

LANDSCAPE MANAGEMENT USING HISTORICAL FIRE REGIMES: BLUE RIVER, OREGON

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Abstract. Landscapes administered for timber production by the U.S. Forest Service in the Pacific Northwest in the 1950s–1980s were managed with dispersed patch clear-cutting, and then briefly in the late 1980s with aggregated patch clear-cutting. In the late 1990s, use of historical landscape patterns and disturbance regimes as a guide for landscape management has emerged as an alternative to the static reserves and standard matrix prescriptions in the Northwest Forest Plan. Use of historical information to guide management recognizes the dynamic and variable character of the landscape and may offer an improved ability to meet ecosystem management objectives.

We describe a landscape management plan based in part on interpretations of historical disturbance regimes. The plan contains a reserve system and other landscape areas where three distinct types of timber harvest are prescribed. Timber harvest prescriptions approximate the frequency, severity, and spatial extent of past fires. Future harvest blocks are mapped and used to project forest patterns 200 yr forward and to map resulting landscape structure.

This plan is compared with an alternative plan for the same area based on the extensive reserves and prescriptions for matrix lands in the Northwest Forest Plan. The management approach based on historical patterns produced more late-successional habitat (71% vs. 59%), more overstory structure in young stands (overstory canopy cover of 15–50% vs. 15%), larger patches (mean patch size of 48 vs. 26 ha), and less edge between young and old forest (edge density of 19 vs. 37 m/ha). While landscape structures resulting from both plans are historically unprecedented, we feel that landscape management plans incorporating key aspects of ecosystem history and variability may pose less risk to native species and ecological processes.

Key words: adaptive management; disturbance ecology; historical fire regime; landscape analysis; landscape plan; landscape structure; late-successional habitat; Northwest Forest Plan.

INTRODUCTION

Approaches to the management of forest landscapes have evolved dramatically over the past 60 yr, especially in the past decade on lands managed by the U.S. Forest Service in the Pacific Northwest. For the first half of the 20th century, the Forest Service focused on forest protection, and little logging occurred on public lands while private-land owners harvested their abundant timber resources. World War II was followed by four decades of emphasis on sustained yield of timber and suppression of forest fires (Franklin and Forman 1987). A system of dispersed patch clear-cutting was used to meet a variety of objectives, including creation of edge and early seral vegetation as habitat

for elk and deer, development of a road network, and dispersal of hydrologic and sedimentation effects. By the late 1980s, growing concern about fragmentation of old-growth forest (Harris 1984) and effects on key species, such as Northern Spotted Owl (*Strix occidentalis caurina*), led to brief consideration of aggregated patterns of forest cutting to minimize forest fragmentation in intensively managed landscapes (Franklin and Forman 1987, Swanson and Franklin 1992). Court-ordered injunctions against further harvest of Spotted Owl habitat temporarily halted timber harvests in 1988, 1989, and 1991; and the owl was formally listed as a threatened species in 1990.

In the 1990s, we have reached a crossroads for management of landscape patterns in federally-managed forests in the Pacific Northwest. Listing of the owl and other events culminated in the Northwest Forest Plan (U.S. Forest Service and U.S. Bureau of Land Man-

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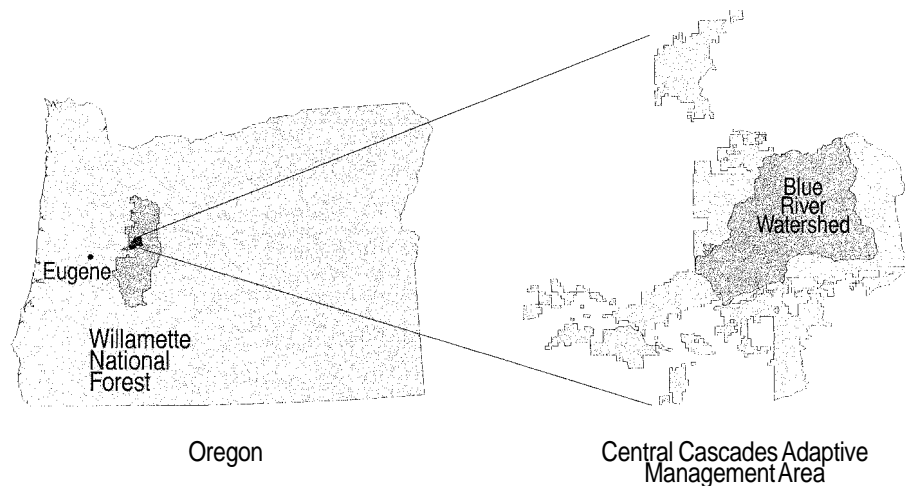


FIG. 1. Location of the Blue River watershed and Central Cascades Adaptive Management Area.

agement 1994), the overriding plan for 9.7×10^6 ha of federally managed forest land. This plan, with its roots in the old-growth and Spotted Owl issues, emphasizes static reserves, corridors, and standardized matrix prescriptions. At the same time, concepts are emerging concerning use of information on historical disturbance regimes and recognition of the dynamic and variable character of many forest landscapes (Baker 1992, Hunter 1993, Mladenoff et al. 1993, Morgan et al. 1994, Swanson et al. 1994, Bunnell 1995, Stuart-Smith and Hebert 1996, Cissel et al. 1998, Landres et al. 1999). These approaches use information on historical and current landscape conditions, disturbance history, and social goals to set objectives for future landscape structures that provide desired plant and wildlife habitat, watershed protection, timber, and other functions. The intent is not to mimic historical conditions, but rather to use them as a reference in developing and evaluating management alternatives to meet these goals. We are left with the question of the relative merits of each approach and how to meld them to best meet overall objectives.

Our objectives in this paper are the following: (1) to describe development of a landscape management plan, based in part on information concerning historical fire regimes; and (2) to compare this plan (here termed the "Landscape Plan") with an alternative plan for the same area, based more heavily on use of reserves and simple prescriptions for matrix lands (the standard prescription of the Northwest Forest Plan, here termed the "Interim Plan"). We approach these tasks by describing the study area, summarizing briefly the methods used to interpret fire regimes and to map future landscape conditions based on planned actions, and, finally, evaluating the resulting landscape structures and their possible ecological implications.

STUDY AREA

The 23900-ha Blue River watershed study area is located within the McKenzie River watershed, a tributary of the Willamette River in western Oregon (Fig. 1). The Blue River area is part of the Willamette National Forest and includes the H. J. Andrews Experimental Forest, a source of extensive ecosystem information. The landscape is steep, highly dissected, volcanic terrain of the Cascade Range. Annual mean precipitation exceeds 2500 mm, falling mostly in October–April as rain at lower elevations and snow in higher areas. The area ranges 317–1639 m in elevation and is covered largely by conifer forests dominated by Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and Pacific silver fir (*Abies amabilis*).

The Northwest Forest Plan sets land use policy for the area by defining systems of reserves and stand management prescriptions for matrix lands between reserves. The study area lies within the Central Cascades Adaptive Management Area, one of ten adaptive management areas in the region where assumptions in the plan are to be tested and new management approaches are to be developed and evaluated. The Landscape Plan is being implemented and monitored as part of an adaptive management program for the Central Cascades Adaptive Management Area. Furthermore, the study area resides in the context of broader scale elements in the Northwest Forest Plan, including a regional network of late-successional reserves intended to sustain old-growth forest ecosystems and associated species.

METHODS

Historical fire regimes

An understanding of forest history, including ecosystem conditions and disturbance processes, is an im-

portant starting point for planning in a landscape such as Blue River. Fire has been a prominent factor shaping landscape structure in the Blue River area for many centuries (Teensma 1987, Morrison and Swanson 1990). Therefore, we synthesized existing fire history studies to produce a fire regime map of the study area with mapping units characterizing frequency, severity, and patch size distribution (Teensma 1987, Morrison and Swanson 1990; P. Morrison, unpublished data).

The general approach for interpretation of historical fire frequency was to interpret fire events from tree origin and fire scar dates, to statistically model point estimates of fire frequency as a function of environmental variables, and then to use the resulting predictive algorithms and other observations to map predicted fire frequency over the study area. Fire history data were assembled and synthesized for 407 sample sites. Fires were not dated precisely using cross dating. A comparison study of cross-dated and noncross-dated fire year estimates for the same study area suggests that ~75% of fire scar years were within 10 yr of their true values (P. Weisberg and F. Swanson, unpublished manuscript). Mean fire return interval (MFRI), or the mean of all fire-free intervals (Romme 1980), was calculated for each site with at least two intervals, or at least three intervals if the period of record was <100 yr, or one interval that was ≥ 200 yr. MFRI was calculated for the time periods before Euro-American settlement (pre-1830). Regression models were used to predict MFRI as a function of topographic, forest type, solar radiation, and wind exposure variables for three geographic subdivisions within the study area and for the entire study area.

A generalized map of fire frequency was derived from predicted MFRI models and other information sources, especially the maps of forest vegetation series, roads, streams, and topography. The intent was to map polygons that were keyed to significant landscape features and could be readily located on the ground. The lower boundary of the low-frequency type was made roughly coincident with the boundary of the Pacific silver fir forest series, which burns with high-severity relatively infrequently, because of a substantial winter snowpack and short summer drought period (Agee 1993).

Fire regimes were further defined by assigning fire severity classes to areas of different fire frequency, based on observations of an inverse association between fire frequency and severity, that were observed for disturbance regimes of many types (Sousa 1984), including forests in the Blue River area (Morrison and Swanson 1990). Fire severity, as used here, refers to the level of overstory tree mortality caused by fire.

Fire regime descriptions were completed by associating mortality patch size with fire frequency, based on patch size distributions calculated from photo-interpreted fire severity mosaics (Morrison and Swanson

1990). Very large fires were not characterized by this process because of the limited size of the analysis area, but we expect that large, high-severity fires will not be simulated in future landscape management, although some wildfires of such characteristics may occur despite fuel management and suppression efforts.

Future management regimes

Interim Plan.—The Interim Plan simulates management direction for the Blue River watershed in the Willamette National Forest Plan (U.S. Forest Service 1990), as amended by the Northwest Forest Plan (U.S. Forest Service and U.S. Bureau of Land Management 1994). Management areas and prescriptions taken from the Willamette National Forest Plan included special area reserves for wildlife or recreational purposes, the H. J. Andrews Experimental Forest, general forest zones where intensive timber management was prescribed, and scenic management zones where timber harvest regimes were modified to meet scenic view objectives (Fig. 2a, Table 1). The Northwest Forest Plan overlaid additional direction including late-successional reserves, riparian reserves, and increased levels of green-tree retention in harvest units. Late-successional reserves were designated around nest sites of pairs of Spotted Owls (40 ha of high-quality habitat). Riparian reserves were applied along all streams in the watershed, at two tree heights wide (104 m) along both sides of fish-bearing streams, and one tree height (52 m) along both sides of other streams.

Specific assumptions and results from the Willamette National Forest timber harvest-scheduling model also were applied. Timber harvest was scheduled on a mean 80-yr rotation with 15% canopy cover retention at the time of harvest. A small proportion of the watershed lies in scenic management areas where rotations were extended to 140 yr.

Landscape Plan.—The Landscape Plan represents an alternative landscape management strategy, based in part on historical fire regimes, to achieve the goals of the Northwest Forest Plan (U.S. Forest Service and U.S. Bureau of Land Management 1994). The primary goals of the Northwest Forest Plan were to maintain viable populations of species associated with late-successional habitat, meet aquatic ecosystem objectives, and sustain timber production. The Landscape Plan contains two primary elements: reserves and landscape areas where varying vegetation management regimes were prescribed. Reserves were identified in two steps, both before and following definition of landscape areas.

“Special area reserves” were identified first (Fig. 2b and Table 1). Objectives for these areas were to allow natural succession to occur. Special area reserves included late-successional reserves allocated in the Northwest Forest Plan, the H. J. Andrews Experimental Forest, and three geologically unique areas allocated

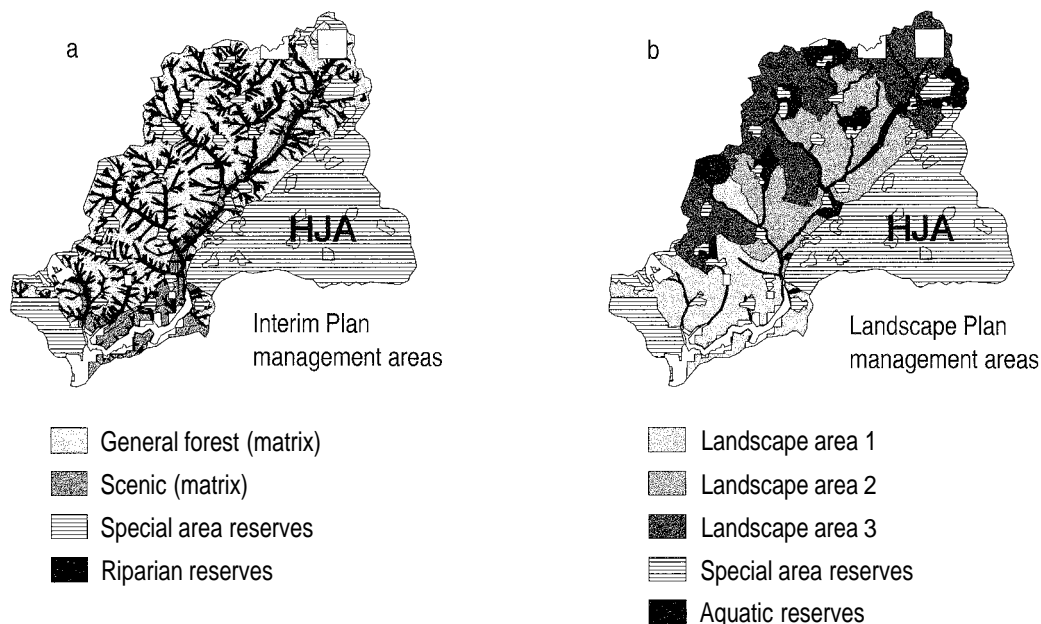


FIG. 2. Management areas for the Blue River watershed (a) managed under matrix and riparian reserve designations under the Northwest Forest Plan (termed "Interim Plan"), and (b) for the Blue River landscape management strategy (termed "Landscape Plan"). One square mile of private land occupies the northeast corner.

as special interest areas in the Willamette National Forest Plan (US Forest Service 1990).

The remainder of the watershed was then subdivided into three noncontiguous zones of distinctive ecological conditions and disturbance regimes, termed "landscape areas" (Fig. 2b, Table 1). Landscape area boundaries were based on and closely followed the interpreted fire regime mapping. Long-term vegetation management prescriptions were developed for each landscape area based on an interpreted range of historical conditions. Historical fire frequency, severity, and spatial pattern directly influenced patch structure, the proportion of the landscape each patch type occupies, and the spatial arrangement of patch types across the landscape. General prescriptions for timber

harvest frequency, intensity, and spatial pattern (Table 2) were derived from corresponding parameters of historical fire regimes.

Timber harvest rotation ages and corresponding cutting frequency approximated the historical frequency of stand-replacing or partial stand-replacing fires for each landscape area. Rotations were arbitrarily lengthened by 20–40 yr relative to the corresponding mean fire return interval in recognition of the likelihood of occasional fires that escape suppression efforts. In terms of disturbance frequency, management disturbance does not completely substitute for fire, nor is it completely additive. Fire suppression and prescribed fire for fuel reduction complicate the picture in unpredictable ways; the actual amount of unplanned fire that

TABLE 1. Area of Interim Plan and Landscape Plan management areas.

Management areas	Interim Plan		Landscape Plan	
	Area (ha)	Area (percentage of watershed)	Area (ha)	Area (percentage of watershed)
Blue River Reservoir	332	1.4	332	1.4
Non-National Forest	1077	4.5	1077	4.5
Special area reserves	8951	37.4	8505	35.5
Riparian reserves	3786	15.9	...	...
Scenic management zones	1441	6.0	...	...
Matrix	8321	34.8	...	...
Aquatic reserves	...	...	2358	9.9
Landscape area 1	...	...	3024	12.7
Landscape area 2	...	...	3876	16.2
Landscape area 3	...	...	4736	19.8
Total	23 908	100.0	23 908	100.0

Note: Management areas are listed in the order of precedence used to calculate area.

TABLE 2. Landscape area prescription elements.

Site	Regeneration harvest frequency (rotation age in yr)	Percentage of landscape area			Retention level (% crown cover in overstory)
		Small block (<40 ha)	Medium block (40–80 ha)	Large block (80–160 ha)	
Landscape area 1	100	60	20	20	50
Landscape area 2	180	40	40	20	30
Landscape area 3	260	20	40	40	15

will occur is largely unknown. The recommended management response to unplanned disturbance at the scale of a forest canopy gap or smaller is to not salvage or modify the disturbed area. Some salvage of wood from larger disturbances could be considered as part of the scheduled timber harvest for that time period.

Density of overstory canopy cover retained at the time of regeneration harvest was matched with the interpreted severity of historical stand-replacing or partial stand-replacing fires in each landscape area. Spatial patterning of overstory retention trees at the site level emphasized a variable pattern by leaving a mix of clumps, gaps, and scattered individual trees; leaving higher densities near streams and on lower slopes; leaving the larger, older and more decadent trees; and protecting sensitive sites (J. Cissel, *unpublished report on file with the Blue River Ranger District, 17April 1997*).

Spatial pattern objectives at the landscape level were developed from analysis of individual fire event and mortality patch sizes resulting from historical fires in each landscape area (Morrison and Swanson 1990). The landscape management strategy calls for a range of created patch sizes (10–160 ha), roughly corresponding with the size of many individual mortality patches from past fires and excluding the infrequent very large fires that historically created patches thousands of hectares in size.

Additional reserves, termed “aquatic reserves,” were then designated primarily to meet aquatic ecosystem objectives and secondarily to contribute to late-successional habitat objectives. The extent of reserves needed to attain these objectives depends in part upon the likely frequency, intensity, and spatial pattern of future timber harvests. For example, ecological processes influencing sediment delivery are linked to the density of forest cover on a site and the proportion of a landscape in early-successional forest (Swanson and Dyrness 1975). Management objectives for aquatic reserves are to maintain or establish late-successional forest conditions and to serve as undisturbed refugia in a landscape where timber harvest is occurring. Aquatic reserves took the form of both small watersheds (50–200ha) and riparian corridors (Fig. 2b, Table 1). Small watersheds were designated, in part, because they are large enough to provide interior late-successional habitat.

Small watershed reserves were distributed throughout the watershed and across elevational zones in locations of highest aquatic habitat diversity. Reserves were placed in headwater locations thought to benefit sensitive amphibians (e.g., *Rhycotriton cascadae*), around important stream junctions, and in locations with a high potential to contribute wood and other materials to streams. In addition, reserves encompass or adjoin late-successional reserves associated with pairs of Spotted Owls with the highest reproductive rates and pairs located in areas with a relatively high concentration of late-successional habitat.

Riparian corridor reserves were designated along both sides of all fish-bearing streams (–70–200 m slope distance on each side). These linear reserves occupy the entire valley bottom and adjacent lower hillslopes. Corridor reserves connect aquatic and riparian areas throughout the basin and link with the small watershed reserves. Unlike the Interim Plan, no additional reserves were established at the landscape scale for nonfish-bearing perennial and intermittent streams. Flexibility is provided in the landscape management strategy for identification of additional reserves at the site scale, if necessary to meet aquatic ecosystem objectives.

Additional components of the Landscape Plan include an analysis of selected sensitive-species habitat, an evaluation of the aquatic ecosystem objectives in the Northwest Forest Plan, watershed restoration, and a monitoring strategy (J. Cissel, *unpublished report on file with the Blue River Ranger District, 17April 1997*).

Future landscape structure simulation

Future landscape structure was simulated for both scenarios following similar procedures. Each scenario was represented by a single simulation. The purpose was to depict the major differences between the scenarios, rather than to provide exact predictions. Multiple simulations could be run for each scenario producing a range of results, but the major bases of comparison between scenarios (e.g., rotation lengths and riparian reserves) create greater variability in landscape structure between scenarios than among alternative simulations using the same rule set.

We first delineated management units, termed “landscape blocks,” representing the spatial locations of fu-

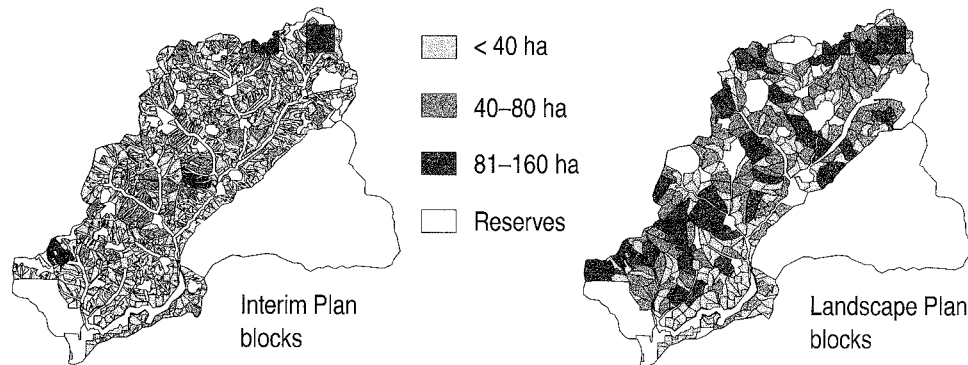


FIG. 3. Landscape blocks for the Blue River watershed managed under matrix and riparian reserve designations under the Northwest Forest Plan (termed "Interim Plan"), and for the Blue River landscape management strategy (termed "Landscape Plan")

ture patches created through timber harvest, prescribed fire, and forest regeneration. Existing stand conditions may be quite variable within a block, ranging from young plantations to old growth. Guidance for the Landscape Plan included specific objectives for landscape block sizes (Table 2). No analogous objectives for landscape spatial pattern were ever developed for the Northwest Forest Plan or included in the Interim Plan. Riparian reserves in the Interim Plan greatly constrain the options available for block delineation, however, resulting in a narrow range of potential block sizes. The criteria for delineating landscape blocks were very similar for both scenarios. Existing large patches and areas of similar landform were included within a block where feasible, and block boundaries were placed to avoid including entire watersheds in a single block. Streams, roads, and ridgelines generally formed block boundaries (Fig. 3).

Timber harvests were scheduled with a simple area control approach using multiple rotation lengths (Davis and Johnson 1987); landscape blocks were the spatial units used to locate future harvests. Each management area that was assigned a different rotation age and harvest rate was treated as an independent area for long-term harvest scheduling. The amount of area suitable for timber harvest in each management area was calculated and multiplied by the corresponding harvest rate to determine the total number of acres to be harvested in each 20-yr period. Specific landscape blocks were then selected for harvest in each time period, starting with the first 20-yr period and then for each successive period over 200 yr. Scheduling criteria included temporally dispersing harvest of blocks adjacent to late-successional reserves and in zones sensitive to potential increases in peak streamflow, and concentrating near-term harvests in the blocks most fragmented by recent clear-cutting. Although the criteria were very similar for both scenarios, scheduling options were much more limited in the Interim Plan, due to the higher harvest frequency (shorter rotation

lengths) and the smaller land base available for harvest (greater area in reserves) (Table 1).

Maps of future landscape structure were then developed for both scenarios. Existing stands were projected forward in time adding 20 yr to each stand's age for each time period, and tracked by age until the end of the planning horizon. When stands were harvested, their age was reset to zero. Timber harvest intensity prescribed for each area (Table 2) determined the resulting stand structure and future stand development trajectory. Maps of landscape structure were produced for each of 10 successive 20-yr time periods.

Comparison of future landscape structures

Landscape metrics for the Landscape Plan and Interim Plan were calculated using FRAGSTATS (McGarigal and Marks 1995) to analyze vector maps of existing and future landscape structure. We used a 100-m edge distance to represent the zone where most microclimatic effects from the edge would likely occur (Chen et al. 1995) to calculate interior habitat. We also created an edge contrast matrix to represent relative edge contrast among all possible edge types in the landscape to calculate edge density (Table 3). The variety and abundance of patch types, patch size, spatial location of patches, and edge density were selected as key indicators of landscape function.

RESULTS

Historical fire regimes

Fire frequency estimates were derived from 44 fire episodes, defined as representing single or multiple fires that occurred closely in time (i.e., within one to two decades) and/or space (i.e., within 1–2 km). Site mean fire return intervals (MFRI) ranged 9–394 yr, with a mean of 151 yr. Fires were less frequent where sites had low topographic dissection, low solar insolation, were lower on the hillslope, or were on more mesic slope aspects. Fire frequency was highly variable

TABLE 3. Edge contrast matrix. Edge contrast based upon potential effect of edge on temperature, light, humidity, wind, and soil moisture.

	Nonforest	Shrub/Pole, 0-15% overstory	Shrub/Pole, 30-50% overstory	Young, 0-15% overstory	Young, 30-50% overstory	Mature 0-15% overstory	Mature 30-50% overstory	Old
Nonforest	...	0.1	0.3	0.5	0.7	0.8	0.9	1.0
Shrub/Pole, 0-15% overstory		...	0.1	0.3	0.6	0.7	0.8	0.9
Shrub/Pole, 30-50% overstory			...	0.2	0.5	0.6	0.7	0.8
Young, 0-15% overstory				...	0.2	0.3	0.5	0.6
Young, 30-50% overstory					...	0.1	0.3	0.4
Mature, 0-15% overstory						...	0.1	0.2
Mature, 30-50% overstory							...	0.1
Old								...

Note: Diagonal elements of triangular matrix are indicated by ellipses (...)

among sites, weakly reflecting topographic and climatic influences (Table 4, Fig. 4a). Although a range of patch sizes were found throughout the watershed, smaller mortality patches were associated with areas that experienced a greater frequency of fires (Morrison and Swanson 1990).

The fire regime map depicts three representative categories of fire frequency, associated fire severity, and mortality patch size classes (Fig. 4b):

1) High frequency (MFRI, 60–100 yr; mean MFRI, 79 yr), small patches (predominantly <40 ha), and low severity (40–60% mortality).

2) Moderate frequency (MFRI, 100–200 yr; mean MFRI, 143 yr), moderate sized patches (predominantly 40–80 ha), and moderate severity (60–80% mortality).

3) Low frequency (MFRI, 200–415 yr; mean MFRI, 231 yr), large patches (predominantly >80 ha), and high severity (>80% mortality).

Existing landscape structure

The existing landscape reflects >500 yr of forest pattern development and disturbance history. Two ex-

tended periods of wildfire, one occurring during the 1500s and another in the mid-1800s, gave rise to the two dominant age classes of native forest in the watershed. Old forests (>200 yr) now cover ~36% of the watershed, and mature forests (80–200 yr) cover 25%. The third major component consists of even-aged plantations (5–45 yr), distributed over 25% of the watershed. These plantations were established following clear-cutting and, with few exceptions, have no residual older trees or snags. Minor components of younger fire-regenerated forest and nonforested vegetation communities also are found in the watershed (Table 5, Fig. 5).

The past practice of dispersing clear-cuts in relatively small patches (5–25 ha) fragmented native forests (Harris 1984). Analyses conducted in a portion of this watershed and a similar federally-managed watershed nearby concluded that the existing amount of interior closed-canopy forest had significantly decreased, and edge density significantly increased, relative to the last 500 yr, due to timber harvest practices (Wallin et al. 1996). A mean patch size of 21.6 ha, total interior

TABLE 4. Environmental influences on site mean fire return interval (MFRI) during AD 1150–1830 for the Blue River watershed, as derived from separate regression models for each geographic subdivision.

Geographic subdivision	Adjusted R ²	Environmental factors (fire frequency effect)?
Whole study area	0.1869	Local elevation (+), slope dissection (+), solar radiation (+), east wind (-).
Mann/Squaw	0.3416	East wind (+), slope dissection (+).
Tidbits/Cook-Quentin	0.2520	Local elevation (+), south aspect (+), east wind (-).
Lookout Creek	0.2063	Intermediate slope positions (-), slope dissection (+), solar radiation (+), east wind (-).

† Shown in parentheses are the effects of significant ($P < 0.05$) predictor variables on fire frequency. Local elevation = the difference in elevation between a grid cell and the average elevation of the 25 grid cells centered on that grid cell; slope dissection = the relative density of secondary ridges and streams along a hill slope, described as low, moderate, and high; solar radiation = modeled solar insolation for 15 August using latitude, slope aspect, slope angle, topographic shading, and albedo (cloud effects on solar radiation not considered); east wind = modeled probability of an east-wind-driven fire burning a site, based on simple relationships between expected fire spread and topography; slope aspect = direction of slope orientation, calculated from a digital elevation model and reclassified as north, east, south, west, and flat; slope position = slope position calculated using estimated flow accumulation in a hydrological Geographical Information System (GIS) model, and then reclassified as valley bottom, lower slope, intermediate slope, upper slope, or ridgetop.

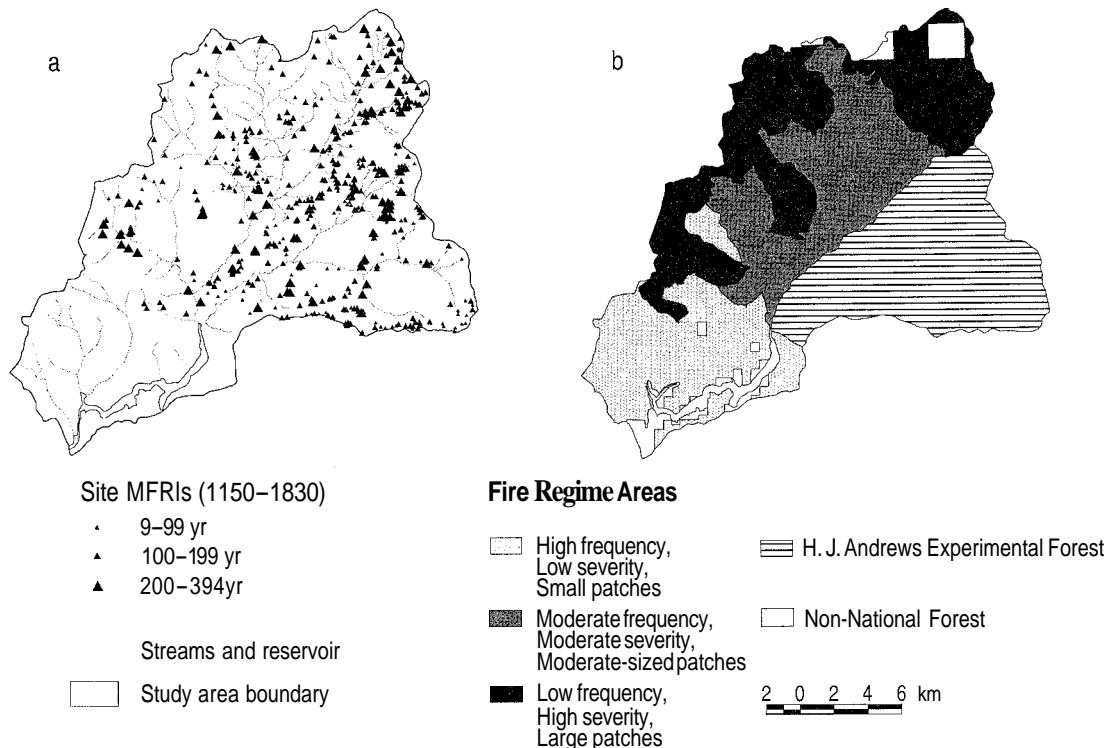


FIG. 4. Fire history for the Blue River watershed reported as (a) sites in three mean fire return interval classes, and (b) generalized fire regimes.

habitat (i.e., core area) of 6809 ha, and edge density of 33.8 m/ha characterize the existing landscape (Fig. 6). Plantations and native forest are interspersed across slope positions throughout the watershed, due to dispersion of past timber harvests (Fig. 5).

Future landscape structures

Four key aspects of landscape structure will be described for each plan: patch type composition, patch size, patch distribution, and density of edges between patches.

Interim Plan.—Patch type composition resulting from implementation of the Interim Plan differs from the existing landscape in several respects (Table 5). Plantations <40-yr-old occupy a similar proportion of the watershed as currently exists, but contain an overstory of retention trees (prescribed at 15% canopy cover). The proportion of young forests (41–80-yr-old) eventually will be doubled in the Interim Plan, relative to the existing landscape (from 9 to 18%), and also will contain overstory retention trees. Mature forest patches essentially disappear from the Interim Plan over time in response to the relatively short rotations (80 yr) in the matrix management area. Old forests initially decline, due to harvests in matrix areas, but then increase to a high of 56% of the watershed in year 200 as younger forests in reserves grow into the “old” class.

Patch sizes diminish in the Interim Plan, due to the combination of relatively high rates of harvest on matrix lands (based on an 80-yr rotation length) and the extensive network of riparian reserves. Mean patch size for all patches decreases over the first 180 yr of the Interim Plan, until finally jumping up to a high of 26.2 ha (21% larger than existing conditions) in yr 200 (Fig. 6a). Plantations currently <20-yr-old in two large reserves finally grow into the “old” category during the final 20-yr period, creating two very large patches and greatly increasing mean patch size. Similar patterns are evident in the number of hectares of interior habitat (Fig. 6b).

The Interim Plan produces a bifurcated landscape pattern with old forests along all lower slopes and young stands on upper slopes (Fig. 5). Except for late-successional reserves, old and mature forests are confined to riparian areas and lower slopes in the Interim Plan, due to the relatively short rotation lengths in the Interim Plan. Similarly, young forests in riparian areas and lower slope positions phase out of the landscape in the Interim Plan, because riparian reserves are designated along all streams.

Density of edges between patch types in the Interim Plan initially decreases to a low of 32.2 m/ha in year 20, before increasing to a relatively constant level of 36 m/ha (a 7% increase from existing edge density;

TABLE 5. Patch type composition of the Interim Plan and the Landscape Plan.

Stand structure	1995 (Yr 0)	2015 (+20)	2035 (+40)	2055 (+60)	2075 (+80)	2095 (+100)	2115 (+120)	2135 (+140)	2155 (+160)	2175 (+180)	2195 (+200)
Interim Plan											
Shrub/Sapling (1–20 yr)											
0% overstory	2293	37	37	37	37	37	37	37	37	37	37
15% overstory	86	2007	1998	986	1986	2067	2013	1973	2007	2023	2014
30% overstory	134	3	3	3	3	3	3	3	3	3	3
50% overstory	0	0	0	0	0	0	0	0	0	0	0
Closed Pole (21–40 yr)											
0% overstory	3460	2757	493	493	493	493	493	493	493	493	493
15% overstory	0	91	2007	998	1986	1986	2067	2013	1973	2007	2023
30% overstory	0	132	0	0	0	0	0	0	0	0	0
50% overstory	0	0	0	0	0	0	0	0	0	0	0
Young (41–80 yr)											
0% overstory	1773	4719	5402	2457	198	198	198	198	198	198	198
15% overstory	266	268	94	2101	4008	3987	3974	4055	4083	3988	3984
30% overstory	0	0	132	132	0	0	0	0	0	0	0
50% overstory	0	0	0	0	0	0	0	0	0	0	0
Mature (81–200 yr)											
0% overstory	4771	3786	4608	6388	4364	4155	4020	3899	2809	1012	122
15% overstory	1320	1118	1050	769	163	341	462	603	499	542	523
30% overstory	0	0	0	0	88	79	79	78	78	78	0
50% overstory	0	0	0	0	0	0	0	0	0	0	0
Old (>200 yr)	8551	7847	6941	6401	9440	9420	9418	9414	10587	12384	13357
Nonforest	1254	1142	1142	1142	1142	1142	1142	1142	1142	1142	1142
Total	23 908	23 908	23 908	23 908	23 908	23 908	23 908	23 908	23 908	23 908	23 908
Landscape Plan											
Shrub/Sapling (1–20 yr)											
0% overstory	2293	35	35	35	35	35	35	35	35	35	35
15% overstory	86	315	325	315	321	323	319	306	305	303	311
30% overstory	134	423	426	424	431	427	427	424	409	441	436
50% overstory	0	505	512	504	498	511	513	490	504	498	511
Closed Pole (21–40 yr)											
0% overstory	3460	2724	495	495	495	495	495	495	495	495	495
15% overstory	0	89	315	325	315	321	323	319	306	305	303
30% overstory	0	136	419	422	421	427	424	424	420	405	437
50% overstory	0	0	505	512	504	498	511	513	490	504	498
Young (41–80 yr)											
0% overstory	1773	4697	5097	2226	196	196	196	196	196	196	196
15% overstory	266	267	92	392	642	643	639	647	645	628	614
30% overstory	0	0	136	545	841	843	848	851	847	844	826
50% overstory	0	0	0	505	1017	1016	1001	1009	1025	1003	994
Mature (81–200 yr)											
0% overstory	4771	4299	5411	7610	5628	5154	4783	4470	3159	1202	126
15% overstory	1320	1112	1189	1013	224	537	858	1147	1363	1686	1936
30% overstory	0	0	0	0	111	515	936	1343	1731	1950	2026
50% overstory	0	0	0	0	0	347	479	504	498	511	513
Old (>200 yr)	8551	8160	7806	7438	11081	10472	9973	9589	10333	11755	12504
Nonforest	1254	1148	1148	1148	1148	1148	1148	1148	1148	1148	1148
Total	23 908	23 908	23 908	23 908	23 908	23 908	23 908	23 908	23 908	23 908	23 908

Notes: Table entries are areas in hectares. Nonforest lands are assumed to be static throughout the modeling horizon. Approximately 1400 ha of the watershed are in other ownerships. These lands are assumed to be unchanged from their existing classification for lack of better information. Stand structure classes are defined by two canopy levels. The dominant cohort is defined by the time since the stand-initiating disturbance. Each of these age classes is further subdivided based on the density of overstory trees that survived the stand-initiating disturbance.

Fig. 6c). The increase in edge results primarily from timber harvest bordering old forests in riparian reserves.

Landscape Plan.—The Landscape Plan develops a substantially different landscape composition over time, compared to existing conditions (Table 5). Plan-

tations <40-yr-old occupy a lower proportion of the watershed than currently (12% vs. 25%) and contain an overstory of retention trees (prescribed at 15%, 30%, and 50% canopy cover). The proportion of young forests (41–80-yr-old) increases slightly in the Landscape Plan relative to the existing landscape and also contains

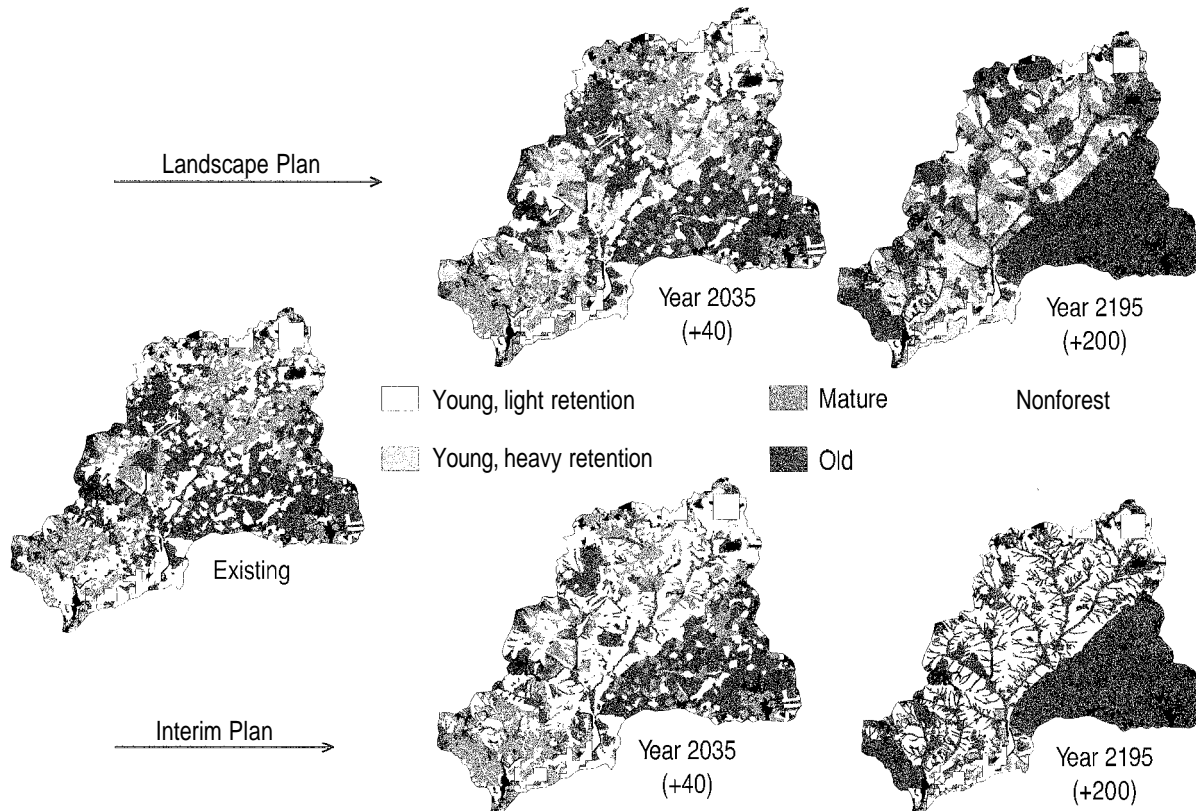


FIG. 5. Projected future landscape structure for the Blue River landscape management strategy (termed "Landscape Plan") and for the Blue River watershed managed under matrix and riparian reserve designations under the Northwest Forest Plan (termed "Interim Plan").

various overstory retention levels. Mature forest patches (81–200-yr-old) decline slightly in the Landscape Plan, but are maintained as a substantial component (19% of the watershed), due to extended rotation lengths. Old forests (>200 yr) initially decline slightly and then increase to a high of 52% by year 200, due to both extended rotation lengths and reserves (Fig. 5, Table 5).

Patch sizes increase in the Landscape Plan, due to the spatial pattern objectives of the plan. Block sizes and configurations were designed specifically to create larger patches in a pattern similar to historical landscapes. Mean patch size increases from 21.6 ha currently to 47.6 ha in year 200 of the Landscape Plan (Fig. 6a). Similar patterns are evident in the number of hectares of interior habitat, which is closely correlated with patch size (Fig. 6b).

Patch types of all ages and retention levels are distributed across all slope positions in the Landscape Plan (Fig. 5). Lower slopes are included in harvest blocks with upper slopes, although greater densities of retention trees are prescribed on lower slopes in the Landscape Plan.

Density of edges between patch types in the Landscape Plan declines over time to a low of 18.9 m/ha in

year 200 (a 44% decrease from existing edge density, Fig. 6c). The decrease in edge results from lower rates of harvest in the plan, as compared to the past 40 yr, and moderate to high levels of overstory retention that reduce the contrast between harvest units and adjacent stands.

Comparison of future landscape structures

Patch type composition of the two plans differs significantly. The Interim Plan creates substantially more area in patches <80-yr-old (37% in year 2195 vs. 24% in the Landscape Plan), due to the higher harvest rates and shorter rotation lengths in the matrix management area. In addition, patches <80-yr-old in the Landscape Plan retain an overstory of varied and generally higher retention levels than the Interim Plan. Mature stands eventually decrease to very low levels in the Interim Plan (3%), creating a large gap in age classes across the watershed. The Landscape Plan maintains 19% of the landscape in the mature class in year 2195 (+200 yr). When mature and old classes are combined as a measure of late-successional habitat, the Landscape Plan produces 71% of the area in late-successional forest by year 200, as compared to 59% for the Interim Plan. The Landscape Plan also includes another 8% of

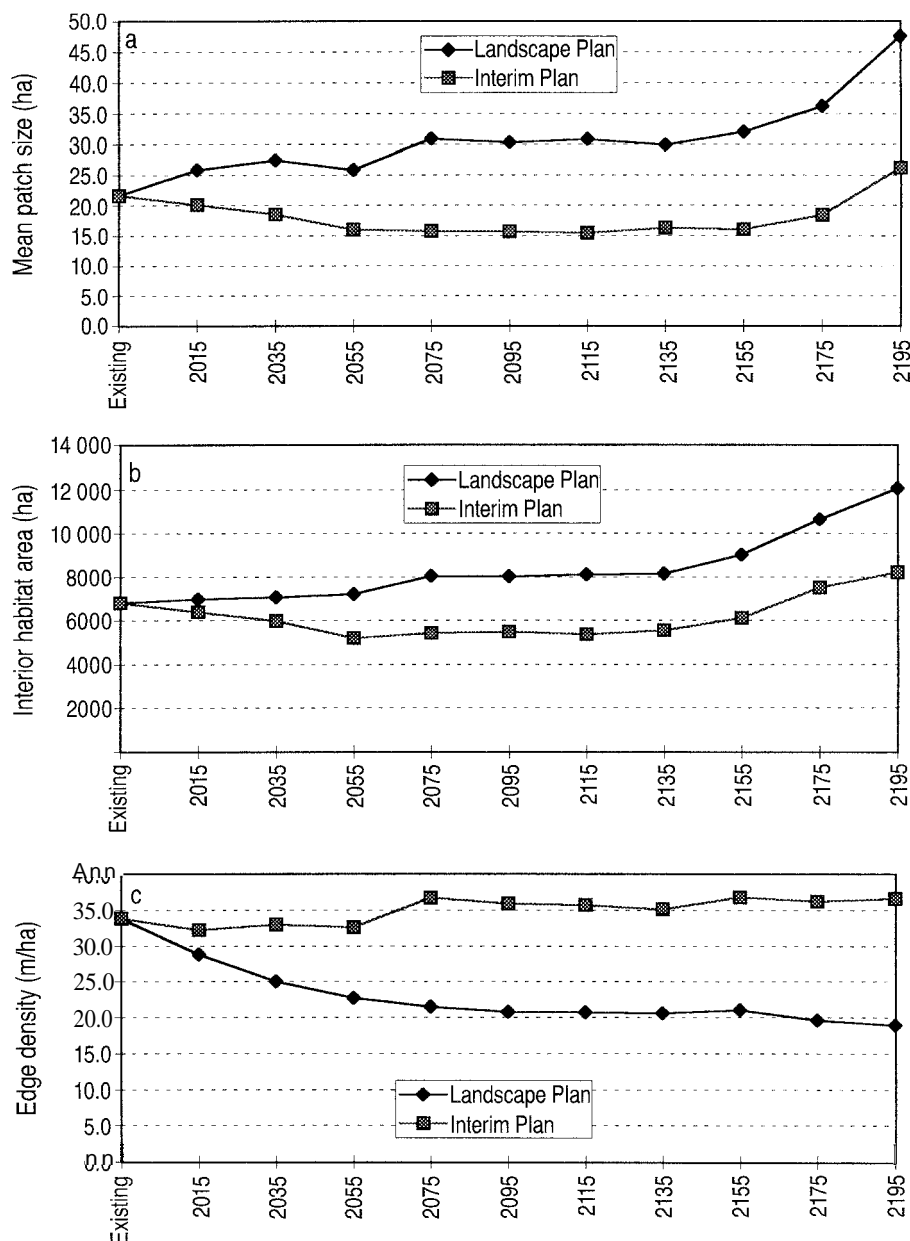


FIG. 6. Comparative landscape metrics for the Interim Plan and Landscape Plan: (a) mean patch size, (b) total interior habitat area, and (c) edge density.

the landscape in younger stands with a 50% canopy cover of older overstory trees, which provide some of the benefits of late-successional habitat (Table 5).

Patch size differs substantially between the two scenarios due to differences in timber harvest rate and spatial pattern. Mean patch size of the Landscape Plan is 28% greater than the Interim Plan after the first 20 yr, and it varies from -50–100% greater thereafter (Fig. 6a). Total interior habitat exhibits a similar pattern, eventually resulting in 50% greater area in interior habitat in the Landscape Plan, as compared to the Interim Plan (Fig. 6b). Extensive riparian reserves in the

Interim Plan constrain the location of timber harvests to relatively small areas between reserves. Less extensive reserves in the Landscape Plan result in larger areas between reserves available for potential harvest. The relatively short rotation lengths (~80 yr) of the Interim Plan also prevent harvested patches from ever merging with older forests in adjacent reserves.

Spatial distribution of patch types across slope positions also differs markedly between the two scenarios (Fig. 5). Old forests are confined to lower slopes in the Interim Plan, while they are distributed across slope positions in the Landscape Plan. Conversely, younger

forests are found on most upper slopes in the Interim Plan and not at all on lower slopes, while the Landscape Plan produces younger forests across all slope positions. Longer rotation lengths (100–260 yr) in the Landscape Plan, as compared to the Interim Plan (80 yr), allow development of mature and old forests within harvested areas. Also in contrast to the Interim Plan, younger patches are created on lower slopes, because harvest blocks include these areas.

The amount of edge between closed-canopy forest and open areas varies significantly between the two scenarios. Edge density in the Landscape Plan is 11% lower than the Interim Plan after 20 yr; thereafter, the difference between the two scenarios steadily increases until reaching a maximum of 48% lower edge density in the Landscape Plan at the end of 200 yr (Fig. 6c). A lower frequency of harvest and reduced contrast between patches due to higher retention levels in the Landscape Plan account for these differences.

Timber production and operational feasibility

Stand growth models were used to simulate long-term, average annual per hectare yields for each silvicultural treatment. These yields were multiplied by the respective number of hectares in the corresponding management category and summed to obtain a long-term sustained yield for each plan. The Landscape Plan produces –17% less wood volume than the Interim Plan in the long term. Differences in manufactured wood volume and wood value are likely less, because the Landscape Plan produces bigger trees due to longer rotation lengths (mean rotation length of 192 yr, compared to the mean rotation length for the Interim Plan of 88 yr). These results should be viewed as highly speculative, however, because empirical data are not available to corroborate model predictions under the combinations of retention levels and rotation ages used in these plans (J. Cissel, *unpublished report on file with the Blue River Ranger District, 17 April 1997*). Additional analyses are under way to further refine these estimates.

The operational feasibility of timber removal varies between plans. The greater complexity and variability of silvicultural prescriptions and higher levels of overstory retention in the Landscape Plan will require a greater effort to plan harvests and mark trees for removal or retention. Monitoring and tracking protocols to ensure compliance with the specifics of the prescriptions will also be different and probably more intensive. Safety protocols will need to be enhanced to handle working in and around high levels of large, residual trees. Logging costs may be higher in some cases under the Interim Plan, because many harvest blocks are small and spatially isolated due to extensive riparian reserves.

Collectively, these additional considerations for the Landscape Plan will likely result in higher costs for

planning and implementing timber harvest activities and a lower amount of timber volume harvested per hectare. This may result in a net loss of revenue, but will depend on trends in the timber market. Increased prices for the higher wood quality associated with harvesting bigger trees may offset the increased costs.

DISCUSSION

Comparison of ecological effects

Rigorous comparison of the ecological effects of the two scenarios is constrained by limited knowledge of habitat requirements for most species; interactions of species and populations with disturbance events; effects of past and future climate variability on disturbance regime, fauna, and flora; and effects of disturbance processes, such as windthrow, on the unprecedented types of stand structures and edges created under the two plans. Neither of the landscapes created by the two plans has historical precedents; both represent management “experiments.” Nevertheless, important distinctions can be made between the two management approaches.

The majority of young forests present in the Landscape Plan contain higher densities (15–50%) of large, upper canopy level trees than do young forests in the Interim Plan (15%). Residual green trees provide habitat for some organisms and energy sources for non-autotrophic organisms, moderate understory environments and reduce understory tree growth, become future large snags and down logs, enhance connectivity in a managed landscape, and serve as dispersal sources for surviving organisms (Franklin et al. 1997). A series of studies in the Blue River area evaluated effects of leaving residual trees in timber harvest units. Two groups of lichens associated with old growth, cyanolichens and alectoroid lichens, were observed to have higher biomass in young stands with remnant trees present than in plantations without remnant trees; cyanolichen biomass was positively correlated with remnant tree density (Peck and McCune 1997). Schowalter (1995) found that recent harvest units with remnant trees supported invertebrate communities, including predators of pest species, more like older forests than did plantations without residual trees. Monitoring of songbird response to green-tree retention in harvest units showed species-specific responses to residual tree density; thus, community structure varied with residual tree density (Hansen et al. 1995). In a related retrospective study of natural stands that developed following fire, residual tree basal area reduced the basal area, volume and growth of the understory tree cohort in a curvilinear relationship, with the effect per unit residual basal area decreasing as residual tree basal area increased (Acker et al. 1998). Residual structure also is thought to benefit some amphibians (Bury and Corn 1988) and may provide coarse woody debris associated with certain hypogeous fungi found in older forests

(Amaranthus et al. 1994). We believe that the higher densities of overstory trees in the Landscape Plan will allow for more rapid recovery of preharvest communities and processes.

The extent of mature forest over the study area differs significantly between the two scenarios. Many species associated with old forests also use mature forests as habitat. Spotted owls, for example, use mature as well as old forests (Gutierrez 1996), as do many species of invertebrates (Schowalter 1995) and fungi (J. Smith, *personal communication*). We believe that the greater amount of late-successional forest (here defined as the sum of mature and old age classes) found in the Landscape Plan will provide higher levels of habitat for most species associated with older forests than does the Interim Plan.

Significantly larger patch sizes in the Landscape Plan are expected to favor species associated with interior habitats. Although empirical evidence showing strong preference for interior habitat by vertebrates is sparse, studies and observations suggest that Northern Spotted Owls more frequently use larger patches for nesting (Ripple et al. 1997), have higher reproductive rates where patch sizes are larger (K. Swindle, *personal communication*), and avoid edges with early seral stage patches when foraging (Johnson 1992). Microclimatic edge effects, which may extend ≥ 200 m into the interior of older forests (Chen et al. 1995, Brosofske et al. 1997), strongly limit the extent of interior forest habitat associated with the riparian reserves of the Interim Plan.

Distribution of patch types across slope positions differs greatly between the two scenarios, which lead us to predict different effects on terrestrial and aquatic biota as well as ecological and hydrological processes. The broader distribution of forest patch types in the Landscape Plan may provide more dispersal habitat for many species. Species whose dispersal is favored by late-successional characteristics will find these features occur across most of the landscape the majority of the time in the Landscape Plan, but are confined to lower slope positions only in the Interim Plan. Riparian and adjacent lower slopes along nonfish-bearing streams would experience some partial cutting under the Landscape Plan. The Landscape Plan provides greater flexibility for management in riparian and adjacent lower slope zones by relying, in part, on lower cutting frequencies through long rotation lengths, as well as lower cutting intensities through greater green-tree retention in the uplands. Some disturbance in these zones is accepted as part of the range of historical conditions. Consequences of these treatments include higher light levels leading to potential localized increases in stream productivity and stream temperature and less than maximum large wood input to streams. Some aquatic organisms, such as the aquatic lichen *Hydothyria venosa*, would benefit from higher light levels. Channel sta-

bility, stream flow, and sediment inputs are expected to be very similar in the two scenarios. These interpretations are based on analyses for both the Blue River area (J. Cissel, *unpublished report on file with the Blue River Ranger District, 17 April 1997*) and the nearby Augusta Creek area (Cissel et al. 1998).

Edges between young and old patch types in the Landscape Plan are less numerous and less distinct in the Landscape Plan as compared to the Interim Plan. The relatively abrupt transition from riparian areas and lower slopes to upper slopes in the Interim Plan introduces artificial gradients in environmental conditions, such as light, temperature, moisture, and wind (Chen et al. 1995). Plant communities and mortality rates may be affected by abrupt edges (Chen et al. 1992). Sharp edges create substantial windthrow potential but may benefit species that favor edges, such as elk (*Cervus elaphus*).

Limited knowledge of untested elements of the stand and landscape management prescriptions in the plans make it difficult to compare some important aspects of the ecological risks created. One aspect of ecological risk is that natural disturbance processes can make it difficult to implement the plans as intended. As analyzed in Cissel et al. (1998), a variety of factors favor spread of fire in landscapes produced by either plan, but, overall, the Interim Plan was judged to have higher potential for spread under extreme fire and weather conditions. Windthrow risk between the two landscapes has some similarly equivocal aspects. Patches of windthrow in riparian zones are more likely in the sharp-edged landscape of the Interim Plan, but dispersed windthrow may be more common in the Landscape Plan in response to higher densities and greater extent of residual trees in cutting units (Cissel et al. 1998). More will be learned by monitoring test cases of each plan.

Temporal variability in landscape structure resulting from implementation of either landscape plan will inevitably be reduced, compared to the historical landscape, due to the deterministic nature of the timber harvest schedule. Variability will be greater in the Landscape Plan due to spatial variation in cutting frequencies, intensities, and patch sizes that are built into the plan. More complex prescriptions and a stochastic planning model could be developed, potentially leading to a more temporally variable plan. Complex silvicultural regimes greatly increase the challenges of on-the-ground implementation.

Maintaining future options is an important evaluation criterion of alternative management plans. Greater diversity of age classes, both across the landscape and as cohorts within stands, under the Landscape Plan provides greater flexibility to create a diversity of future stand conditions if objectives change. Lower cutting rates in the Landscape Plan provide greater flexibility to respond to changing objectives. In addition,

the near elimination of the entire mature age class in the Interim Plan poses substantial risks and reduced flexibility over the long term. Should natural disturbances, climate change, natural processes of senescence, or other factors cause high mortality of the old-growth forests in the Interim Plan, there will be no mature forest available for replacement.

These and other distinctions between these two approaches lead us to conclude that the landscape management approach using information on historical conditions holds substantial promise, although it is still in early stages of development. While landscape structures resulting from both plans are historically unprecedented, we feel that the Landscape Plan more closely resembles historical conditions than does the Interim Plan and, thus, poses less risk to native species and ecological processes.

Managing ecosystems

This study demonstrates that information on historical disturbance regimes can be applied to landscape management in Douglas-fir forests of the Pacific Northwest and that substantial ecological benefits may be provided by this approach in the long term. We also find that this study site is highly suitable, in terms of ecological conditions and management objectives, for application of these concepts. An important land management objective for the area is to maintain native habitats and ecosystem processes, which is consistent with the Landscape Plan approach. Landscape-scale disturbances have played prominent roles in structuring these ecosystems, and an extended history of disturbance events is accessible in the tree ring and other records, making it appropriate and possible to use this information in future landscape management. More broadly, use of information on historical disturbance regimes follows a growing emphasis on using knowledge of ecosystems as a basis for their management (Christensen et al. 1996).

Landscape management plans based on reserve and standard matrix prescriptions, such as in the Interim Plan, are likely to dominate where efforts to protect key species and past land use severely limit options. This species conservation approach may evolve as habitat and populations recover. Furthermore, fire suppression and succession of vegetation and associated fuels may eventually create conditions that require more active management to meet ecosystem and/or hazard management objectives. The Landscape Plan demonstrates how historical information can be integrated with a reserve network to meet overall landscape management objectives.

We are following an adaptive management model by implementing, testing, and monitoring the Landscape Plan in the Blue River area in keeping with its designation as part of an adaptive management area (U.S. Forest Service and U.S. Bureau of Land Management

1994). A first step is to observe how well landscape management objectives, derived from interpretations of historical disturbance regimes and landscape structure, can actually be carried forward into project implementation. Many factors, such as site-specific conditions and social challenges, both internal and external to federal managing agencies, cause modifications to broad landscape plans. Natural processes, such as windthrow of retained trees or wildfire, also may cause deviation of landscape structure from the planned structure. We are monitoring and analyzing effects of plan implementation on landscape structure, ecological and watershed responses, and social acceptability. Additional information on landscape management will be collected by comparative analysis of landscape structure development and function with areas on other landscape management paths. Basic understanding of landscape dynamics and function will emerge from long-term research about issues such as historical variability itself, the consequences of deviation from historical conditions, and the ecological effects of variability in landscape conditions. Finally, management practices must adapt to new information, completing the adaptive management cycle.

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