2587

Past, Present, and Future Landscape Patterns in the Douglas-fir Region of the Pacific Northwest

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Landscape patterns in the Douglas-fir region of the western Pacific Northwest (PNW) have been strongly influenced by both natural and anthropogenic disturbances. Historically, landscape patterns were driven primarily by wildfire, which varied in frequency and intensity along regional moisture gradients and in response to variable climatic trends. At the time of settlement, however, old-growth forests covered about half of the forest land base. Over the past 150 years, settlement activities and timber harvesting have resulted in extensive fragmentation of the pre-settlement old-growth forest matrix, producing more regular patterns with more predictable trajectories. Fifty years of dispersed clearcutting have created a checkerboard-like pattern of young and older forest patches throughout federally-managed lands. Use of short-rotation, large aggregated clearcuts has produced large patches of young seral forests on non-federal timber lands.

Future landscape pattern will be driven by recent changes in forest-management policies. The ecosystem-management based approach adopted for federally-managed lands uses a series of land allocations to achieve biodiversity and commodity production objectives. Forest-management guidelines for state and private industrial lands impose structural retention requirements for aquatic and upslope areas. Based on a qualitative assessment of future large-scale patterns under these plans, it becomes apparent that late-successional forests largely will be restricted to large blocks of federal reserves distributed throughout the region and along aquatic systems on all federally-managed lands. Also apparent is that large-scale connectivity (both physical and functional) of these reserves will be highly dependent on site-specific management prescriptions on intervening land allocations and ownerships. Understanding how to manage these intervening lands to enhance connectivity of late-successional forests within and among landscapes is an important management and research question.

Key words: forest fragmentation, forest management, ecosystem management, landscape pattern, natural disturbance, Pacific Northwest

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1. INTRODUCTION

Landscape patterns in the Douglas-fir region of the western Pacific Northwest (PNW) have been strongly influenced by both natural and anthropogenic disturbances. Prior to Euro-American settlement, landscape patterns were driven by wildfire and other natural disturbances, which in turn were influenced by a variable climatic regime. Forest patterns created by historical disturbances changed slowly with settlement in the mid 1800's, then more rapidly as timber harvesting became widespread. A significant consequence of land-use activities over the past 150 years has been the gradual fragmentation of the old-growth forest matrix. Today, only 50-60% of the pre-settlement old-growth Douglas-fir (*Pseudotsuga menziesii*) forests remain (Bolsinger and Waddell, 1993), and connectivity of these forests is greatly reduced by extensive areas of managed plantations.

Future landscape patterns will be guided by the recent Pacific Northwest Forest Management Plan (NWFP) (FEMAT, 1993) for federal ownerships, and state forest practices regulations (Oregon Department of Forestry, 1997; Washington State Department of Natural Resources, 1997) for state and private industrial timber lands. Although goals and objectives differ between federal and state forest policies, both impose guidelines for stand or landscape structure to better balance ecological diversity and commodity production. Under these plans, large-scale trends in landscape pattern will depend on a variety of factors. These include current conditions, the management strategies of adjacent ownerships, and the dispersion of ownerships. Viewing future conditions in the context of these factors is important to understand the potential benefits and limitations of current policies to reduce fragmentation of older forests throughout the region.

The purpose of this chapter is to provide a synopsis of historical and future landscape pattern dynamics in the western PNW region. Specifically, we review the influence of natural disturbance, primarily wildfire, and historical timber harvesting on forest-pattern development, and provide case studies of contemporary landscape conditions for western Oregon. We also provide a qualitative prognosis of future landscape conditions under current federal and state forest-management policies.

2. THE REGION AND FOREST COMMUNITIES

The Douglas-fir region of the PNW comprises 14.1 million hectares west of the crest of the Oregon and Washington Cascade mountains to the Pacific Ocean (Figure 1). About 38% of the total land base is administered by federal agencies (26% USDA Forest Service, 7% USDI Bureau of Land Management, >5% National Park and other agencies). Seventy-seven percent of this region is designated as forest land with 66% classified as commercial timber land. Of the designated timber lands, 48% is in public ownership (38% USDA Forest Service and USDI Bureau of Land Management, remainder state and county) and 32% is classified as private industrial forest lands.

Nine forest zones are recognized in this region (Franklin and Dyrness, 1988). Of these, the western hemlock zone is the most extensive and includes the majority of the Douglas-fir forests. At the time of Euro-American settlement, an estimated 60-70% of the forested land base was covered by old-growth Douglas-fir (Franklin and Spies, 1984; Booth, 1991). General characteristics of these forests include large (>100-cm dbh) overstory stems; multiple sub-canopy layers comprised of shade-tolerant species such as western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*); and large snags and large amounts of downed logs (Franklin and Spies, 1991). These and additional features provide unique habitat conditions for a range of plant and animal species relative to other seral stages and forest communities. Other dominant forest zones in the region include Sitka spruce (*Picea sitchensis*), which occurs along a narrow (<16 km) coastal zone, and Pacific silver fir (*Abies amabilis*) and mountain hemlock (*Tsuga mertensiana*) which occupy high elevation sites. Oregon white oak (*Quercus garryana*) savannahs occur in the valley fringes and bottoms, and were more extensive prior to urban and agricultural development and wildfire suppression. Red alder (*Alnus rubra*) and big-leaf maple (*Acer macrophyllum*) are the most common and wide-

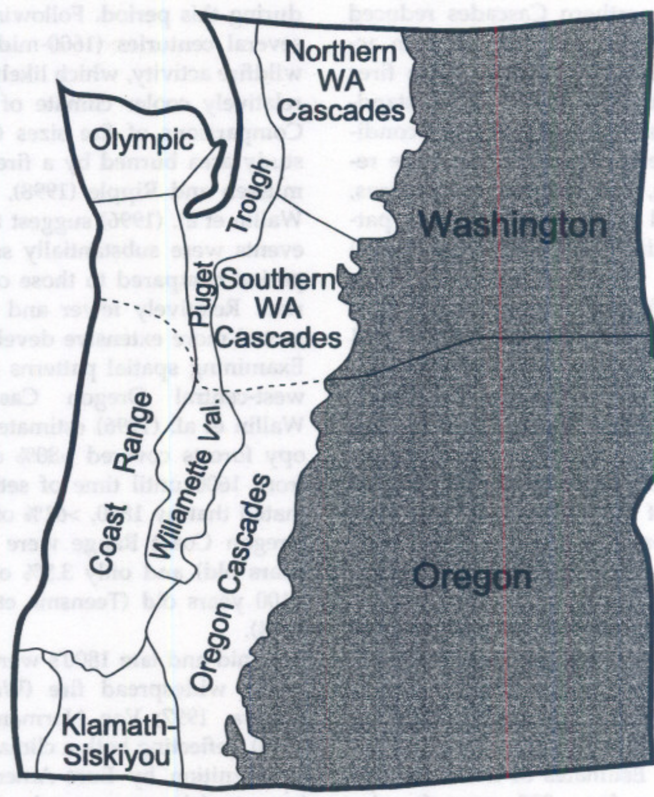

Figure 1. Provinces of the Douglas-fir region in the Pacific Northwest.

spread hardwood species, but thrive at lower elevations in riparian areas and on highly disturbed sites.

3. NATURAL LANDSCAPE PATTERNS

Wildfire has been the primary natural disturbance process in the region (Agee, 1990), although windthrow (Ruth and Yoder, 1953), insect- and disease-induced mortality (Rudinsky, 1962; Powers, 1995), and other disturbances were significant in specific subregions. Prior to Euro-American settlement, lightning was the primary ignition source (Agee, 1993), which increased with distance from the ocean and with increasing elevation (Morris, 1934). Native Americans had a profound, rather well-documented role in the burning of the Willamette Valley (Agee, 1993; Zyback, 1993), and along waterways in the Oregon Coast Range (Sauter and Johnson, 1974). Their use of upper elevation, mountainous terrain and of valley floor interiors is indicated by widespread artifacts (e.g., obsidian flakes and points); however, there is little evidence that they had a wide-spread influence on the fire regime of these areas (Agee, 1990).

Understanding pre-historic wildfire patterns and landscape conditions is problematic due to the spatial limitations of lake-sediment paleoecological studies and erasure of tree-ring records by more recent disturbances. However, fire-history reconstruction studies covering the last 500 yrs suggest broad geographic patterns in frequency, severity, and patch size decreasing severity of fire from the mesic..... (Agee, 1993; Heyerdahl et al., 1995). The general pattern from the 1450-1850 AD period appears to be one of increasing frequency and decreasing severity from the mesic northern Cascades to the drier southern portions of the range. Wetter conditions of the northern Cascades reduced the occurrence of fires, which resulted in accumulation of high fuel loadings. When fires did occur, they tended to be large stand-replacement events. Warmer and drier conditions in the southern portion of the range resulted in frequent, low severity underburns, which created and maintained fine-scale patterns (i.e., small, dispersed canopy openings) (Agee, 1998).

A latitudinal difference in fire regimes is also evident. Work by Impara (1997) and Weisberg (1998) in central western Oregon (latitude of Eugene, OR) indicate an interior Coast Range fire regime characterized by infrequent but high severity, large stand-replacement events. Fires in the moderate-severity regime of the west-central Oregon Cascades were more frequent but less severe. Fires in this regime are characterized as producing a complex mosaic of patches experiencing different severities due to the range of weather conditions during burning, and variable topographic and fuel conditions (Agee, 1998). Low severity but relatively frequent fires occurred along the east and west fringe of the Willamette Valley. Estimates of mean fire return intervals range from 230 years for the entire Coastal region (Fahnestock and Agee, 1983) to 237-242 years for the Oregon Coast Range (Ripple 1994). Teensma et al. (1991) estimated 150-300 years between stand-replacement fires in the Oregon Coast Range. Based on charcoal distribution within sediments of a Coastal Oregon lake, Long (1995) estimated a local fire-return interval of 175 years. Estimates of mean fire return intervals for the west-central Oregon Cascades range from 95 to 145 years (Morrison and Swanson, 1990; Teensma, 1987; Means, 1982; Weisberg, 1998); Weisberg (1998) estimated a return interval of 197 years for just stand-replacement events.

General temporal trends in landscape patterns over the past 500 years also are evident from fire-history reconstruction studies. The period 400-500 years before present was one of extensive, high severity fires which initiated many of today's old-growth stands. Studies in the west-central Oregon Cascades (Wallin et al., 1996) and the Oregon Coast Range (Impara, 1997) suggest that few but large fires occurred during this period. Following this period was several centuries (1600-mid 1800's) with low wildfire activity, which likely resulted from the relatively cooler climate of the little ice age. Comparisons of fire sizes (i.e., proportion of study area burned by a fire) reported in Rasmussen and Ripple (1998), Garza (1995), and Wallin et al. (1996) suggest that individual fire events were substantially smaller during this period compared to those of the previous period. Relatively fewer and smaller fires promoted more extensive development of forests. Examining spatial patterns of wildfire in two west-central Oregon Cascade landscapes, Wallin et al. (1996) estimated that closed canopy forests covered >80% of his study areas from 1600 until time of settlement. It is estimated that by 1840, >61% of the forests in the Oregon Coast Range were old-growth (>200 years old) and only 3.5% of the forests were <100 years old (Teensma et al., 1991; Ripple, 1994).

The mid and late 1800's were characterized by rather widespread fire (Wallin et al., 1996; Impara, 1997; Van Norman, 1998; Weisberg, 1998), reflecting both a climatic warming trend and ignition by Euro-American settlers. The impact of human-caused wildfires was fairly extensive. Fires linked to settlers burned over 34% of the Oregon Coast Range in the mid 1800's (Teensma et al., 1991). Morris (1934) estimated that in western Oregon seven times as much land was deforested by human-caused fires in the mid 1800's than by natural wildfire in the three previous decades. The past century has been one of relatively little wildfire due to increasingly effective fire suppression efforts (Agee, 1990).

4. FOREST MANAGEMENT AND LANDSCAPE PATTERNS

4.1 Historical Trends

Timber harvesting has been an important regional industry since the mid to late 1800's. By 1900, log production was estimated to be ca. 1.5 and 0.4 billion (i.e., 10^9) board feet in Washington and Oregon, respectively (Wall, 1972). A growing population and increasing demand for wood products resulted in an almost linear

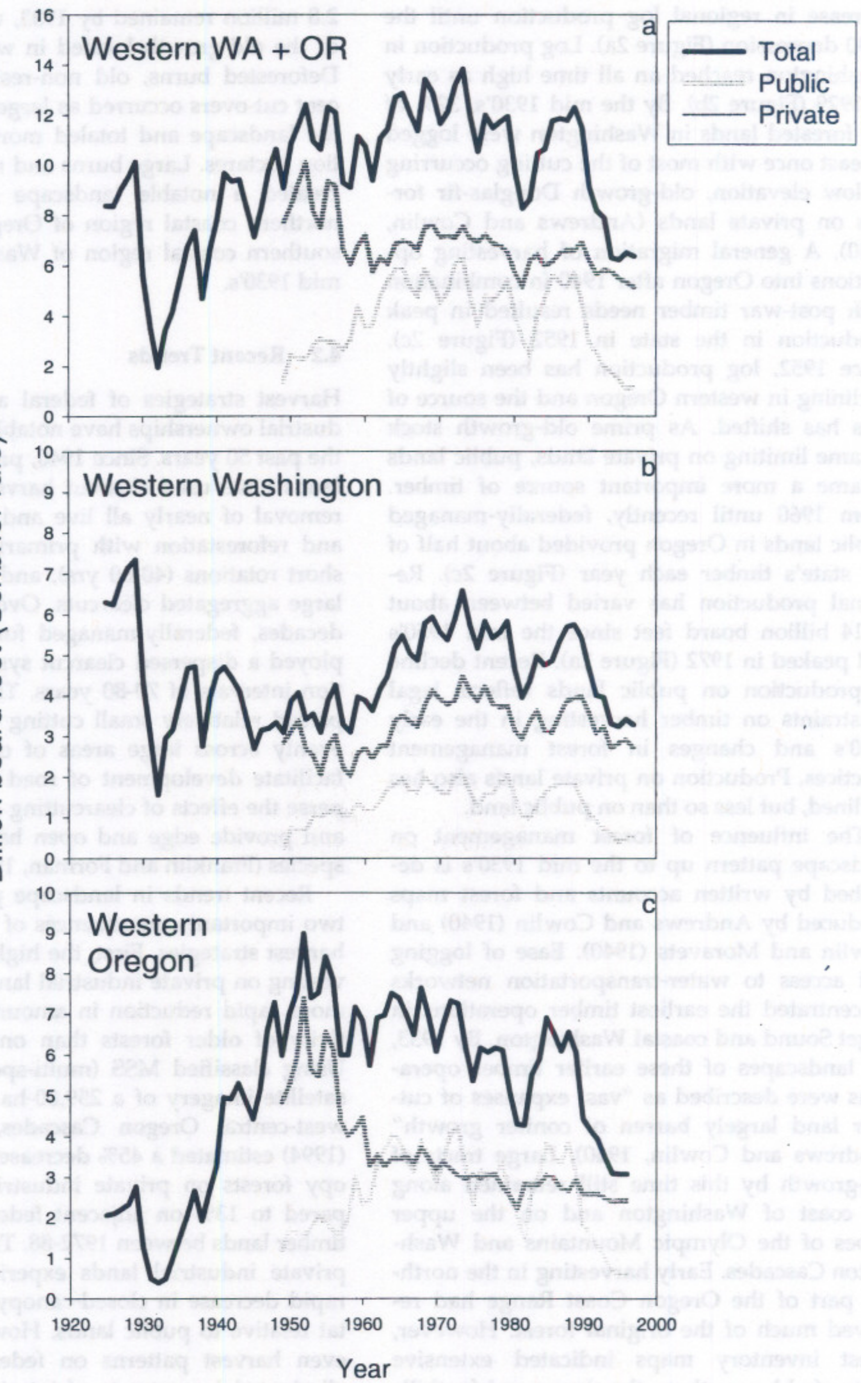

Figure 2. Historical trends in log production in western Washington and western Oregon by general ownership categories. Data from Wall (1972), Gedney et al. (1986a,b; 1987), MacLean et al. (1992), Bourhill (1994), and Larsen (1997). Ownership data only shown for 1948-96.

increase in regional log production until the 1930 depression (Figure 2a). Log production in Washington reached an all time high as early as 1929 (Figure 2b). By the mid 1930's, 32% of the forested lands in Washington were logged at least once with most of the cutting occurring in low elevation, old-growth Douglas-fir forests on private lands (Andrews and Cowlin, 1940). A general migration of harvesting operations into Oregon after 1940 in combination with post-war timber needs resulted in peak production in the state in 1952 (Figure 2c). Since 1952, log production has been slightly declining in western Oregon and the source of logs has shifted. As prime old-growth stock became limiting on private lands, public lands became a more important source of timber. From 1960 until recently, federally-managed public lands in Oregon provided about half of the state's timber each year (Figure 2c). Regional production has varied between about 11-14 billion board feet since the mid 1950's and peaked in 1972 (Figure 2a). Recent decline in production on public lands reflects legal constraints on timber harvesting in the early 1990's and changes in forest management practices. Production on private lands also has declined, but less so than on public land.

The influence of forest management on landscape pattern up to the mid 1930's is described by written accounts and forest maps produced by Andrews and Cowlin (1940) and Cowlin and Moravets (1940). Ease of logging and access to water-transportation networks concentrated the earliest timber operations in Puget Sound and coastal Washington. By 1933, the landscapes of these earlier timber operations were described as "vast expanses of cut-over land largely barren of conifer growth" (Andrews and Cowlin, 1940). Large tracts of old-growth by this time still remained along the coast of Washington and on the upper slopes of the Olympic Mountains and Washington Cascades. Early harvesting in the northern part of the Oregon Coast Range had removed much of the original forest. However, forest inventory maps indicated extensive tracts of old-growth on the slopes and foothills of the Oregon Cascade Range, and in the southwest region of the Oregon Coast Range. Of the estimated 5.7 million ha of Douglas-fir old-growth in the region prior to logging, only 2.8 million remained by 1933, with about 75% of the old-growth located in western Oregon. Deforested burns, old non-restocked and recent cut-overs occurred as large patches across the landscape and totaled more than 1.7 million hectares. Large burns and recent cut-overs created a notable landscape mosaic in the northern coastal region of Oregon and in the southern coastal region of Washington in the mid 1930's.

4.2 Recent Trends

Harvest strategies of federal and private industrial ownerships have notably differed over the past 50 years. Since 1940, private industrial lands have used clearcut harvesting with the removal of nearly all live and dead material and reforestation with primarily Douglas-fir, short rotations (40-60 yrs), and until recently, large aggregated clearcuts. Over the past five decades, federally-managed forests have employed a dispersed clearcut system with rotation intervals of 70-80 years. This system dispersed relatively small cutting units (5-25 ha) evenly across large areas of older forests to facilitate development of road networks, disperse the effects of clearcutting on watersheds, and provide edge and open habitat for game species (Franklin and Forman, 1987).

Recent trends in landscape patterns reflect two important consequences of these different harvest strategies. First, the higher rate of harvesting on private industrial lands promoted a more rapid reduction in amount and connectivity of older forests than on public lands. Using classified MSS (multi-spectral scanner) satellite imagery of a 259,00-ha section of the west-central Oregon Cascades, Spies et al. (1994) estimated a 45% decrease in closed canopy forests on private industrial lands compared to 13% on adjacent federally-managed timber lands between 1972-88. They also found private industrial lands experienced a more rapid decrease in closed-canopy interior habitat relative to public lands. However by 1988, even harvest patterns on federal lands had eliminated large tracts of interior forests outside of special land allocations (i.e., wilderness areas, experimental forest and natural areas, river corridors).

Second, although rates of fragmentation of older forests have been lower on federally-managed lands, the dispersed cutting scheme produced a template for accelerated fragmentation of the old-growth matrix. By the mid 1980's, 40 years of dispersing small patch cuts across the landscape was beginning to create a checkerboard pattern of old-growth and younger forests. The potential for continued dispersed cutting to accentuate fragmentation of late-successional forests was suggested by Franklin and Forman (1987). Simulation studies have demonstrated the dispersed cutting system to substantially decrease extent and patch size of interior forests compared to an aggregated, long-rotation strategy (Li et al., 1993; Wallin et al., 1994), and compared to natural disturbance patterns (Wallin et al., 1994). Using subsamples of classified MSS satellite imagery, Spies et al. (1994) empirically demonstrated the effects of the dispersed scheme by comparisons of closed-canopy forest patterns between public and private ownerships. For comparable proportions of area cut, the dispersed cutting patterns on public lands resulted in ca. 10-30% less closed-canopy interior and twice as much edge habitat (closed - open-canopy forest interface) than the aggregated cutting scheme used on private industrial lands. At the landscape level, however, private lands had much less interior forest and more edge than public lands because of the historical high rate of cutting on private lands.

4.3 Contemporary Patterns

Assessments of landscape conditions using satellite imagery offer a comprehensive picture of contemporary forest patterns. Results of ongoing assessments for the Oregon Cascade and Coastal Provinces using 1988 Thematic Mapper (TM) satellite imagery are summarized here to illustrate important ownership and geographic differences.

4.3.1 Oregon Cascade Range

To illustrate landscape patterns of the Cascade Range, we used a 0.5-million ha section of the land-cover map produced by Cohen et al. (1995) (Figure 3). In this sample, differences in land-use practices among ownerships are clearly evident. Extensive timber harvesting on private industrial (PI) and land-clearing on private nonindustrial (PNI) ownerships have resulted in large, extensive patches of regeneration forest (semi-closed, closed mixed, and young conifer forests combined) (Figures 3,4). Mature and old conifer forest, combined, accounted for <23% of the land base of either ownership (Figure 4). Forest Service (USFS) lands had more mature and old conifer forest compared to PI lands, reflecting differences in harvesting histories (Figure 4). Bureau of Land Management (BLM) lands had a higher proportion of regeneration forest and lower proportions of mature and old conifer compared to USFS lands, but higher or similar proportions compared to the PI ownership (Figure 4).

Distributions of forest patch sizes further illustrate differences in landscape conditions among ownerships. About 89% of regeneration forest occurred in patches >1000 ha on PNI and PI ownerships (Figure 5a), and these large patches comprised >67% of the land base of an ownership (Figure 5b). In contrast, 60% of regeneration forest on USFS lands occurred in patches >1000 ha (Figure 5a), but only comprised 23% of this ownership (Figure 5b). The relatively small size of the BLM parcels restricted maximum patch sizes. Most of the regeneration forest in this ownership occurred in patches 10-1,000 ha in size (Figure 5a), although these patches encompassed about 55% of the BLM land base (Figure 5b). Connectivity of old conifer was highest on USFS lands. Large (>1000 ha) patches of old conifer comprised 30% of the USFS land base (Figure 5e,f). BLM lands had noticeably smaller patches of old conifer compared to USFS lands. Most (>77%) of the old conifer on private lands occurred in small (<100 ha) patches (Figure 5e), and comprised only about 10% of the land base of an ownership (Figure 5f). Mature conifer forest was limited across all ownerships and only occurred in patches >100 ha on USFS lands (Figure 5d).

The extent to which these patterns are representative of other portions of the Cascade Range varies with geographic location. Federal ownership dominates this province (e.g., Figure 6). Wilderness areas and National Parks, which generally occupy the higher elevations, contain more contiguous tracts of older forest and extensive amounts of nonforest (i.e., alpine

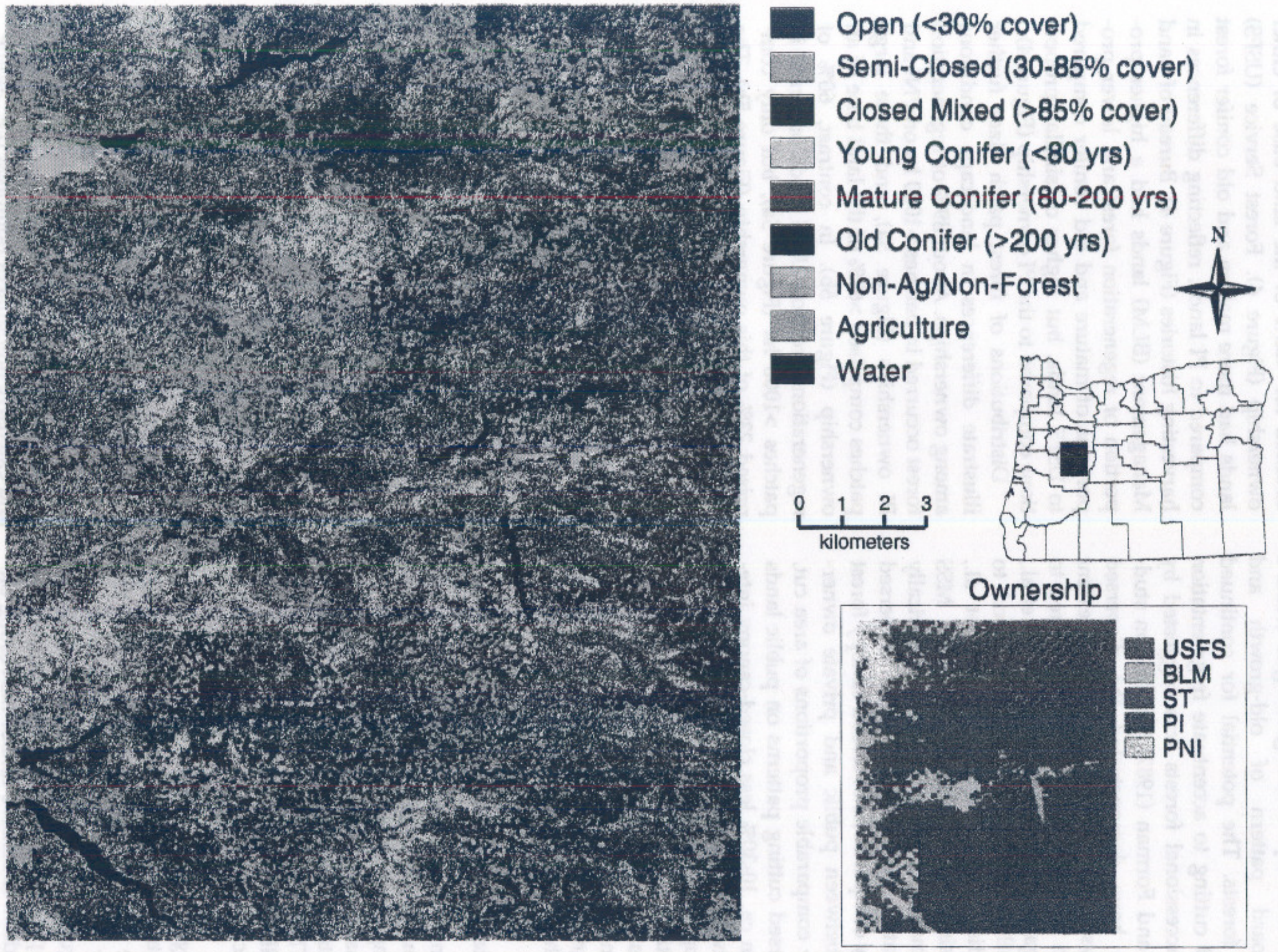

Figure 3. Land-cover map for a section of the west-central Oregon Cascades, based on classified Thematic Mapper satellite imagery (Cohen et al., 1995). Open, semi-closed, and closed-mixed types have <86% canopy cover of conifer species. PNI - private nonindustrial forests; PI - private industrial forests; STATE - all State lands; BLM - USDI Bureau of Land Management; USFS - USDA Forest Service.

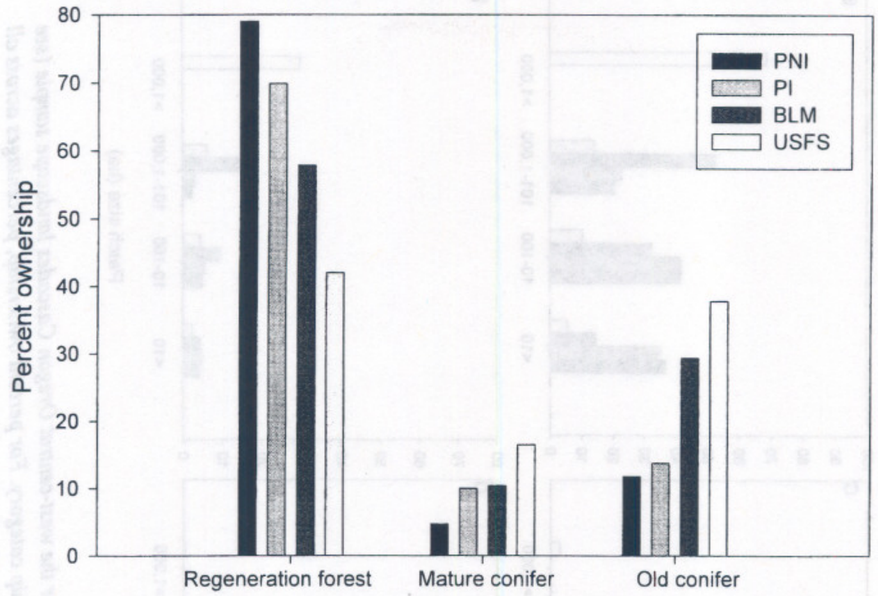

Figure 4. Distribution of forest types by ownership category for a 0.5 million-ha sample of the west-central Oregon Cascade landscape (see Figure 3). State lands not included due to small sample size. Regeneration forest - semi-closed, closed-mixed, and young conifer combined.

meadows, boulder fields, snow capped mountain peaks). Outside of these areas, however, managed federal and private industrial landscapes are qualitatively similar to our sample. Studies to further quantify landscape conditions across this province are in progress (Cohen, pers. comm.)

4.3.2 *Oregon Coast Range*

Assessment of the ecological effects of the ownership mosaic of the Oregon Coast Range is an ongoing effort of the Coastal Landscape Analysis and Modeling Study (CLAMS) (Spies et al., in prep.). Covering 5-million ha, the CLAMS study area extends from the Pacific Ocean to the Willamette Valley fringe (see gray area on locator map, Figure 7). The ownership mosaic of this region has substantially influenced overall landscape pattern and has significant implications for future patterns. Ownership is dominated by private lands (24% PNI, 38% PI), with federal lands comprising 25% (11% USFS, 14% BLM) and Oregon State lands comprising 12% of the land base. Simply based on the geometry of ownership parcels, Forest Service and State lands can support the largest contiguous patches of forests; the checkerboard pattern of BLM lands and intervening PI lands limits potential patch sizes on these ownerships (e.g., see Figure 6).

Similar to the Oregon Cascade example, landscape patterns of federal and private ownerships in the Oregon Coast Range can be quite distinctive. The sample of the Coast Range land-cover map in Figure 7 illustrates pattern differences among ownerships. In this sample, PI lands are dominated by younger forest (i.e., semi-closed, small/medium classes) and USFS lands by older forests (i.e., large, very large). Also apparent in this sample is the staggered clearcutting on federal lands (e.g., lower left, Figure 7).

Assessments of riparian ($\leq$ 100 m from water) and upslope (>100 m from water) forest patterns have illustrated differences in historical land-use strategies. Riparian zones across all ownerships were dominated by the early-successional class (open, semi-closed, broadleaf classes combined), with the large class (comprised of mostly conifer species) the second most dominant (Figure 8a). The high proportion of the early-successional class on PNI

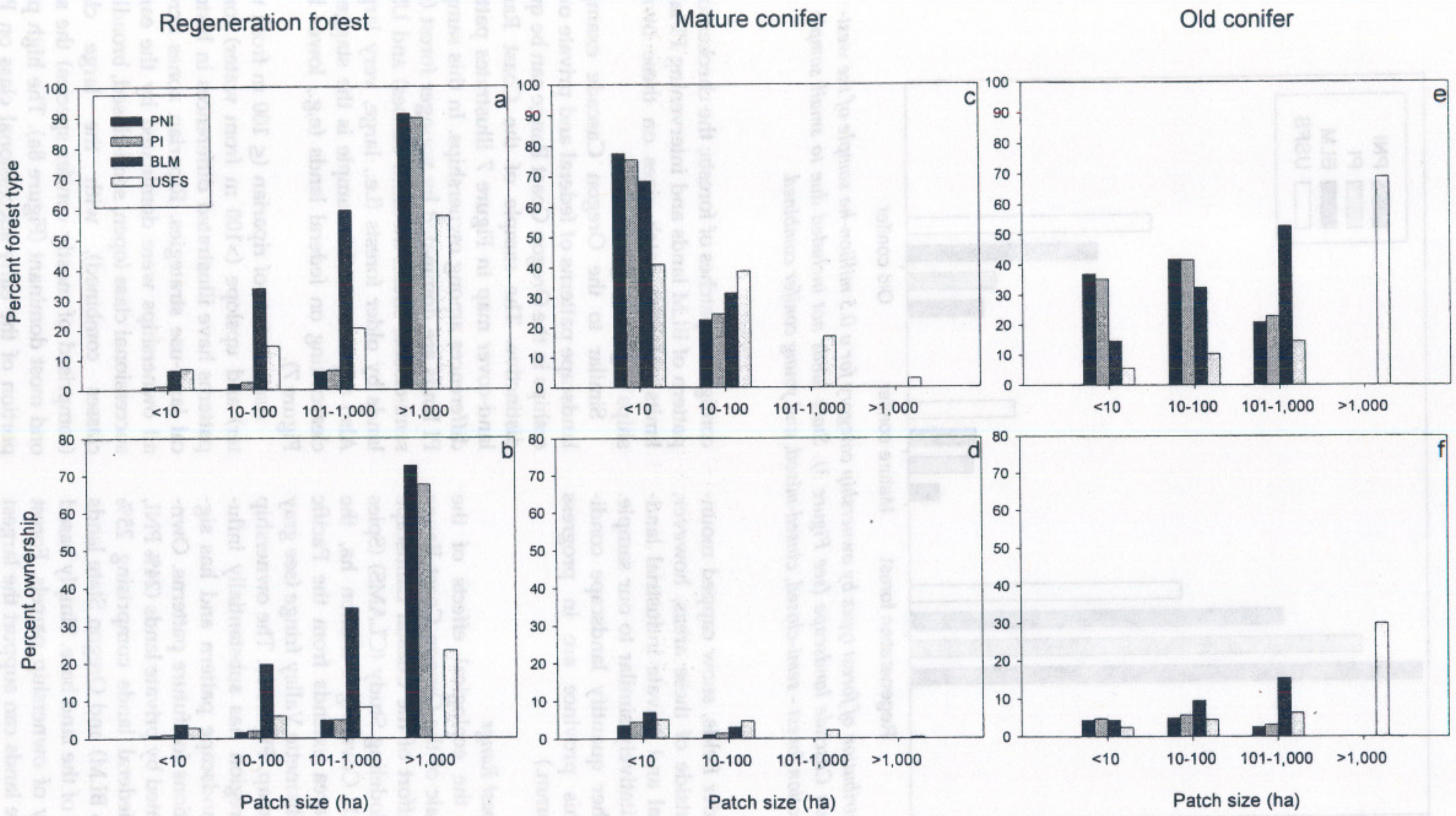

Figure 5. Frequency distribution of forest types by patch size and ownership category for the west-central Oregon Cascades landscape sample (see Figure 3). For percent forest type, percentages of a forest type sum to 100 for an ownership category. For percent ownership, percentages across all three forest types sum to 100 for an ownership. Regeneration forest - semi-closed, closed-mixed, and young conifer classes combined (classes defined in Figure 3).

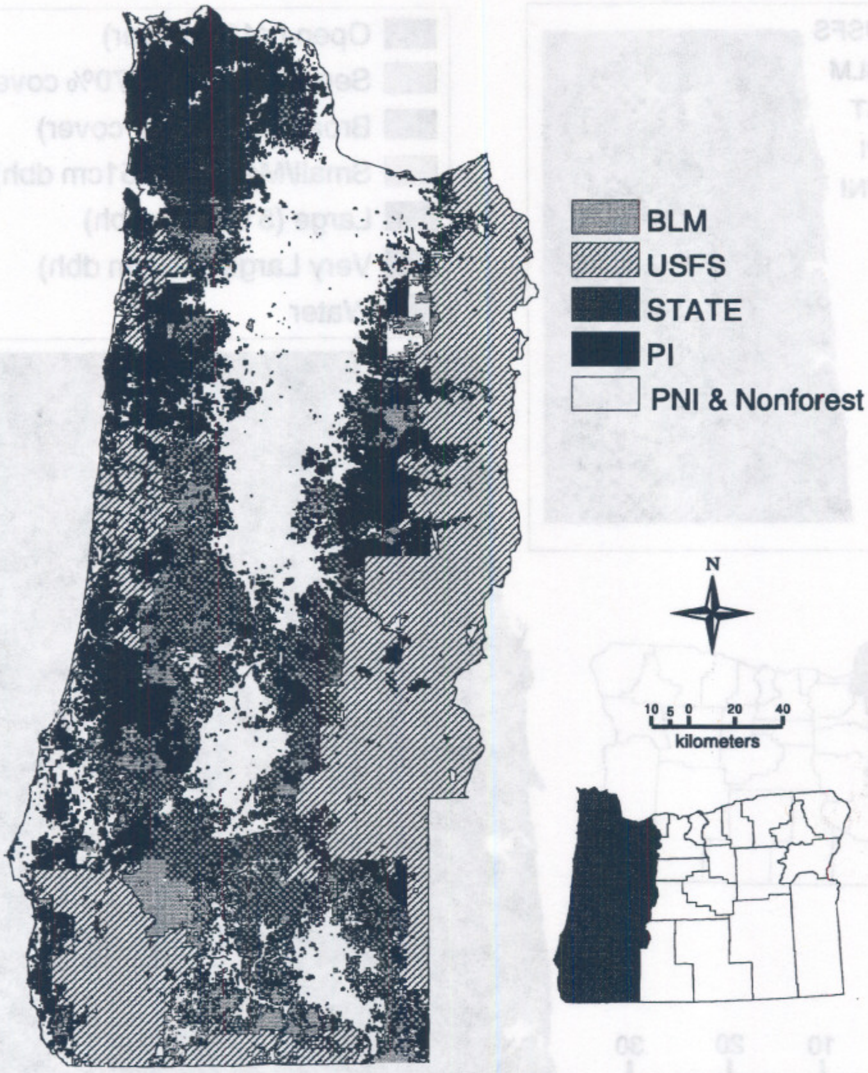

Figure 6. Ownership patterns in western Oregon. Ownership codes are defined in Figure 3.

lands reflected the extent of land-clearing and agriculture. Greater protection of aquatic systems on public lands, however, has resulted in lower proportions of this class than on PI lands. Riparian areas on federally-managed lands were comprised of almost equal proportions of the large and early-successional classes. Similar to riparian areas, upslope areas on private lands were dominated by the early-successional class (Figure 8b). However, large or medium classes were slightly more prominent than the early-successional class on federal and state lands. BLM lands had the highest proportion of old-growht in both riparian and upslope areas, followed by USFS lands. Even adjusting for differences in land and area, BLM lands supported the highest amount of old-growth of all ownerships in 1988.

Pattern differences among ownerships were also evident. For the PNI ownership, land clearing, agriculture, and natural regrowth of disturbed sites have resulted in the predomi-

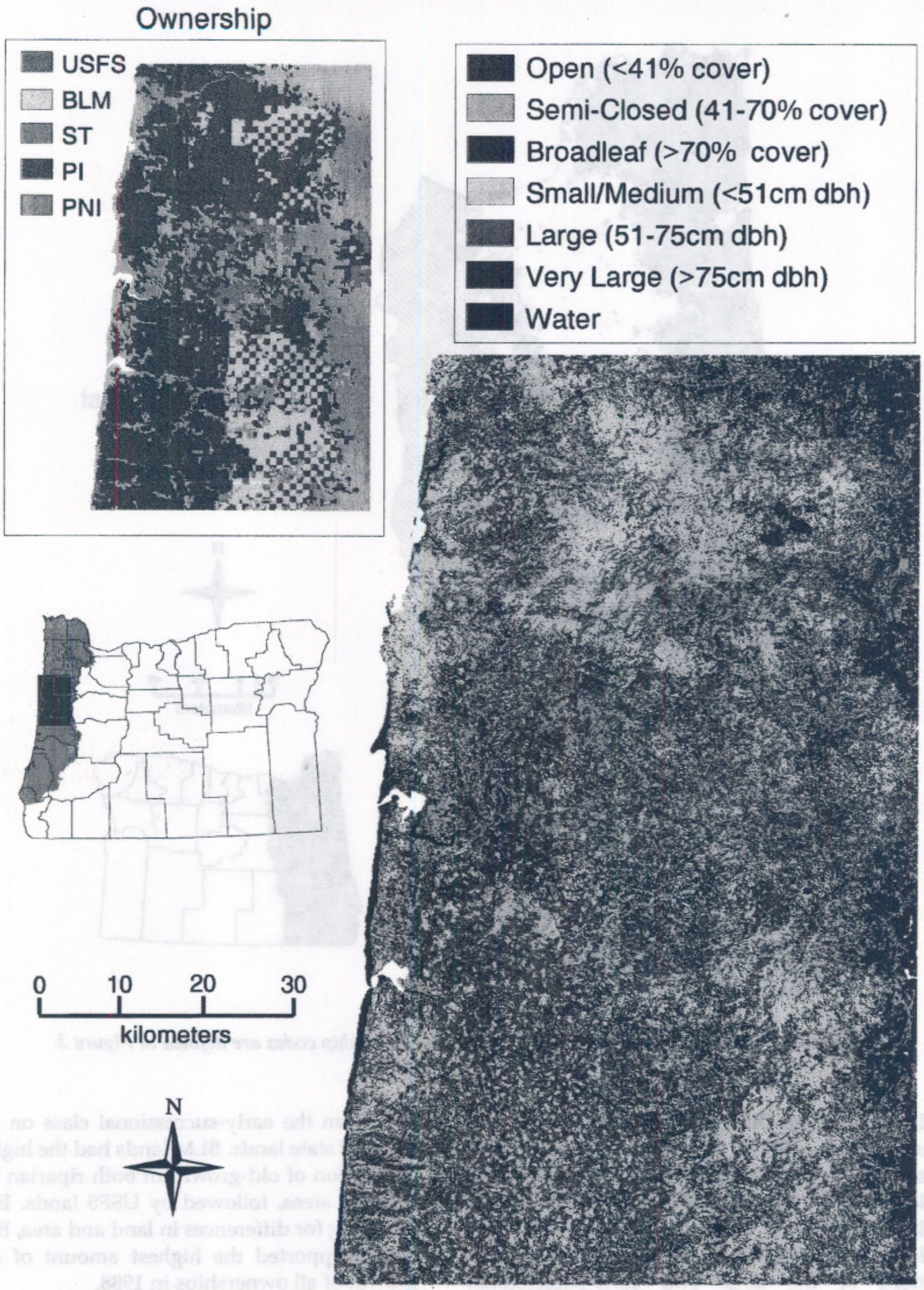

Figure 7. Land-cover map for a section of the Oregon Coast Range, based on classified Thematic Mapper satellite imagery (Spies et al., in prep.). Forest types are defined in Figure 8. Ownership codes are defined in Figure 3 (ST - STATE).

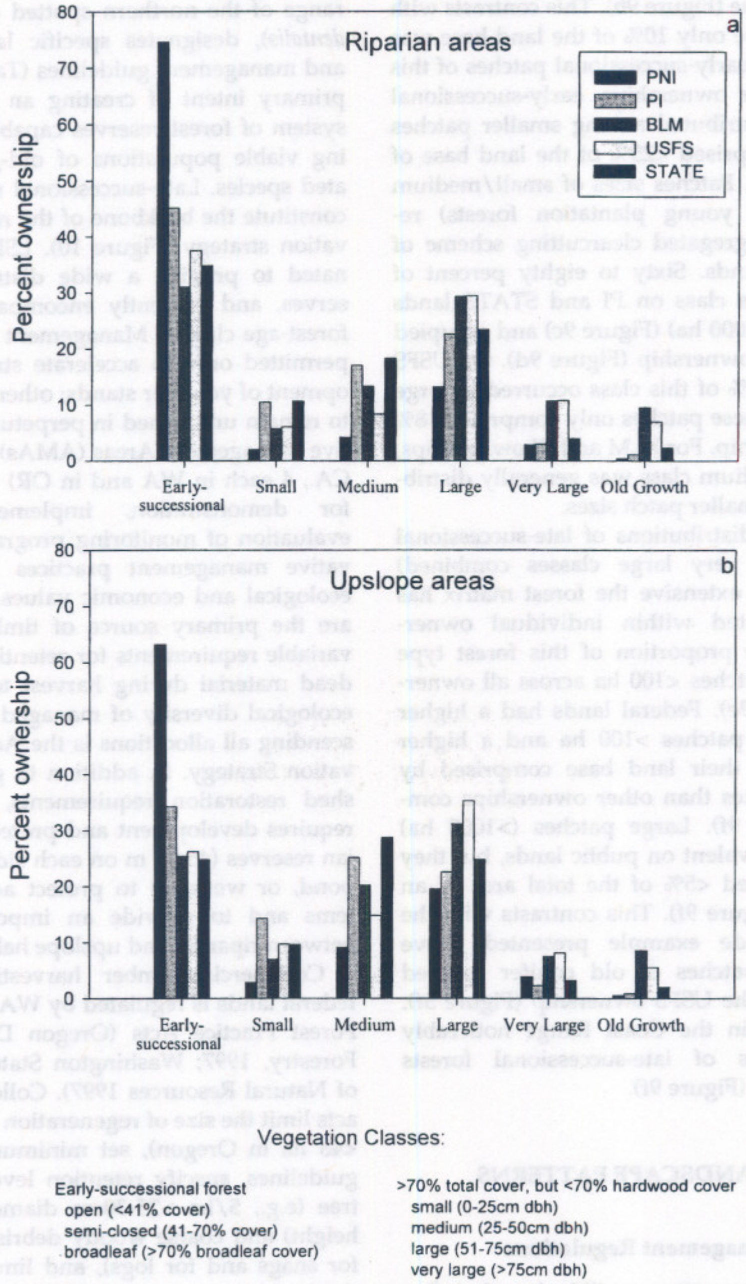

Figure 8. Distribution of vegetation classes by ownership category for the Oregon Coastal Landscape Analysis and Modeling Study (CLAMS) study area. Cover classes derived from Thematic Mapper satellite imagery. Small, medium, large, and very large classes are based on average of overstory trees using the diameter model of Cohen et al. (1995). Old Growth based on a canopy mosaic algorithm (Spies et al., in prep.). Ownership codes are defined in Figure 3.

nance of large patches (>1000 ha) of early-successional forest (Figure 9a) over almost half of the land base (Figure 9b). This contrasts with PI lands where only 10% of the land base was comprised of early-successional patches of this size. On other ownerships, early-successional forest was distributed among smaller patches and only comprised <25% of the land base of an ownership. Patches sizes of small/medium class (mostly young plantation forests) reflected the aggregated clearcutting scheme of non-federal lands. Sixty to eighty percent of patches of this class on PI and STATE lands were large (>1000 ha) (Figure 9c) and occupied 30-40% of an ownership (Figure 9d). On USFS lands, only 45% of this class occurred in large patches and these patches only comprised 18% of this ownership. For BLM and PI ownerships, the small/medium class was generally distributed among smaller patch sizes.

Patch-size distributions of late-successional forest (large, very large classes combined) illustrate how extensive the forest matrix has been fragmented within individual ownerships. A large proportion of this forest type occurred in patches <100 ha across all ownerships (Figure 9e). Federal lands had a higher proportion of patches >100 ha and a higher proportion of their land base comprised by these patch sizes than other ownerships combined (Figure 9f). Large patches (>1000 ha) were most prevalent on public lands, but they only represented <5% of the total area of an ownership (Figure 9f). This contrasts with the Oregon Cascade example presented above where large patches of old conifer covered about 30% of the USFS ownership (Figure 5f). Private lands in the Coast Range noticeably lacked patches of late-successional forests >100 ha in size (Figure 9f).

5. FUTURE LANDSCAPE PATTERNS

5.1 Forest Management Regulations

Future landscape patterns will be largely influenced by current federal and state forest-management guidelines. Recent concerns for sustaining biological diversity and late-successional ecosystems have led to significant changes in forest policy for federal lands. The Northwest Forest Plan (NWFP) (FEMAT, 1993), which applies to all federal lands within the range of the northern spotted owl (*Strix occidentalis*), designates specific land allocations and management guidelines (Table 1) with the primary intent of creating an interconnected system of forest reserves capable of maintaining viable populations of old-growth associated species. Late-successional reserves (LSRs) constitute the backbone of the regional conservation strategy (Figure 10). LSRs were designated to provide a wide distribution of reserves, and currently encompass a range of forest-age classes. Management intervention is permitted only to accelerate structural development of younger stands; otherwise, LSRs are to remain untouched in perpetuity. Ten Adaptive Management Areas (AMAs) (2 in northern CA., 4 each in WA and in OR) were set aside for demonstration, implementation, and evaluation of monitoring programs and innovative management practices that integrate ecological and economic values. Matrix lands are the primary source of timber, and have variable requirements for retention of live and dead material during harvest to enhance the ecological diversity of managed forests. Transcending all allocations is the Aquatic Conservation Strategy. In addition to general watershed restoration requirements, this strategy requires development and protection of riparian reserves (45-90 m on each side of a stream, pond, or wetland) to protect aquatic ecosystems and to provide an important linkage between riparian and upslope habitats.

Commercial timber harvesting on non-federal lands is regulated by WA and OR State Forest Practice Acts (Oregon Department of Forestry, 1997; Washington State Department of Natural Resources 1997). Collectively, these acts limit the size of regeneration harvests (e.g., <48 ha in Oregon), set minimum re-stocking guidelines, specify retention levels for green-tree (e.g., 5/ha >25-30cm diameter at breast height) and coarse woody debris (e.g., 5-7/ha for snags and for logs), and limit harvest activities in riparian zones. Recent enhancements over the past decade include increased structural, compositional, and width requirements for riparian buffers (Lorensen et al., 1994). In Oregon, riparian reserves are 6 m on each side of most streams. Riparian management zones

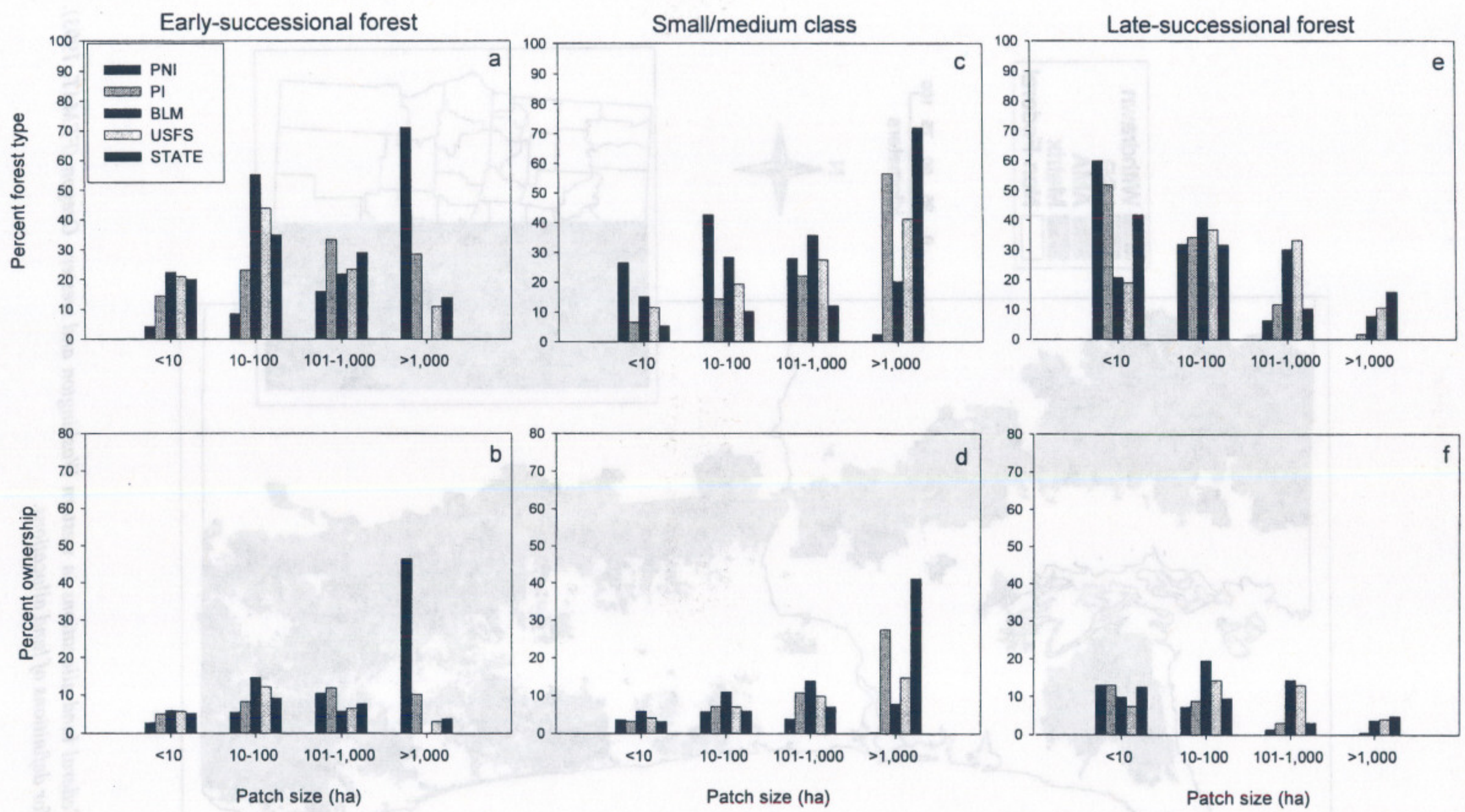

Figure 9. Frequency distribution of forest types by patch size and ownership category for the Oregon Coastal Landscape Analysis and Modeling Study (CLAMS) study area. For percent forest type, percentages of a forest type sum to 100 for an ownership category. For percent ownership, percentages across all three forest types sum to 100 for an ownership. Early-successional - open, semi-closed and broadleaf classes combined; Late-successional - large and very large classes combined (classes defined in Figure 8).

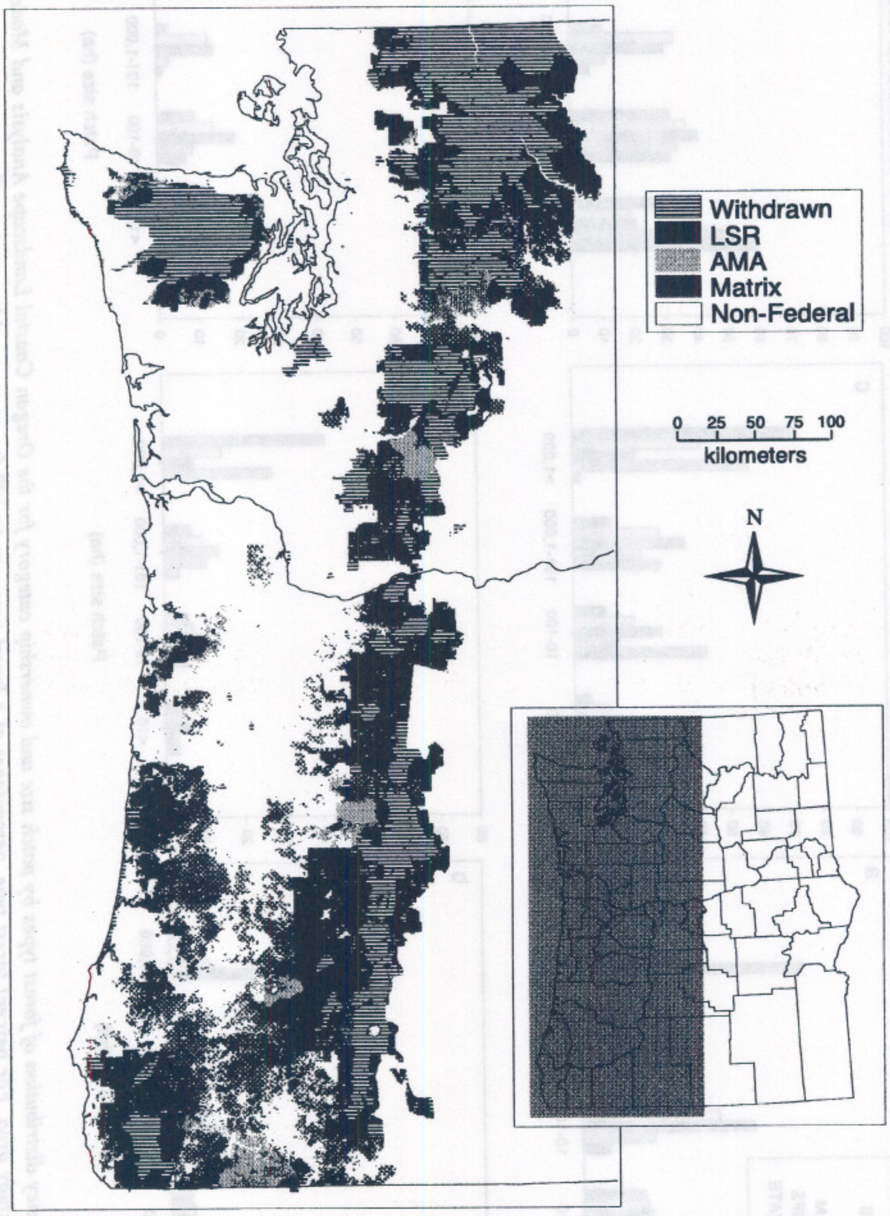

Figure 10. Federal land allocations in western Washington and western Oregon (FEMAT, 1993). See Table 1 for definitions of land allocations.

Table 1. Summary of land allocations and management standards and guidelines for federal ownerships within the range of the northern spotted owl (Interagency ROD-S&G Team, 1994)

Land Allocations	Standards and Guidelines (S&G)
Congressionally Reserved	No alteration of congressional mandates for these areas (National Parks and Monuments, Wilderness Areas, Wild and Scenic Rivers, National Wildlife Refuges, Dept. of Defense Lands).
Administratively Withdrawn Areas	The most restrictive S&G or existing plans apply (recreational and visual areas, back country and other areas not scheduled for timber harvest).
Late-Successional Reserves (LSR)	Thinning or other silvicultural treatments which will promote late-successional forest conditions may occur in stands <80-100 years old.
Managed Late-Successional Areas	Suitable owl habitat surrounding owl activity centers will be maintained with various management methods.
Adaptive Management Areas (AMA)	Potential to demonstrate and test alternative silvicultural and landscape designs (may be subject to LSR polcies).
Matrix	The more restrictive S&G apply where appropriate. Late-successional habitat maintained around owl activity centers. Manage for renewable supply of large down logs and for snags. Variable retention requirements depending on geographic location (e.g., 15%, ≥15/ha). 25-30% of Oregon BLM lands north of Grants Pass managed in late-successional conditions (connectivity/diversity blocks).
Riparian Reserves (40% of all allocations)	Promote, maintain buffers: width depends on aquatic category (i.e., fish bearing, domestic water supply). Silvicultural prescriptions permitted which promote renewable supply of large trees to streams.

(RMZ) can extend out to 30 m on a side in which 10-23m^2/ha of mostly conifer basal area must be retained during a harvest. In Washington, required leave-tree densities in RMZs (8-30 m on each side) range from 61-247/ha, but there are also strict shade requirements which can lead to higher retention levels.

5.2 Prognosis of Future Patterns

Portraying future trends in landscape patterns under current management guidelines is difficult due to uncertainty of management intentions and other factors. However, broad generalizations can be made based on current conditions, and ownership and land allocation patterns. For instance, development of large tracts of older forests will likely be confined to federal reserves (LSRs, riparian reserves, spotted owl activity centers, marbled murrelet (*Brachyramphus marmoratus*) sites, and portions of Administratively Withdrawn areas) and on portions of BLM matrix lands (Table 1). Because of the range of forest conditions currently present within these areas, the proposed network of late-successional forest reserves will not be fully realized for some time. Currently, 30-40% of the stands in LSRs are young with a substantive proportion being managed Douglas-fir plantations. Results from computer simulations suggest that in the absence of catastrophic natural disturbances and management intervention, these stands may require >140 yrs to develop late-successional characteristics; even with thinning, stands may still require >80 yrs to begin to resemble late-successional forests (Garman, 1999). The range of current

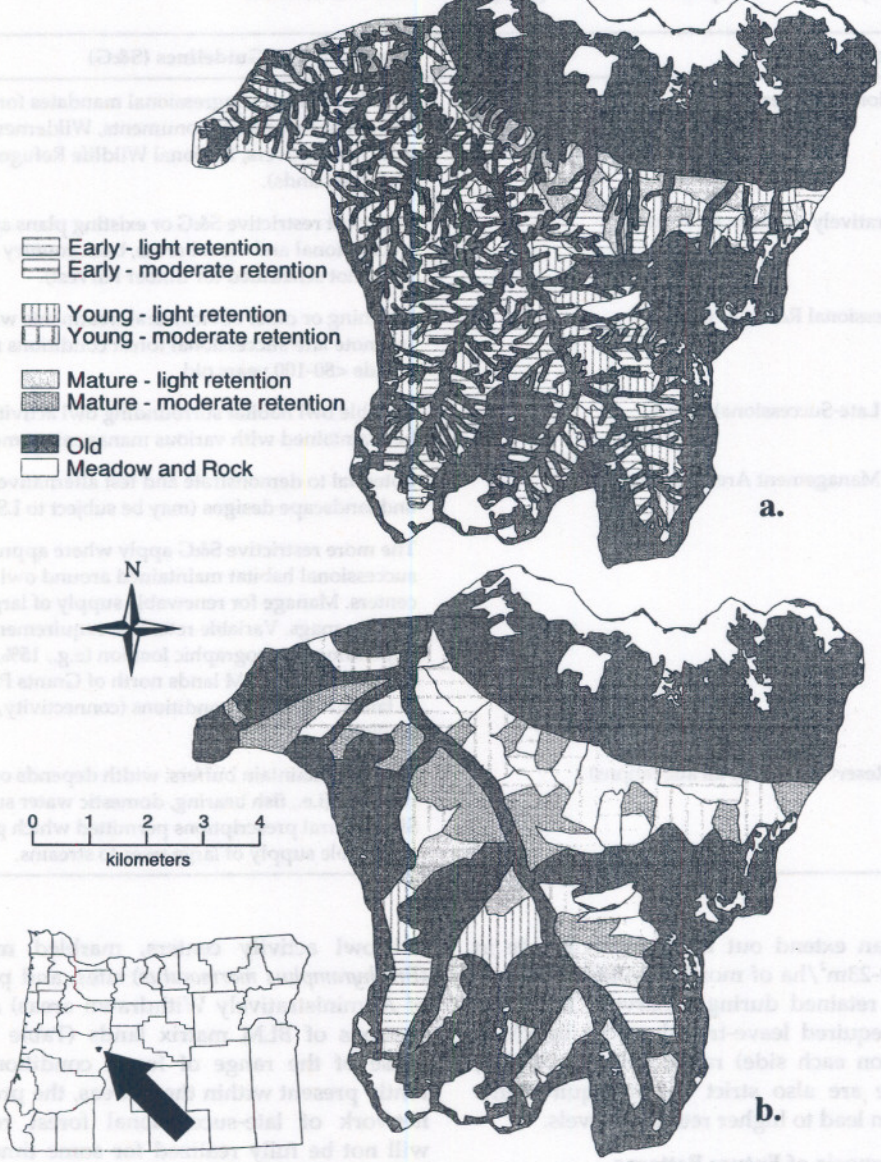

Figure 11. Projected landscape conditions (200 yrs from the present) of the Augusta Creek watershed under an interim forest plan (a) and a landscape design based on historical fire regimes (b) (Cissel et al., 1998). The interim forest plan was based on the matrix and riparian reserve standards and guidelines of the Pacific Northwest Forest Management Plan (FEMAT, 1993). Cover types were based on years since harvest and canopy retention levels. Early - ≤40 yrs, Young - 41-80 yrs, Mature - 81-200 yrs, Old >200 yrs; light retention - 15% canopy cover, moderate retention - 30-50% canopy cover.

forest conditions within designated riparian reserves also will determine developmental rate of these late-successional reserves. The Oregon Coast Range case study presented above illustrated that 30-35% of the riparian area on federally-managed lands was comprised of early-successional forests (open, semi-closed, broadleaf classes). Even with active restoration efforts, it may require several centuries to develop conifer-dominated forests in coastal riparian areas currently occupied by hardwoods or shrubs. In some areas, conifer-dominated forests may not develop due to competitive abilities of coastal shrub species (Nierenberg, 1996).

Landscape patterns on matrix lands will depend on several factors. An important consequence of the NWFP is that it limits late-successional forests on matrix lands to stream-side areas. Riparian reserves may form a large single patch, depending on the stream network, but will be narrow and provide little interior habitat (e.g., Figure 11a). Structurally diverse forests may develop within the harvested portions of matrix lands, but that will depend on how required levels of green-tree retention are distributed. For non-coastal and non-BLM matrix lands, 15% of the area to be harvested must be retained, with 70% of this retention aggregated (>0.2 ha patches) and the remainder dispersed. Use of small, widely spaced retention patches with the remaining retention also widely distributed would promote greater vertical structure over a harvest unit than aggregating retention in large patches. However, large retention patches distributed in relation to retention patches on adjacent harvest units could provide important refugia or dispersal habitat for certain species across the managed area. An additional consideration is whether retention patches are retained or harvested in subsequent harvest entries. Retaining some of these patches through multiple rotations (80 yrs on most matrix lands) would provide overall greater spatial diversity of forest structure than always establishing new retention patches comprised of the most recent cohort.

Other matrix lands with special patch-retention requirements are the connectivity/diversity blocks (263 ha in size) of the BLM checkerboard ownership. These lands are to be managed on a long rotation (150 yrs) with 20-30% of the block managed as late-successional forest at any point in time. Pattern development on these lands similarly will be influenced by both the dispersion of the late-successional forest patches within and among blocks and the turnover rate of these patches. Where late-successional stands within riparian reserves satisfy the percentage requirement, patches of forest reserves will likely not be established on uplsope areas.

Management requirements for other matrix lands include retention of 15-20 trees/ha at harvest for non-coastal BLM matrix lands south of Grants Pass, OR, and protection of stands occupied by marbled murrelets (0.8 km around an occupied site) for coastal matrix lands. Patterns on these lands will consist of riparian and other reserves, and young (<80 yrs) managed stands of varying structural characteristics.

Landscape patterns in AMAs will be determined by the type and amount of other land allocations they contain and the types of management experiments implemented. Management experiments are currently being designed. An example of the landscape experiment being conducted in the Central Cascades AMA is presented below.

Landscape patterns on non-federal commercial forest lands largely will be driven by state forest-management policies, and goals and objectives of individual land owners. Harvesting rates will be influenced by market prices. Based on historical cutting rates, however, it would be expected that about 20% of this land base will be clearcut harvested each decade. The current retention requirements for clearcut sites have the potential to enhance the structural and functional diversity of managed stands, but do not promote the development and maintenance of late-successional forests. Tracts of late-successional forests may be established by Habitat Conservation Plans to provide habitat for threatened and endangered species (e.g., Oregon Dept. of Forestry, 1998). Aquatic zone regulations in both Washington and Oregon provide protection of stream-side forests. However, estimates suggest that these areas are only a small portion of the land base. For example, <5% of the state and private industrial land base in Coastal Oregon is estimated to be within riparian management zones (RMZs), and only 20% of this area is protected from thinning of any kind. Minimum requirements for retained stand structures can be exceeded, and exceptions to regulations are possible if a land owner can demonstrate increased effectiveness of alternative strategies. In general, however, future patterns on these lands likely will consist of a mosaic of <60-yr old Douglas-fir stands managed primarily for high volume production.

Potential landscapes patterns in combination with the dispersion of land allocations will lead to varying levels of connectivity of late-successional forests throughout the region. LSRs in the Cascade Range will likely produce a more complete network of interacting late-successional forests than in the Coast Range where reserves are more dispersed because of federal ownership patterns (e.g., Figure 10). However even in the Cascade Range, patterns on matrix lands separating LSRs will have an important role in determining connectivity. Specifically, stream densities and management approaches to green-tree retention on harvested portions of matrix lands will determine the degree to which late-successional forests are physically connected among LSRs. For the connectivity/diversity blocks of the BLM ownership to provide large, contiguous patches of late-successional habitat, placement of older stands must be coordinated among adjacent blocks. Gap-crossing abilities and patch-size requirements of species determine the degree to which a landscape is functionally connected (With, 1999). For certain species associated with late-successional forests, riparian reserves on matrix lands and aquatic buffers on non-federal timber lands may be sufficient for them to readily disperse among reserves. For other species, the extent of physically connected, large patches of older forests will determine their ability to move throughout the landscape.

The interspersion of multiple ownerships has important implications for future landscape diversity and connectivity at basin scales. Multiple ownerships with contrasting management objectives can potentially create a greater range of forest and habitat conditions than a single ownership. For instance, the hypothetical example of future patterns of a Coastal Oregon watershed shown in Figure 12 illustrates the importance of private lands in maintaining open areas and broadleaf forests between large tracts of late-successional forests (i.e., the Large class in Figure 12) on federal lands. This mixture of conditions has the potential to support both late-successional species and those requiring open and closed forests in proximity for feeding and nesting. This example also illustrates how connectivity of late-successional forests within a watershed will depend on management objectives of intervening ownerships as well as the configuration of reserve parcels (e.g., BLM lands in Figure 12). Both the spatial configuration of intervening parcels and the amount of time forests on these parcels differ structurally and functionally from late-successional forests will influence connectivity of surrounding reserves. A more subtle point illustrated in this watershed example is the potential for undesired interactions among contrasting forest patterns. For instance, exposure of forested edges by clearcutting on adjacent ownerships could induce edge-related compositional changes due to climatic factors and increase susceptibility of stands to natural disturbances such as windthrow. An effect of this interaction would be a reduction in the effective size of a forested patch. Long-term conditions and connectivity of late-successional reserves on the checkerboard portion of the BLM ownership especially will be sensitive to management actions on adjacent lands.

5.2.1 *Natural Disturbance*

Adding to the uncertainty of long-term landscape patterns is the potential influence of natural disturbances. Regardless of preventive measures, landscapes will be affected by outbreaks of insects and pathogens, landslides, floods, and windthrow. Even with suppression efforts, wildfires burn thousands of hectares of forests annually (Agee, 1990). Patterns produced by natural disturbances will vary with frequency and intensity of the disturbance, and restoration efforts. Small non-stand replacing events have the potential to increase the overall spatial and compositional diversity of forested stands. Stand-replacement events have a similar role when viewed over a larger spatial extent. Predicting when and where disturbances will occur is nearly impossible. How

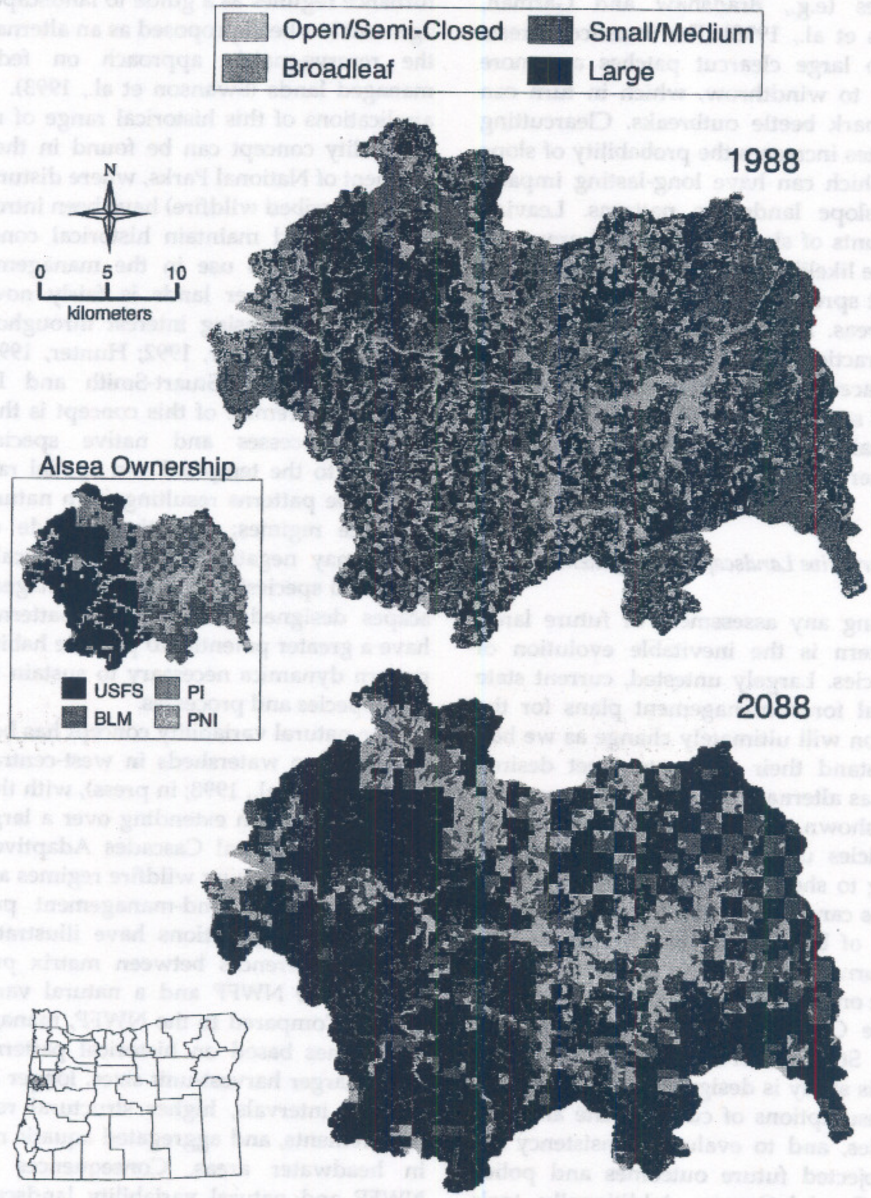

Figure 12. Recent and hypothetical future landscape patterns for the 118,000-ha Alsea Basin, Oregon (Johnson, unpubl). Future conditions simulated using LSR objectives for federal lands, current management practices for PI lands, and assuming land-clearing to dominate PNI lands. Riparian management zones on PI lands were not considered. See Figure 8 for definition of vegetation classes.

ever, studies have shown that spatial pattern of previous disturbances can significantly influence initiation and propagation of subsequent disturbances (e.g., Bradshaw and Garman, 1994; Jones et al., 1998). For instance, forests adjacent to large clearcut patches are more susceptible to windthrow, which in turn can influence bark beetle outbreaks. Clearcutting on steep sites increases the probability of slope failures, which can have long-lasting impacts on down-slope landscape patterns. Leaving large amounts of slash in harvested areas can increase the likelihood of wildfire ignition, and subsequent spreading of fire into surrounding forested areas. In general, areas where management practices create contrasting conditions among adjacent forests or adversely impact the stability of steep slopes will be more susceptible to certain natural disturbances, and thus have greater variability in landscape patterns over time.

5.2.2 Alternative Landscape Management Designs

Confounding any assessment of future landscape pattern is the inevitable evolution of forest policies. Largely untested, current state and federal forest-management plans for the PNW region will ultimately change as we better understand their ability to meet desired goals and as alternative management prescriptions are shown to be better. Assessments of forest policies using computer modeling are continuing to show how current management approaches can be modified to provide greater protection of biodiversity and long-term economic returns (e.g., Carey et al., 1996). One of the largest ongoing efforts to assess forest policies is the Coastal Landscape Analysis and Modeling Study (CLAMS) (Spies et al., in prep.). This study is designed to quantitatively test the assumptions of current state and federal policies, and to evaluate consistency between projected future outcomes and policy goals for Coastal Oregon. Additionally, tools and methods developed in this effort will facilitate the design and testing of alternative forest-management policies. Because of the spatial extent and scope of proposed assessments, results of the CLAMS project have a significant potential to influence landscape policies of different ownerships in the Coastal Oregon province.

Use of historical natural patterns and disturbance regimes as a guide to landscape management has been proposed as an alternative to the reserve-matrix approach on federally-managed lands (Swanson et al., 1993). Earlier applications of this historical range of natural variability concept can be found in the management of National Parks, where disturbances (e.g., prescribed wildfire) have been introduced to restore and maintain historical conditions (Agee, 1993). Its use in the management of commercial timber lands is fairly novel, although of increasing interest throughout the United States (Baker, 1992; Hunter, 1993) and western Canada (Stuart-Smith and Hebert, 1996). The premise of this concept is that ecological processes and native species are adapted to the temporal and spatial range of landscape patterns resulting from natural disturbance regimes; operating outside of this range may negatively affect ecological processes and species' populations. Managed landscapes designed from natural patterns thus have a greater potential to provide habitat and pattern dynamics necessary to sustain indigenous species and processes.

The natural variability concept has been applied to two watersheds in west-central Oregon (Cissel et al., 1998; in press), with the most recent application extending over a large portion of the Central Cascades Adaptive Management Area. Using wildfire regimes as reference points for land-management prescriptions, these applications have illustrated important differences between matrix prescriptions of the NWFP and a natural variability design. Compared to the NWFP, management approaches based on historical patterns produced larger harvest-unit sizes, longer harvest rotation intervals, higher structural retention requirements, and aggregated aquatic reserves in headwater areas. Consequences of the NWFP and natural variability landscape designs have been examined by long-term (200 yr) projections of patterns (e.g., Figure 11). Over this projection, the natural variability designs maintained large, spatially connected tracts of structurally-diverse older forests in addition to a range of other seral stages on the matrix allocation (e.g., Figure 11b). In contrast, prescriptions under the NWFP produced a landscape quickly dominated by young, structurally simple forests, with late-successional forests on matrix lands limited to riparian areas (e.g., Figure 11a). Additional benefits of the natural variability design were greater habitat protection for most species with only a nominal reduction in timber production. Given the inherent adaptive nature of landscape management, the ability to quickly modify landscape patterns to meet evolving resource objectives is essential. In comparison with the NWFP design, the distribution of mature and older forests maintained by the natural variability designs provided increased flexibility to add or redistribute reserve locations, modify sizes and shapes of closed-canopy forests patches, and to increase amounts and dispersion of open-canopy forests.

The benefits and limitations of using historical patterns to design future landscapes will continue to be assessed as these alternative landscape designs are implemented and monitored. However, the currently perceived benefits make the natural variability approach an appealing alternative to the matrix-riparian reserve design of the NWFP. Wide-spread adoption of the natural variability concept, in total or in part, on other allocations or ownerships has the potential to produce landscape patterns very different from what would be expected under current forest-management guidelines.

6. CONCLUSIONS

Landscape patterns of the western PNW region have changed considerably since Euro-American settlement, yet the region still retains the largest blocks of temperate old-growth forests in North America. The mosaic of older and younger forests produced by variable natural disturbance regimes has been simplified by settlement activities and clearcut timber harvesting over the past 150 years. Land clearing and agriculture on private nonindustrial lands has produced large patches of open and early-successional habitat. The high rate and method of timber harvesting on non-federal timber lands over the past century have resulted in large patches of young plantation forests and small fragments of older forests on these ownerships. Because of the shorter history of harvesting, federally-managed lands currently contain more and larger patches of the pre-settlement forest compared to other ownerships, but dispersed cutting practices over the past 50 years has also promoted the development of a checkerboard of plantation and older forests.

Current forest-management policies have a mixed potential to reverse recent trends in fragmentation of older forests. The structural retention requirements for upslope and riparian areas on non-federal commercial forest lands have a limited potential to promote the development of diverse, managed forests, but do not address the development of late-successional forests or interior forest condition. Under the NWFP, federally-managed forests will support the majority of late-successional forests which will be distributed across the landscape mostly as large blocks of forest reserves and along riparian systems within landscapes managed for timber production. Large-scale connectivity (both physical and functional) of late-successional reserves will be highly dependent on management prescriptions in intervening land allocations and ownerships. Understanding how to manage these intervening lands to enhance connectivity of late-successional forests within and among landscapes is an important management and research question. At least for federally-managed lands, experimentation with silvicultural prescriptions and landscape designs to improve on ecological diversity and commodity production is an integral part of future management. In general, testing and refinement of forest policies over time will be essential to ensure the continued evolution of management practices which best satisfy multiple resource objectives. Also, continual adjustment of management practices will be important as we better understand the effects of landscape pattern on species' populations and ecological processes.

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