$

where NFR is the natural fire rotation, $YEARS$ is the length of the fire history record, $NFIRES$ is the total number of fires in the record, $FSIZE_i$ is the size of the ith fire in the record, and $TAREA$ is the total area of the landscape.

We chose this metric to measure fire frequency because it does not depend on a particular statistical model of fire frequency and therefore does not assume that the fire regime remains constant over time and space (Fall 1998). However, the estimated natural fire rotation will be biased upward if evidence of the oldest fire events is overwritten by more recent fires. We therefore used an alternative method, adapted from Morrison and Swanson (1990), to correct for our reduced ability to sample the oldest fires:

$$NFR = \frac{YEARS}{\sum_{i=1}^{NFIRES} (FSIZE_i / RAREA_i)}, \qquad (12.2)$$

where $RAREA_i$ is the area available to record each fire, which is computed as the total area that did not experience a stand-replacing fire more recently than the occurrence of the recorded fire.

Fire-size distributions were computed using estimates of fire size from historical maps of forest vegetation in 1850, 1890, 1920, and 1940 (Teensma et al. 1991). Most of the fires represented in these maps occurred after settlement of the study area had begun, but before the establishment of an effective fire suppression program in the latter half of the twentieth century. Human influences and a warm climate both contributed to widespread fires between 1850 and 1940 (Weisberg and Swanson 2003), and we assumed that the frequency distribution of fire sizes from this period was generally representative of the pre-European settlement fire regime. These historical fire regimes were contrasted with modern disturbance regimes measured in a remote-sensing study of landscape change from 1972 to 1995 (Cohen et al. 2002). A map of the locations and sizes of clearcuts that occurred during this time was used to determine the size distribution of the disturbances caused by timber harvesting and to calculate a harvest rotation using the same approach as used in equation 12.1. Because the time period of the study of landscape change (23 yr) was less than the harvest rotations commonly used in the Coast Range (>30 yr), we assumed that no clearcuts had been overwritten by subsequent disturbances.

Simulation of Pre-European Settlement Landscape Dynamics

Pre-European settlement landscape dynamics were simulated using the Landscape Age-Class Dynamics Simulator (LADS), a spatial simulation model that predicts the initiation, spread, and effects of fires (Wimberly 2002). Multiple spatial data layers delineated simulation area boundaries, topography, and major climatic zones as raster data layers with a 9-ha resolution (300×300-m^2 cells). The model used a statistical approach to simulate fire regimes, and modeled the frequencies, sizes, and severities of individual fires as probability distributions derived from empirical data (Gardner et al. 1999). Different probability distributions were derived for the coastal-interior and Willamette Valley margin climatic zones to reflect broad-scale spatial trends in the study area's fire history (see figure 12.1a). Fire ignition and spread were modeled using a stochastic cellular-automata algorithm that allowed fire to occur more frequently on more susceptible landforms and in stands with high levels of fuel accumulation. Stand dynamics were simulated using an age-driven model of forest cohorts, which assumed that structural diversity recovered more rapidly after moderate-severity fires than after stand-replacing fires. Forest vegetation was mapped using five structure classes (table 12.1): early successional, young, mature, old growth (early transition), and old growth (late transition—shifting mosaic). For the purposes of our analysis and to permit comparison with the present-day landscape, the two old-growth classes were combined into a single structure class. Additional details on the development, parameterization, and sensitivity analysis of the LADS model are provided by Wimberly (2002).

Previous research has demonstrated that the disturbance regimes and landscape dynamics of the Coast Range are scale dependent. Pre-European settlement landscape variability must be studied over relatively large areas (>100,000 ha) and long time intervals (>500 yr) because the occurrence of occasional large fires makes landscape dynamics unpredictable at finer scales (Wimberly et al. 2000). Our simulations of landscape dynamics therefore encompassed the spatial extent of the Coast Range (approximately 23,000 km^2) and were carried out based on the fire regime that characterized the 1000-yr period prior to settlement. This period was deemed most relevant to present-day management questions and was found in a previous study to represent an era in which climate, fire regimes, and species composition were generally similar to those of the present day (Wimberly 2002). The model was run for a total of 50,000 simulation years following a 1000-yr initialization period. Landscape patterns were output as digital maps at 200-yr intervals, generating 250 sample landscapes. Running the model for 50,000 simulation years does not imply that the simulated fire regime was representative of the actual 50,000 yr prior to settlement. Instead, the long simulation period was needed to generate a large number of independent landscapes that represented the range of variability that could have occurred over the 1000-yr time frame of the model.

The spatial pattern of each sample landscape was summarized by computing the total area and largest patch size for each structure class. In addition, we computed a spatial index that measured the relative isolation of each structure class from the other classes. In equation 12.3, this isolation index (I_s) was calculated for a given

TABLE 12.1. Classification of Forest Patches into Structure Classes based on AGE (Time Since Stand Initiation) and TFIRE (Time Since Last Fire)

AGE (yr)	TFIRE (yr)	Structure Class	Description
Any	<30	Early successional	Open canopy to dense, closed canopy with high tree densities. May have residual live trees, snags, and downed trees from the prefire stand.
>30	30–80	Young	Closed canopy with low levels of understory tree regeneration, shrubs, and herbs. May have residual live trees, snags, and downed trees from the prefire stand.
80–200	80–200	Mature	Canopy gaps allow light to reach the forest floor, facilitating reestablishment of the understory layer. Typically has low volumes of dead wood compared with older and younger age classes.
>200	80–500	Old growth (early transition)	Characterized by large living trees (>100 cm dbh); accumulations of large snags and downed trees; a diverse, multilayered canopy dominated by shade-tolerant trees in the mid-canopy layers; and a heterogeneous spatial pattern of canopy gaps and forest patches in various age classes.
>500	>80	Old growth (late transition–shifting mosaic)	Similar to the old growth (early transition) phase, but with decreasing numbers of living remnant trees from the establishment phase and increasing dominance of canopy-gap dynamics.

Notes: AGE = TFIRE for even-aged stands, but AGE > TFIRE for stands that have had one or more fires of moderate severity. See Wimberly et al. (2000) for a detailed explanation of this classification scheme. Descriptions of stand structure classes are from Spies and Franklin (1991) and Spies (1997).

structure class (s) by first computing the distances (d_{ij}) in km from every cell (i) in the raster map to its nearest neighbor (j) belonging to class s. The isolation index for structure class s was then computed as:

$$I_s = \frac{\sum_{i=1}^{N} \sigma_i \cdot d_{ij}}{\sum_{i=1}^{N} \sigma_i}, \tag{12.3}$$

where N is the total number of cells in the simulated landscape, $\sigma_i = 0$ for cells belonging to structure class s, and $\sigma_i = 1$ for cells that do not belong to structure class s. This index was similar to the *GISfrag* index proposed by Ripple et al. (1991), except that distance values of 0 were not included in our computation. The isolation index computed for a particular structure class reflected the mean distance from each cell that was not a member of that structure class to its nearest neighboring cell that was a member. For example, computing a low isolation index for the old-growth class would indicate that forests in other classes tended to be located in close proximity to old-growth patches, suggesting a high potential for dispersal of organisms from old-growth refugia into the younger forests. In contrast, a high isolation index computed for old-growth forest would suggest a limited potential for organisms to disperse from old-growth refugia into the surrounding landscape.

Simulations of the historical landscape were contrasted with a 1996 map of forest vegetation patterns derived from forest inventory plots, Landsat TM imagery, and GIS layers describing ownership, topography, and climate (Ohmann and Gregory 2002). This map provided a set of compositional and structural measurements for each forested patch, including an estimate of stand age. Patches in the 1996 map were reclassified into the same age-based structure classes used in the simulation model. The 1996 vegetation map initially had a 25-m spatial resolution, and was rescaled to a 300-m resolution to match the resolution of the simulation model's output. The total area, largest patch size, and isolation index were computed for each of the four structure classes based on the 1996 map. These values were compared with the probability distributions of the same indices derived from simulation of the pre-European settlement fire regimes.

Results

Comparison of Disturbance Regimes

The paleoecological records showed that fires have burned in the central Coast Range for at least the past 9000 yr (Long et al. 1998). However, mean fire-return intervals varied considerably as climate changed over this epoch. From 9000 to 6850 yr before the present (YBP), the climate was warmer and drier than the present climate and the mean fire-return interval at Little Lake averaged 110 yr. The interval at Little Lake lengthened over time as climate became cooler and more humid, averaging 160 yr between 6850 and 2750 YBP and 230 yr between 2750 YBP and the present day (Long et al. 1998). Values of the mean fire-return interval at Taylor Lake showed similar trends, averaging 140 yr between 4600 and 2700 YBP and increasing to 240 yr between 2700 YBP and the present day (Long and Whitlock 2002).

Using equation 12.1, Impara (1997) reported a natural fire rotation of 452 yr for the central Coast Range over the 367-yr period prior to settlement in 1845. Wimberly (2002) used the same data to compute natural fire rotation values of approximately 200 yr for the coastal-interior portion of the study area and 100 yr for the Willamette Valley margin portion of the study area. This calculation included only fires that were severe enough to initiate tree regeneration, and used equation 12.2 to correct for bias introduced by the erasure of evidence of older fires by subsequent burns. We used these values in our simulations of historical landscape dynamics because the 200-yr natural fire rotation computed for the coastal-interior region was reasonably close to the mean fire-return interval values reported for the past 1000 yr (Long et al. 1998, Long and Whitlock 2002). Running the simulations with natural fire rotation values at the shorter end of the range of estimates provided a conservative estimate of the amount of older forests in the pre-European settlement landscape.

Natural fire rotation decreased to 78 yr during the settlement period from 1845 to 1910, probably because of the warming climate combined with increased fire ignitions by settlers (Impara 1997). This increase in the rate of burning reflected a regional trend of increased fire frequency during the settlement era (Weisberg and Swanson 2003). In contrast, natural fire rotation increased considerably in the twentieth century as fire suppression became more effective, averaging 335 yr between 1910 and 1994 (Impara 1997). Stand-replacing fires burned only 0.06% of the Coast Range between 1972 and 1995 (Cohen et al. 2002). If this rate of burning is extrapolated over long time periods, it is equivalent to a natural fire rotation of greater than 1600 yr.

Most of the fires reconstructed by Impara (1997) conformed to one of two distinctive patterns. Widespread fires were large burns that encompassed both the coastal-interior and Willamette Valley margin climate zones and were predominantly stand-replacing disturbances. Historically documented examples of such events (Loy et al. 1976) include the Nestucca fire of 1848 (120,000 ha); the Siletz fire of 1849 (325,000 ha); the Yaquina fire of 1853 (195,000 ha); the Coos Bay fire of 1868 (118,000 ha); and the Tillamook fires of 1933 (96,000 ha), 1939 (76,000 ha), and 1945 (72,000 ha). In contrast, Willamette Valley margin fires were smaller, predominantly moderate- and low-severity burns that left significant cohorts of remnant live trees (Impara 1997). Fire-size data from reconstructed forest age maps for the Oregon Coast Range in 1850, 1890, 1920, and 1940 (Teensma et al. 1991) also suggest a pattern of a few large, widespread fires combined with smaller, more numerous fires along the Willamette Valley margin. Mean fire size in the coastal-interior climate zone was 12,309 ha, whereas the mean fire size in the Willamette Valley margin climate zone was only 2576 ha (Wimberly 2002). These fire-size distributions were heavily skewed, with fires smaller than 10,000 ha accounting for 89% of the total number of fires. However, fires larger than 10,000 ha accounted for 84% of the total area burned (figure 12.2). The five largest fires, all larger than 50,000 ha, accounted for 71% of the total burned area.

Between 1972 and 1995, 27% of the Coast Range was clearcut, equivalent to a harvest rotation of 85 yr (Cohen et al. 2002). In contrast with fires, most clearcuts retain few live trees, snags, or large downed trees within their boundaries. Densities of large trees and snags (>50 cm dbh) can be three to five times higher in postfire stands than in logged stands of similar age (Hansen et al. 1991). The mean size of clearcuts was less than 200 ha, with no units larger than 5000 ha (Cohen et al. 2002). Spatial variability in harvest rotations and the sizes of timber harvests is presently controlled by the management regimes used in different classes of forest ownership (figure 12.3). Between 1972 and 1995, the harvest rotation on private industrial lands was 51 yr, compared with 100 yr on private nonindustrial lands, 189 yr on state-owned lands, and an average of

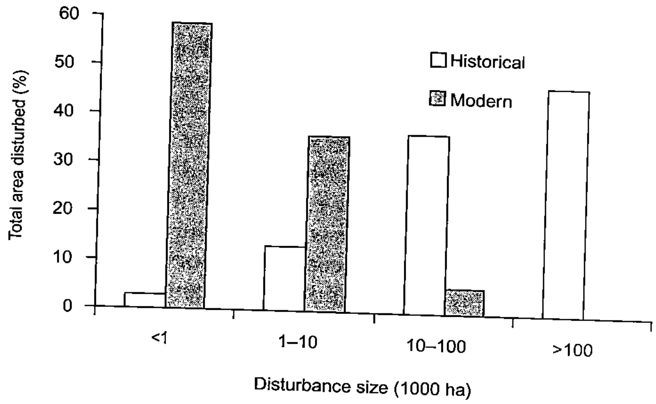

FIGURE 12.2. Size-class distribution for historical wildfires (1850–1940) and modern wildfire and timber harvest disturbances (1972–1995), expressed as percentages of the total area disturbed. Historical fire data are from Teensma et al. (1991), and timber harvest data are from Cohen et al. (2002).

160 yr on federal lands managed by the Bureau of Land Management and the U.S. Department of Agriculture Forest Service. Similarly, the mean size of clearcuts was more than twice as large on private industrial lands as in any other ownership class.

The harvest rotations presented in figure 12.3 must be interpreted with the caveat that they are based on only 23 yr of data. On state lands, little harvesting occurred from 1972 to 1995, because much of the forest was below harvestable age. The calculated harvest rotation on state lands will decrease in the future, as stands reach merchantable age and new management plans are implemented. On federal lands, the reported harvest rotations mostly reflect the period prior to the implementation of the Northwest Forest Plan. Under current policies, future rates of clearcutting on federal lands will be lower than those reported here.

Simulation of Pre-European Settlement Landscape Dynamics

Old growth was the most common structure class in the simulated pre-European settlement landscape (color plate 17); in our simulations (figure 12.4), it occupied a median of 42% of the Coast Range, with values ranging from 29% (fifth percentile) to 52% (ninety-fifth percentile). In contrast, median abundances were 21% for the young class, 17% for the early-successional class, and 16% for the mature class. In the present-day Coast Range, the percentages of mature and old-growth forests are smaller than would be expected under the pre-European settlement fire regime, and the percentages of early-successional and young forests are greater than expected. In the simulated pre-European settlement landscapes, there was at least one large (>100,000-ha) patch of old-growth forest present at all times, but the largest old-growth patch in the present-day landscape occupies only 650 ha (figure 12.5). In contrast, a mosaic of early-successional and young forests dominates the present-day landscape, with the largest patch of early-successional forest larger than 500,000 ha and the largest patch of young forest larger than 300,000 ha. In the simulated pre-European settlement forests, most early-successional, young, and mature forests were within 1 km of an old-growth forest, as shown by

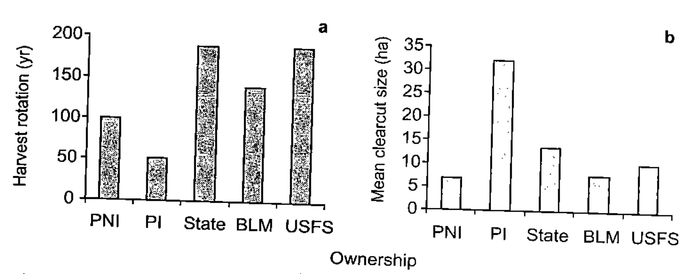

FIGURE 12.3. Distribution of (a) timber harvest rotations and (b) clearcut sizes in the Oregon Coast Range from 1972 to 1995. PNI = private nonindustrial, PI = private industrial, State = state of Oregon, BLM = Bureau of Land Management, USFS = U.S. Department of Agriculture Forest Service. Based on data from Cohen et al. (2002).

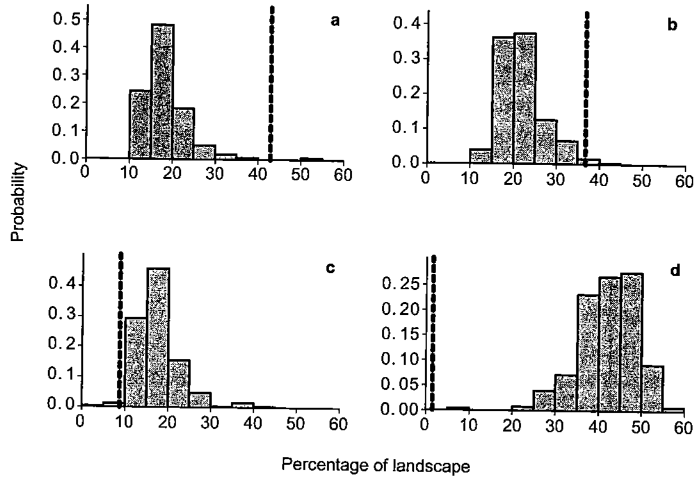

FIGURE 12.4. Simulated historical (pre-European settlement) ranges of variability for the percentages of the landscape covered by (a) early-successional, (b) young, (c) mature, and (d) old-growth forests in the Oregon Coast Range. Dashed lines represent the percentage of the landscape covered by each class in the present-day landscape.

the isolation index values for old-growth forest, which were mostly less than 1 (figure 12.6). The spatial isolation of old-growth patches has increased considerably in the present-day landscape, whereas the isolation of early-successional and young patches has decreased.

Discussion

Changes in the Disturbance Regime and Their Ecological Implications

One hundred and fifty yr of postsettlement land use in the Oregon Coast Range has brought about a wholesale change in the spatial pattern and dynamics of the forest landscape. Historically, the Coast Range was a shifting landscape mosaic dominated by large patches of old-growth forest. Smaller fragments of old-growth forest were also widely distributed in blocks of younger forest. In contrast, early-successional and young forests dominate the current landscape, with old-growth forest present only as small, fragmented patches. These changes have occurred because disturbance rates over the past 150 yr have been consistently higher than under the pre-European settlement disturbance regime. Increased burning in the late nineteenth and early twentieth centuries was at least partially the result of an increase in ignitions by settlers (Weisberg and Swanson 2003). Although fire suppression has greatly reduced the incidence of forest fires in the latter half of the twentieth century, disturbance from timber harvests in the modern landscape has occurred at a more rapid rate than did disturbance by fire in the pre-European settlement landscape. Clearcutting has typically removed the majority of trees from a site, in contrast to the variable numbers of remnant live trees left by the range

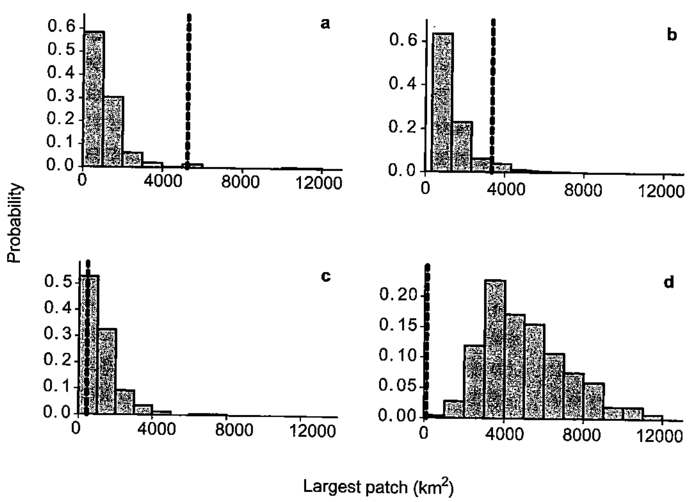

FIGURE 12.5. Simulated historical (pre-European settlement) ranges of variability for the largest patch of (a) early-successional, (b) young, (c) mature, and (d) old-growth forests in the Oregon Coast Range. Dashed lines represent the largest patch in the present-day landscape.

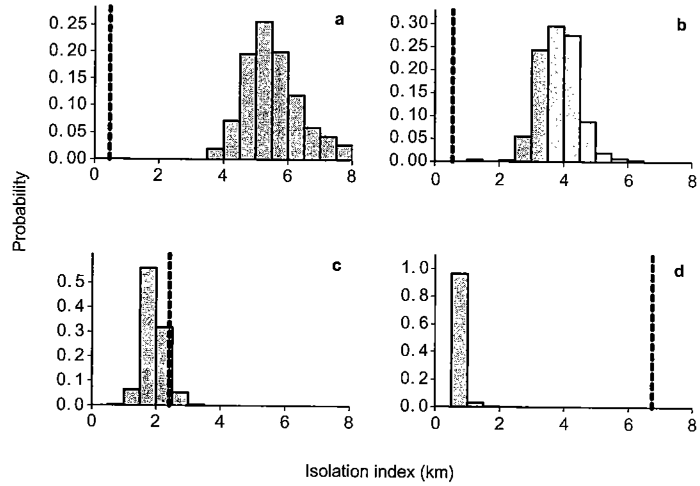

FIGURE 12.6. Simulated historical (pre-European settlement) ranges of variability for the isolation index of (a) early-successional, (b) young, (c) mature, and (d) old-growth forests in the Oregon Coast Range. Dashed lines represent the value of the isolation index in the present-day landscape.

of fire severities that characterized historical fire regimes. The small sizes and spatial dispersion of most harvested areas compared with the historical pattern of large fires have also altered the spatial pattern of the forest landscape.

These changes in landscape patterns have several ecological implications. Approximately one-third of all vertebrates and one-half of all amphibians inhabiting forests in western Oregon have been characterized as "closely associated" with old-growth habitats (Olson et al. 2001). Although many of these species are also found in younger forests, it is reasonable to hypothesize that the significant decline in their preferred habitat has affected their populations. Species that require large concentrations of mature or old-growth habitat, such as the northern spotted owl, may be particularly sensitive to the decreased size and dispersed pattern of patches of mature and old-growth forest (McComb et al. 2002). Although small patches historically represented only a minor portion of the total area of old-growth forest, they may still have facilitated the persistence of disturbance-sensitive, dispersal-limited species such as the lichen *Lobaria oregana* (Tuck.) Mull. Arg. This species can survive and reproduce in young forests, but is typically eliminated by stand-replacing disturbance and must recolonize regenerating stands through dispersal from undisturbed forest (Sillett et al. 2000). Loss of the numerous, scattered old-growth patches that were historically left by fires may greatly reduce the number of sources of propagules for reestablishing disturbance-sensitive, dispersal-limited species in young forests (Wimberly and Spies 2002).

Changes in the temporal and spatial patterns of stand-replacing disturbance may also affect broad-scale ecosystem processes, particularly the watershed-level dynamics of water, wood, and sediment. The large fires that occurred under the pre-European settlement disturbance regime often burned substantial areas within a watershed, reducing slope stability and initiating landslides and debris flows that delivered large pulses of wood and sediment to streams (Benda et al. 1998). In the short term, these disturbances likely destroyed habitat for Pacific salmon (*Oncorhynchus* spp.) and other native fish species. Over time, however, the wood and sediment inputs that occurred after fires provided raw materials for the development of diverse aquatic habitats. Long fire-return intervals provided time for fluvial processes to generate complex habitats that included pools, large pieces of in-stream wood, and a variety of different substrate types (Reeves et al. 1995). These fire-free periods also allowed forests on the surrounding slopes to reestablish themselves and develop into late-successional stands with large living and dead trees.

In contrast, the present-day disturbance regime is dominated by timber harvesting, which produces disturbances that are more frequent, smaller, and more widely dispersed than historical fires. Although individual timber harvests only affect small portions of a particular watershed, a larger number of disturbances occurs than takes place under the natural fire regime, and these disturbances are distributed more evenly in time and space than were historical fires. Consequently, wood and sediment inputs resulting from these disturbances have shifted from an episodic to a chronic process. Furthermore, the predominantly young forests produced by this disturbance regime have smaller trees and lower volumes of dead wood than the mature and old-growth forests that dominated the pre-European settlement landscape. These fundamental changes suggest that disturbance regimes driven by forest management activities aimed solely at maximizing timber production may not sustain the production of high-quality fish habitat (Reeves et al. 1995).

Prospects for Forest Management Based on Natural Disturbance Regimes

Current forest management practices in the Coast Range could be altered to better emulate the pre-European settlement disturbance regime. Timber harvests could be spatially clustered to generate large disturbed patches similar to those created by fire, while retaining contiguous blocks of uncut forest (Gustafson 1996; Cissel et al. 1999). However, changing only the spatial pattern of harvesting will not influence the distribution of forest age classes. Protecting old-growth and late-successional forests through long-term deferrals, reserves, and wilderness areas can limit further declines in the amount of older forests. In managed landscapes, longer rotation lengths could increase the proportion of older forests (Curtis 1997). Development of old-growth characteristics in young managed stands could be hastened through thinning, underplanting, or other silvicultural treatments (McComb et al. 1993; Tappeiner et al. 1997). It is also possible to retain some elements of old-growth structure in young stands by leaving residual trees, logs, and snags on the site after timber harvests in mature and old-growth stands, thereby emulating the effects of moderate-severity fires (Franklin et al. 1997).

Despite the many opportunities for modifying forest management practices, major ecological and social obstacles limit the potential for implementing management based on natural disturbance regimes in the Coast Range. The major ecological impediment is that our ability to manipulate landscape structures and composition in the near term is constrained by the past 150 yr of disturbance history. Fires and logging have already eliminated the majority of old-growth forests, and simply shifting the frequency and pattern of timber harvesting may do little to hasten the recovery of this forest type (Wallin et al. 1994; Baker 1995). Whereas old-growth forests can be rapidly converted into young forests through disturbance, the development of old-growth forests occurs over hundreds of years through the relatively slow processes of forest succession and stand dynamics. Thus, any attempt at landscape management based on natural disturbance regimes and historical landscape patterns must also consider the protection of existing old growth, as well as of mature forests that will develop into old growth over the next century.

The complex pattern of forest ownership is perhaps an even greater obstacle to implementing management based on natural disturbance regimes in the Coast Range. Forest management within each ownership type is influenced by a unique set of management goals and regulatory constraints, limiting the range of conditions that can be produced within a particular ownership class. For example, management on most private lands is driven by predominantly economic considerations, which prescribe clearcutting at fairly short rotations (40–60 yr) as the prevalent management practice. If present forest management regimes are extrapolated 100 yr into the future, private lands will continue to consist primarily of early-successional forest and young, closed-canopy forest (Spies et al. 2002).

In contrast, the U.S. Department of Agriculture Forest Service and the Bureau of Land Management operate under regulations imposed by the Northwest Forest Plan, which in the Coast Range allows only minimal timber harvests outside of late-successional and riparian reserves (Forest Ecosystem Management and Assessment Team 1993). If fire suppression policies continue to be effective, most federal lands will succeed to old-growth conditions. The Oregon State Department of Forestry intends to manage state forest lands in the northern Coast Range using a structure-based management approach, in which stands are harvested on 80- to 130-yr rotations, with active management to provide for large trees, snags, downed trees, and other old-growth structural components. Current plans call for eventually maintaining 20–30% of the land base in an older forest structure, which is intended to emulate the structural features and functional characteristics of old-growth forests (Oregon Department of Forestry 2001).

If Coast Range forests continue to be managed under existing policies, increasing the amounts of old-growth forest on public lands will move overall landscape patterns closer to the range of historical variability. However, the disparate disturbance regimes on federal and private lands may eventually leave few forests in the mature structure class. Harvest rotations on most private lands are too short to allow forests to reach the mature stage, and the continued exclusion of fire and timber harvesting on federal lands will allow most forests to pass through the mature stage and develop into old growth. Under current forest management policies, this divergence in the age structure of forests under public and private ownership is predicted to occur gradually over the next 100 yr (Spies et al. 2002). Some new mature forests will develop on state and private nonindustrial lands managed under long rotations, but the total area of mature forests will likely account for only a small portion of the Coast Range. If old growth is lost in the future as a result of fire, wind, or other natural disturbances, this gap in the forest age structure could limit the potential for rapid development of new old-growth habitats.

The spatial pattern of ownership also limits future possibilities for replicating large, historical fire events through timber harvesting. For example, the boundaries of the largest blocks of public land in the Coast Range correspond to those of large historical fires (see figure 12.1a, color plate 16b). The southern block of the Siuslaw National Forest includes a large area burned by the Siletz fire, and the northern block encompasses a significant portion of the Nestucca fire. The Tillamook State Forest includes the majority of land burned by the Tillamook fires, and the Elliot State Forest covers most of the area of the Coos Bay fire. Arbitrary human-imposed boundaries dominate in other areas, such as the checkerboard pattern of ownership in the southeastern portion of the Coast Range, where Bureau of Land Management lands and private lands are interspersed in 2.6-km^2 blocks. Also, many large blocks of private land actually have multiple landowners, each acting largely independently to manage their land.

Our present social, political, and regulatory systems do not provide a framework for management coordinated among multiple private landowners or between private and public ownerships. Therefore, the size of a particular ownership sets an upper boundary on the spatial scale of the forest management regime that can be applied therein. Because the largest ownership blocks in the Coast Range are artifacts of past fires, management strategies aimed at maintaining a range of forest structures in a single ownership block necessitate timber harvests that are considerably smaller than the largest historical burns. These management strategies may eventually produce novel landscape patterns that contain a habitat mosaic with finer resolution than was present under the pre-European settlement fire regime. The relative importance of habitat amount versus habitat pattern for species conservation is presently a subject of active scientific debate (Schmiegelow and Monkkonen 2002), and the implications of altering the spatial scale of the forest habitat mosaic are unclear.

Conclusions

The shift from a disturbance regime dominated by fire to one dominated by timber harvesting has had significant impacts on the pattern and dynamics of forest habitats in the Oregon Coast Range. Clearcuts are smaller and occur at shorter rotations than did historical fires. In addition, clearcutting removes a larger proportion of both live and dead trees from the site than do many wildfires. Whereas pre-European settlement fire regimes varied primarily along a climatic gradient, forest management policies vary among landowners. In turn, the pattern of land ownership reflects a legacy of past wildfires as well as the social, economic, and political history of the region. The present-day forest landscape has smaller areas of mature and old-growth forests than would be expected under the pre-European settlement disturbance regime. Whereas large (>100,000-ha) patches of old-growth forest were common in pre-European settlement landscapes, old growth is currently distributed in small (<650-ha) fragments that are isolated from other habitat types.

Any future forest management policy based on emulating natural disturbance in the Coast Range will necessarily represent a compromise between our scientific understanding of disturbance and its ecological effects, and the economic, social, and political realities of the region. Given the history of human land use and the constraints imposed by current ownership patterns, attempting to closely replicate the temporal and spatial patterns of natural disturbance may be an unrealistic goal, and could actually move landscape patterns further from the range of historical variability if the remaining old-growth forests are disturbed. Instead, a more tenable short-term goal might be to maintain key elements of historical landscape processes and structures at multiple scales. Examples of this approach include maintaining a few large patches of old-growth forest at the regional scale, numerous small patches of old growth at a landscape scale, and individual old-growth structures (e.g., large trees, snags, and downed trees) at a stand scale. Given the wide range of landowner goals and regulatory constraints, these broad-scale goals would have to be achieved through a mixture of strategies, including a combination of active management and reserve-based approaches.

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