Chapter 9

Landscape Management: Diversity of Approaches and Points of Comparison

Frederick J. Swanson
USDA Forest Service, Pacific Northwest Research Station,
3200 SW Jefferson Way, Corvallis, OR 97331, USA
John H. Cissel
USDI Bureau of Land Management, 3200 SW Jefferson Way,
Corvallis, OR 97331, USA
Allison Reger
USDA Forest Service, Willamette National Forest, Box 10607,
Eugene, OR 97440, USA

1. Introduction

Forest scientists and managers have long considered landscapes important entities to be studied and managed, although only in the past two decades has the term "landscape" become widely adopted in these fields (Harris 1984, Franklin and Forman 1987, Szaro et al. 1999). Contemporary forest management issues at landscape scales have been framed as concerns about cumulative watershed effects, species viability, fire hazard, and ecosystem health or integrity (Szaro et al. 1999). Because many issues emerge at the landscape scale, it is an essential scale for addressing compatibility and tradeoffs among land use objectives when policy decisions are made.

The type of forest landscapes considered in this chapter (and in many landscape ecology studies) are areas composed of various physical and biotic features as well as socioeconomic units. For example, a landscape may contain patches of forest with different structures and compositions, and there may be different ownerships or land allocations. Landscape studies commonly concern areas ranging from 5000 to 50 000 hectares (ha) and time scales of decades to centuries. These scales are broad enough to encompass many of the coarse-scale temporal and spatial dynamics of ecosystems.

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Landscapes are a useful scale for management planning for various reasons. Many issues benefit from examination at scales larger than the traditional forest stand or patch. For example, species that require habitat that includes multiple patch types, dispersal of organisms across multiple patches, movement of disturbances such as fire, and watershed processes such as sediment input to streams are all suited to study at the landscape scale. More generally, federal land managers must provide a mixture of habitats so populations of native species remain viable; this requires a landscape large enough to assess the balance of habitat elements across space and time. Relatively small landscapes, such as those considered in this chapter, offer a way to address some of these challenges. These landscapes are large enough for analysts and planners to see broad patterns, assess cumulative effects, and plan for a balance of habitats over space and time. On the other hand, these landscapes are small enough that analysts and planners can retain the site specificity of their data, use the full precision of the primary data, and still comprehend the big picture.

Both broad-scale ecosystem science and management of natural resources commonly consider the world as operating in hierarchies of nested scales—biological, geophysical, sociopolitical, and institutional. A common property of hierarchical systems (O'Neill et al. 1986) is that specific issues may emerge at a particular scale; therefore up- or down-scaling cannot be accomplished as a simple, additive process. As a result, analyses of hierarchical systems must be attentive to multiple scales simultaneously to achieve scientific and management objectives. In forest landscape management, the landscape scale is a critical bridge between the regional scale, such as the range of the northern spotted owl (*Strix occidentalis caurina*) or other wide-ranging species, and the forest-stand scale, at which vegetation management is conducted.

The diversity of forest management approaches represented on the land today, even within a single region, provides a fertile ground for study of landscape dynamics. This diversity reflects specific management objectives, such as recreational use of Congressionally-designated wilderness areas or intensive production of wood fiber from industrial lands. Consequently, existing management approaches span a great spectrum of disturbance frequency, severity, and spatial pattern—from 40-year cutting rotation to no-cut, and fire suppression with disturbance patch sizes ranging from small and uniform to highly variable. Real landscapes are commonly complicated by a mixture of ownerships and land allocations that exhibit different types and stages of management.

The objective of this chapter is to bring science and management perspectives together and examine aspects of diverse approaches to forest landscape management in a region where forestry issues have been hotly contested for several decades. This chapter addresses (1) lessons from a modeling exercise that examined diverse landscape management approaches and selected socioeconomic and ecological consequences, (2) issues of compatibility among forest uses for different objectives, and (3) general perspectives concerning current and future landscape management. We draw from our experiences in developing and implementing different management systems and working collaboratively at the science-management-policy interface. This discussion focuses on the effects of different management systems on forest and watershed processes and features. It is based on examples from Oregon and Washington, where a broad range of management approaches has been used. The range of management systems considered here includes many that have little relevance to private forest management, such as a no-cut and no-fire treatment and very long rotations. However, we believe that the general points concerning landscape planning and management are applicable in diverse settings when the findings are scaled to local conditions.

2. Modeling Alternative Landscape Management Strategies

2.1. Modeling Approach

Modeling future landscape patterns under alternative management approaches is useful for comparing the effects of these approaches in terms of different societal expectations of forest lands, and for examining the compatibility among forest uses and desired conditions. We modeled a single landscape under a wide variety of management rules to produce a set of maps depicting landscape change over time (landscape-change scenarios). These modeled landscape-change scenarios extend over a 600-year period and represent the broad range of stages in forest development that are matters of policy concern in the region. A common landscape is used for the different scenarios so the effects of landscape change can be revealed in the simulations without the potentially confounding influence of topography or other features that would arise if we used different study areas.

These simulations were developed for the 17 500-ha Blue River watershed in western Cascade Range of Oregon, exclusive of the H.J. Andrews Experimental Forest and contained within the Willamette National Forest and the Central Cascades Adaptive Management Area (Figure 1). This steep, mountainous area ranges in elevation from about 300 to over 1600 meters (m) and is dominated by Douglas-fir/western hemlock (*Pseudotsuga menziesii* (Mirb.) Franco/*Tsuga heterophylla* (Raf.) Sarg) forest at lower and middle elevations and Pacific silver (*Abies amabilis* Dougl. ex Forbes) forest at higher elevations. Wildfire over the past 500 plus years and forest cutting since about 1950 have created a complex pattern of forest age classes across the current landscape (Figure 1). This area is broadly representative of steep, federal forest lands west of the crest of the Cascades in the Douglas-fir region (western Oregon and Washington).

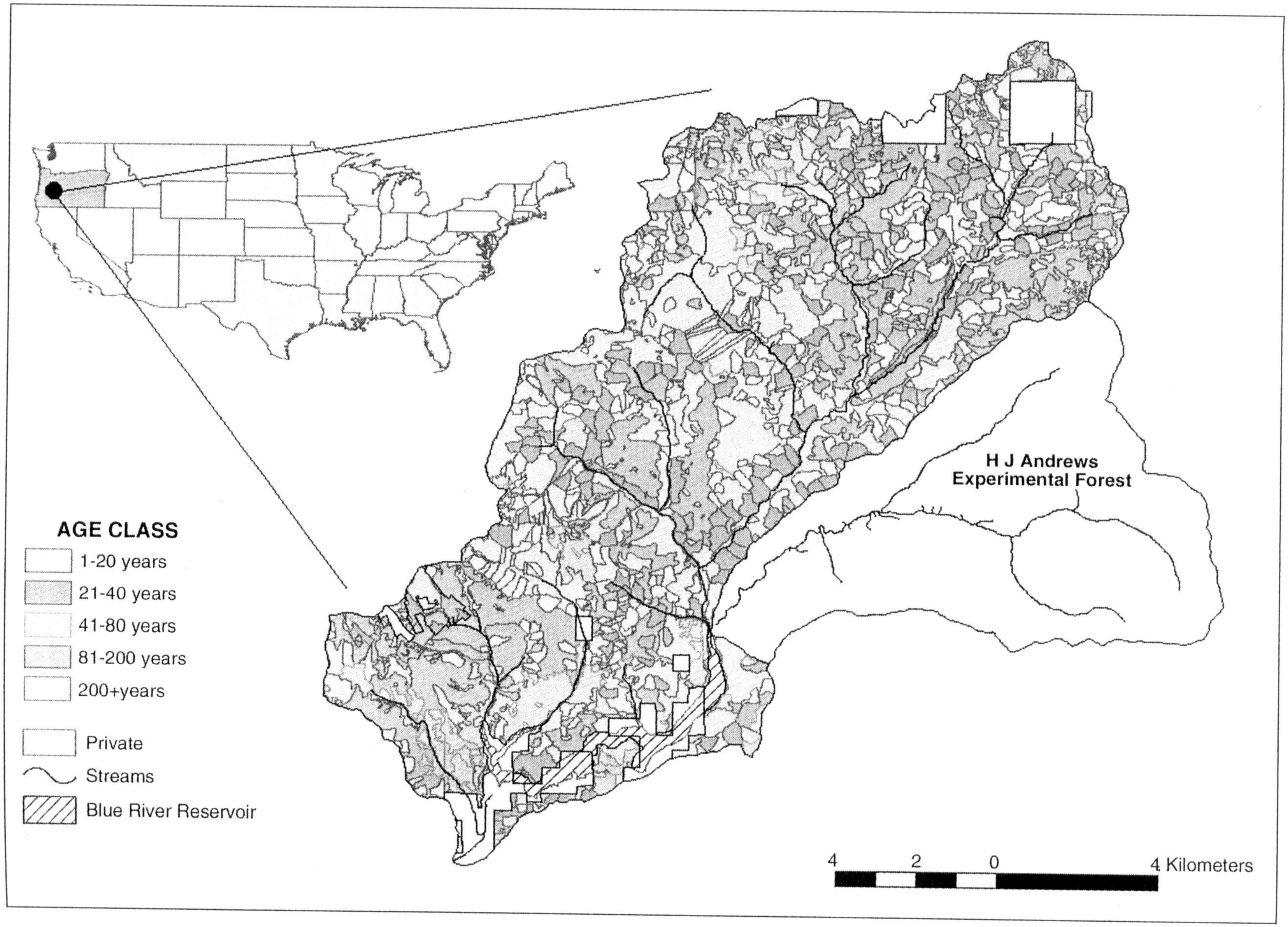

Figure 1. Location of the Blue River, Oregon, landscape study area and current vegetation age classes.

We modeled six scenarios for the Blue River watershed by using the TELSA (Tool for Exploratory Landscape Scenario Analysis) modeling system (ESSA Technologies Ltd. 1999). TELSA is a patch-based, simulation model that employs successional pathways, management regimes, and disturbance regimes defined by the user at levels of temporal and spatial resolution, also controlled by the user. TELSA is both temporally and spatially specific and has numerous methods for controlling or constraining the distribution of management activities and disturbance regimes across space and time. We used 10-year time steps and a minimum spatial resolution of 0.1 ha, although most polygons were substantially larger.

We examined the landscape structure in terms of different forest age classes, mean size of forest patches, and density of the edge between forest and areas of open canopy less than 40 years old. These measures of landscape structure were used because they relate to evaluations of habitat and hydrology effects as well as vulnerability to disturbance, such as windthrow at edges of forest openings (Gratkowski 1956, Sinton et al. 2000). Edge environments are also distinctive in terms of microclimatic effects of the canopy opening penetrating into the adjacent forest (Chen et al. 1995).

We then estimated the consequences of each of these scenarios at year 100 in terms of wood production, extent of early- and late-seral vegetation habitat as indicators of biodiversity protection, and response of annual and summer low streamflow. We used the year 100 for comparisons because most scenarios developed rather stable proportions of the different age classes, and most legacies of earlier landscape patterns (Wallin et al. 1994) were erased. Also, the legacy of forest structure from the current landscape condition, notably dead wood, was largely lost through decomposition and other processes. The amount of carbon stored on the landscape was not compared at year 100, but was estimated based on steady-state landscape conditions in simulation analyses by Harmon and Marks (2002), outlined below. Note that we make simple estimates, requiring major assumptions, which are outlined below, to comparatively analyze scenarios at a coarse resolution.

2.2. Modeled Landscape-Change Scenarios

The modeled scenarios portray a wide range of management approaches and intensities (Table 1). For each scenario involving harvest, we defined the land base subject to timber removal, the type and intensity of harvest prescribed for different zones, and spatial constraints or scheduling rules applicable to the scenario. No harvest was simulated in two of the scenarios, and one scenario simulated historical wildfire regimes.

Several landscape features were simulated in common across scenarios (Table 1). Nonforest vegetation types and lands unsuited for timber harvest because of low productivity and sensitive soils (as determined by the

Table 1. Selected characteristics of modeled landscape-change scenarios.

Landscape characteristics	Landscape-change scenarios					
	Intensive plantation	1990 forest plan	NWFP	AMA	Wildfire	Succession
Cutting rotation (years)	40	80	80	100, 180, 260	119-224[1]	--[2]
Retention (% live canopy)	0	0	15	50, 30, 15	30 (avg.)	--
Reserves (% area)	16	23	42	27	0	0
Fire	No	No	No	No	Yes	No
Context: regional conservation strategy	No	No	Yes	Yes	No	No

[1] Mean fire return interval.
[2] Not applicable.
Note: NWFP = Northwest Forest Plan, AMA = adaptive management area.

Willamette National Forest) were excluded from timber harvest in all scenarios, but might have been subject to burning in the wildfire scenario. Also, 40-ha reserves were defined around all spotted owl nest sites in all scenarios, but these areas were subject to fire. Fire was ignored as a disturbance process in all scenarios except the wildfire scenario. We recognize that some wildfire will occur in the future even with aggressive fire suppression, but excluded it from the modeled scenarios to better contrast tradeoffs and compatibilities.

A plantation forestry scenario, here termed the *intensive plantation scenario*, was intended to represent the highest rate of change, and is common on some private timberlands of the western Cascade Range west of Blue River and elsewhere in the Douglas-fir region. The scenario used a 40-year cutting rotation with aggregated harvest patches, 0% retention of live trees at the time of cutting, and minimal use of reserves for species protection. Riparian reserves (30 m on the main stem of Blue River and 18 m on other streams with significant use by fish for spawning, rearing, or migration) and maximum cutting unit size (64 ha) approximate current Oregon State Practices rules (Table 1). Note that forest practice rules change over time and that actual practices may deviate from regulations.

The *1990 forest plan scenario*, based on the Willamette National Forest plan finalized in that year (Willamette National Forest 1990), represented federal forest land management pre-dating the Northwest Forest Plan (NWFP). This scenario used an 80-year rotation length, dispersed harvest patches, 0% retention of live trees in most cutting units, and limited use of reserves. Special management areas for geologically unique areas and riparian reserves along fish-bearing streams were adopted from the Willamette Forest plan, as were constraints on timber harvest unit dispersion and size (24 ha maximum) of cutting units. The forest planning effort also included constraints to limit the extent of open canopy in areas of rain-on-snow effects, but no regional conservation strategy was involved.

The *Northwest Forest Plan scenario* (USDA and USDI 1994) was based on an 80-year rotation length, extensive riparian reserves approximately 55 m on each side of all non-fish-bearing streams (twice that along fish-bearing streams), and 15% retention of live trees in cutting units. Special management areas and constraints on dispersion and cutting unit size were the same as in the 1990 forest plan scenario. The NWFP sets a strong regional context for work in any included landscape. For example, a network of large late-successional reserves provides prime habitat for old-growth-associated species, including northern spotted owl. It also prescribes management of matrix lands where cutting may occur (such as land in this scenario) with the intent of providing dispersal habitat between late-successional reserves.

The *adaptive management scenario* (AMA) refers to the landscape plan in early stages of implementation in the Central Cascades AMA in western Oregon. The scenario was developed by incorporating interpretations of the historical wildfire disturbance regime to set cutting frequency, severity, and spatial patterns (Cissel et al. 1999). The resulting management approach involved three landscape areas with harvest rotation lengths of 100, 180, and 260 years with retention levels of 50, 30, and 15% of canopy cover, respectively. It also had aquatic reserves and landscape blocks designated to schedule harvest over time and space. This plan significantly reduced the extent of riparian reserves as designated in the Northwest Forest Plan, but added aquatic reserves in certain headwater areas (Cissel et al. 1999). A 40-year sequencing of harvest activity among subbasins was intended to reflect historical wildfire disturbance patterns more closely than in other scenarios. The AMA scenario is set within the regional conservation strategy of the Northwest Forest Plan, so it is strongly linked to management plans in surrounding areas.

The *wildfire scenario* was intended to represent the historical disturbance regime interpreted through reconstruction of fire frequency and severity by using tree-ring dating (Weisberg 1998, Cissel et al. 1999) and data on fire-size distributions from Pennington (2002). Fire frequency in the model ranged from 119 to 244 years. The scenario represented future landscape change as if historical wildfire frequency and spatial pattern were acting on the existing landscape, and into the future. Thus, the landscape change involved no harvest, no reserves, mixed disturbance severity (mean survival of approximately 30% live tree canopy), and no fire suppression. The TELSA model simulates fire by stochastically determining ignitions from the fire frequency distribution, growing a fire across the landscape to the extent that fuel conditions permit and up to the maximum size constrained by the fire size distribution. The upper size limits of successive fires, therefore, may decline.

The *succession-only scenario* represented no disturbance by fire, harvest, or other processes, so landscape change occurred only in response to forest growth over time.

2.3. Methods for Modeling and Assessing Landscape-Change Scenarios

Forest landscapes simulated in the TELSA model are described in terms of forested patch types defined by five age classes: 1 to 20, 21 to 40, 41 to 80, 81 to 200, and 201 plus years. Because many different age-class delineations are used in relevant studies (see Appendix 1, Chapter 1), we refer to age in years rather than by age-class name. In the modeling exercise, each age class was further split into subclasses based on the mean cover of live overstory canopy projected to remain after the initiating disturbance. Data from the Willamette National Forest, Blue River Ranger District (now McKenzie River Ranger District) were used to describe existing conditions. Each of these age classes has distinctive implications in the practice of forestry and in terms of ecological and hydrological effects. The area in the old forest classification, for example, is critically important ecologically because of the habitats and processes it supports, its limited extent in the region, and the length of time required to create more old forest. Many species are linked to old forest habitat; live and dead carbon stores are at a maximum and hydrologic processes are well-buffered in old forests. The youngest age class (less than 20 years old) is distinguished by having the lowest levels of carbon stored in live biomass (assuming no carryover from the previous stand (Harmon et al. 1986)) and minimal biotic control on rain-on-snow peak flow events. The youngest age class provides distinctive habitat important to many species (Johnson and O'Neil 2001). Middle-age classes can fill many of the same ecological roles as old forest, and will eventually grow into the oldest age class, if not disturbed. Wood quantity, quality, and economic incentives for managing for these different age classes vary greatly among ownerships.

2.3.1. Assessing landscape structure—Landscape metrics for the scenarios were calculated by using FRAGSTATS (McGarigal and Marks 1995) to analyze vector maps of existing and future landscape structure. We also used an edge-contrast matrix to represent relative edge contrast among all possible edge types in the landscape to calculate edge density (Cissel et al. 1999 p. 1223). The variety and abundance of patch types, patch size, location of patches, and edge density were selected as key indicators of landscape function.

2.3.2. Assessing timber volume—Prescriptions for thinning and regeneration harvest differed among scenarios. Volume estimates for previously unharvested stands were based on yield tables developed from empirical, stand inventory data stratified by timber type, and on modeling results from the Willamette National Forest plan (Willamette National Forest 1990). Estimates of timber volume yield for managed stands were based on stand inventory data and modeling studies summarized by Garman et al. (in press). Timber harvest values were based on three thinning intensities under the canopy retention levels specified in the scenarios. The prescription for the intensive plantation scenario, for example, consisted of no thinning and a 40-year rotation with 0% retention, whereas a portion of the AMA scenario consisted of three thinnings: a moderate thin at 40 years, a heavy thin at 60 years, and a light thin at 80 years. Note that there is much variation in the type and timing of thinning practices within an individual ownership, across ownerships, and through time, depending on factors such as market conditions and conflict over forest management.

2.3.3. Assessing carbon stores—Estimates of the carbon stored in the simulated landscape are based on results of studies by Harmon and Marks (2002) using their STANDCARB model, which is based on field, remote sensing, and modeling studies of carbon dynamics in the Blue River area and across the region (Harmon et al. 1986, Smithwick et al. 2002). STANDCARB tracks amounts of carbon stored in above- and below-ground organisms, including soil, of a simulated forest landscape that changes under different utilization and rotation lengths in management regimes, and different frequencies and severities of wildfire regimes. Regimes with longer rotations and greater retention level of live and dead vegetation result in more carbon stored in the landscape. Harmon and Marks (2002) simulate a particular regime until the landscape contains a uniform distribution of age classes. They then report the area-weighted amount of carbon stored as a percentage of the maximum stored in old forest for the forest type analyzed. The managed landscape-change scenarios in this chapter contain some no-cut reserves, which we assume have the maximum estimated carbon stores for the area. Thus, we computed total carbon storage in the landscape as an area-weighted average for reserve and managed areas by using values for the managed areas interpreted from Harmon and Marks (2002 Figure 8).

Following Harmon and Marks (2002) and Pennington (2002), we estimated the maximum store of carbon in the modeled landscape as 830 megagrams (Mg) C ha^{-1}, which is well within the range observed in forest plots in the Oregon Cascades (Smithwick et al. 2002). Based on Harmon and Marks (2002), we estimated that the managed part of a landscape produced by the intensive plantation scenario stored 20% of the maximum carbon storage. Managed areas of the 1990 forest plan landscape stored 40% of the estimated maximum (80-year rotation point on the high utilization-high severity line in Figure 8 of Harmon and Marks (2002)). Managed areas in the NWFP scenario also had an 80-year rotation but higher retention levels; 70% of the maximum potential storage was estimated to be stored across the landscape. Each of the three combinations of rotation length and retention level of the AMA scenario stored about 90% of the maximum, so we used this figure for the entire managed area in this scenario. Assuming a wildfire regime averaging moderate severity, we estimated the wildfire scenario would yield a landscape storing 70% of the maximum (Harmon and Marks 2002, Table 3).

2.3.4. Assessing hydrologic effects—Long-term records for small, experimental watersheds in and adjacent to the H.J. Andrews Forest have been used to evaluate and debate the response of peak, low, and annual flows to forest cutting and regrowth, and to a lesser extent, roads (Jones and Grant 1996, Thomas and Megahan 1998, Beschta et al. 2000, Jones 2000, Post and Jones 2001). The low frequency of large peak flows and scarcity of large basins with good flow records lead to small sample sizes and many confounding factors, which are problematic for analyses. Therefore, we do not address peak flow response to the modeled scenarios. To compare scenarios, we assumed that annual water yield was increased by 40% from the 1 to 20 year age class and by 25% from the 21 to 40 age class relative to older forest. For summer low flows we assumed that flow was reduced by 15% for the 21 to 40 year age class relative to all others. These values are based on observations of long-term records for the 10-ha Watershed 10 and other experimental watersheds at the H.J. Andrews Forest (J.A. Jones, Oregon State University, Corvallis, Oregon, personal communication, January 2003). Note that the Blue River modeling study covers a large basin, whereas the experimental watersheds from which these estimates are drawn are all 100 ha or less. We expect that the dominant watershed processes operating in the small watersheds also affect large watersheds, but larger watersheds do not exhibit this magnitude of response to younger age classes because they contain a wide range of age classes.

2.3.5. Assessing biodiversity effects—Many measures of biodiversity have been used to characterize richness, evenness, and other properties of fauna and flora in an area. Intensive field surveys have enumerated many species in many groups of organisms in the Blue River area.[1] These studies reveal strong tendencies for some species to be closely associated with early seral forest habitat and non-forest conditions, whereas others species are associated with late seral habitat, and yet others are generalists (Hansen et al. 1991, Halpern and Spies 1995, Johnson and O'Neil 2001). Hansen et al. (1991) argue that although old-growth forests have been the focus of biodiversity protection issues in the Douglas-fir region and, indeed globally, young forests with standing and down woody debris characteristic of natural, post-disturbance stands may be a critical, limited habitat type in some areas of intensive plantation management.

[1] See http:www.fsl.orst.edu/lter/data and look under data catalog/biodiversity for species lists.

We consider biodiversity in terms of two simple habitat indicators: the extent of young and old forest habitat provided by each scenario. These are distinctive, strongly contrasting habitat conditions; several scenarios differed dramatically in the extent of these habitat types, and provision of a range of habitat conditions is part of a coarse-filter approach to habitat management (Hunter 2002). Additional factors that may affect species include the arrangement of habitat patches within the modeled landscape and the state of the surrounding landscape, which can be expressed as the regional context of the management plan. We consider arrangement in terms of the extent of reserves, which is the direct product of the conservation strategy, and edge density and mean patch size, which are byproducts of the strategy.

2.4. Results

2.4.1. Modeled landscape age-class composition and structure—The composition of the landscape, expressed as the extent of forest vegetation in different age classes produced by each scenario, is an important reference point for judging landscape performance. The proportion of the landscape in each age class represents, at a coarse level, the mix of habitat types, the capacity to store carbon, and the potential for the landscape to either ameliorate or amplify hydrologic processes.

Several features were common to model runs for each scenario. Each scenario began with the vegetation age-class distribution and arrangement existing in the Blue River landscape as of 1995 (Figure 1). The distribution of age classes (Figure 1, year 0 in Figure 2) and landscape structures, as of 1995, include plantations resulting from roughly three decades of patch clearcutting in a landscape with age classes dating from wildfires that occurred in the 1500s and 1800s (Weisberg 1998). Projections of future age-class distributions across the landscape reflect a transition from the current landscape to an age-class distribution resulting from the rules for the scenario (Figures 2 through 7). This transition occurs over the maximum rotation length used in each scenario involving timber harvest; very young stands in reserves in 1995 may take up to 200 years to reach the oldest age class considered here. Forestland in a reserve status, which is effectively the entire landscape for the succession scenario and parts of the managed landscape scenarios, is not subject to management disturbance; therefore, it simply grows into older age classes over the course of the model runs.

We present the landscape-change scenarios in sequence from the highest disturbance frequency and severity to the lowest. Four scenarios have strong management components, which are modeled in a completely deterministic manner, thus restricting variability. The wildfire scenario, which is strongly stochastic, can be viewed as a reference system for a disturbance regime that historically maintained a range of habitat conditions that sustained native

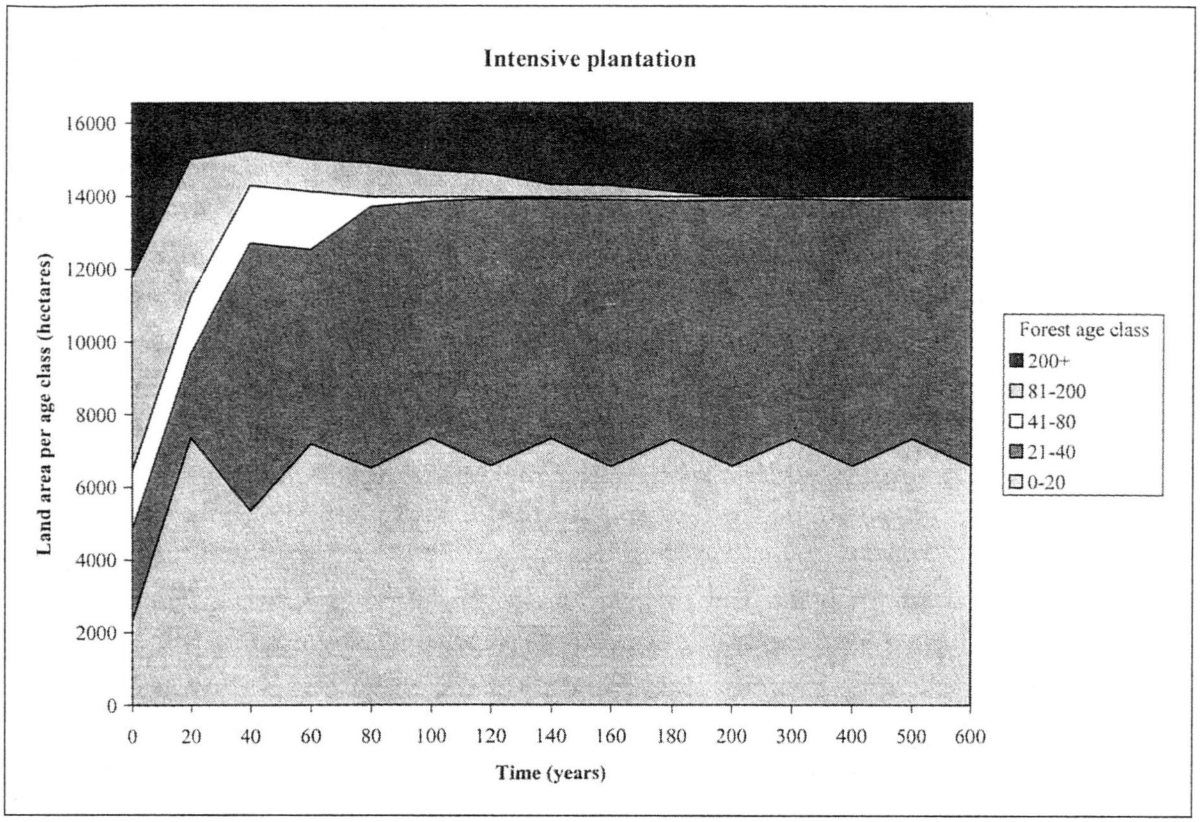

Figure 2. Distribution of forest vegetation age classes over the 600-year modeling timeframe based on the intensive plantation scenario (see Table 1 and text). Note that scale on time axis changes at year 200.

species in the landscape (Engstrom et al. 1999). The succession scenario, which is deterministic but gradually changing, may be considered both a reference condition and a management scenario because wilderness areas and other reserves commonly are managed in this manner. The current condition of the landscape reflects wildfire and about four decades of management similar to the 1990 forest plan, however, with fewer constraints than pertained to federal forestry in the pre-1990 period.

The *intensive plantation scenario* produced a landscape dominated (83% of area) by stands less than 40 years old as a consequence of short (40 years) rotations and limited area in reserves (Figure 2). Within 100 years the 41 to 200 year age classes were nearly eliminated from the landscape. Much of the reserve area in this scenario represented core area reserves for northern spotted owls, which likely would be much smaller on actual intensive plantation forestry lands, so the extent of young age classes in such lands may be higher. This scenario resulted in an initial decrease in mean patch size, characteristic of four of the six scenarios, and increased thereafter (Figure 3), amounting to a nearly 50% increase by year 100. Edge density declined by approximately 18% by year 100 (Figure 4), which in part, reflected the preponderance of very young forest across the landscape.

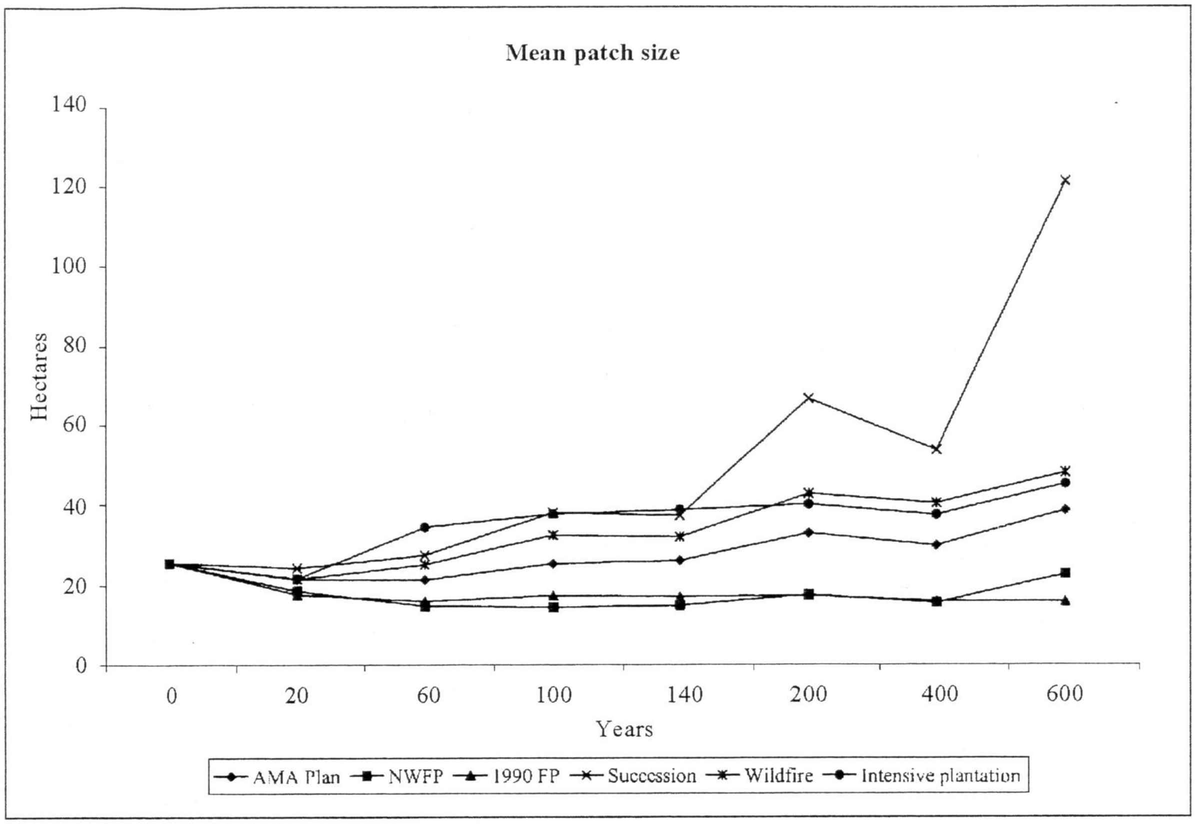

Figure 3. Mean size of vegetation patches in landscapes simulated over 600 years.

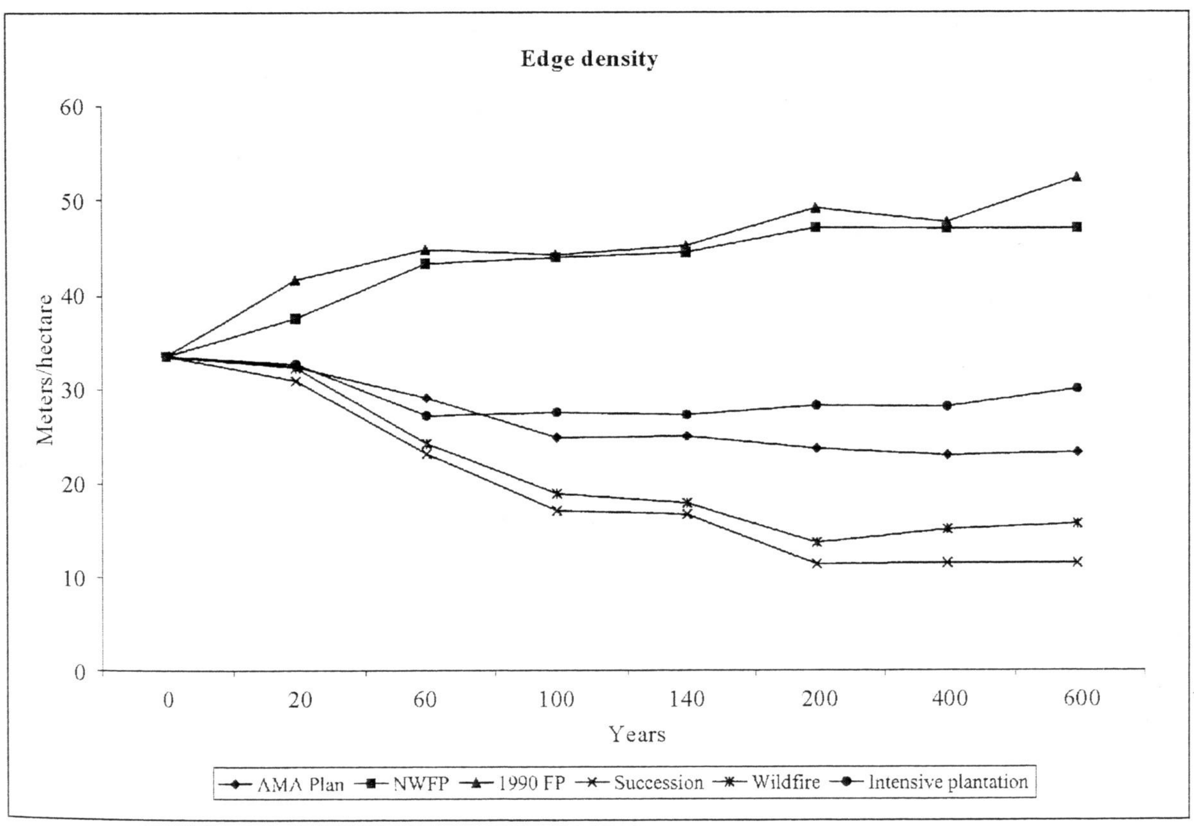

Figure 4. Density of edges between forest and open canopy areas less than 40 years in age.

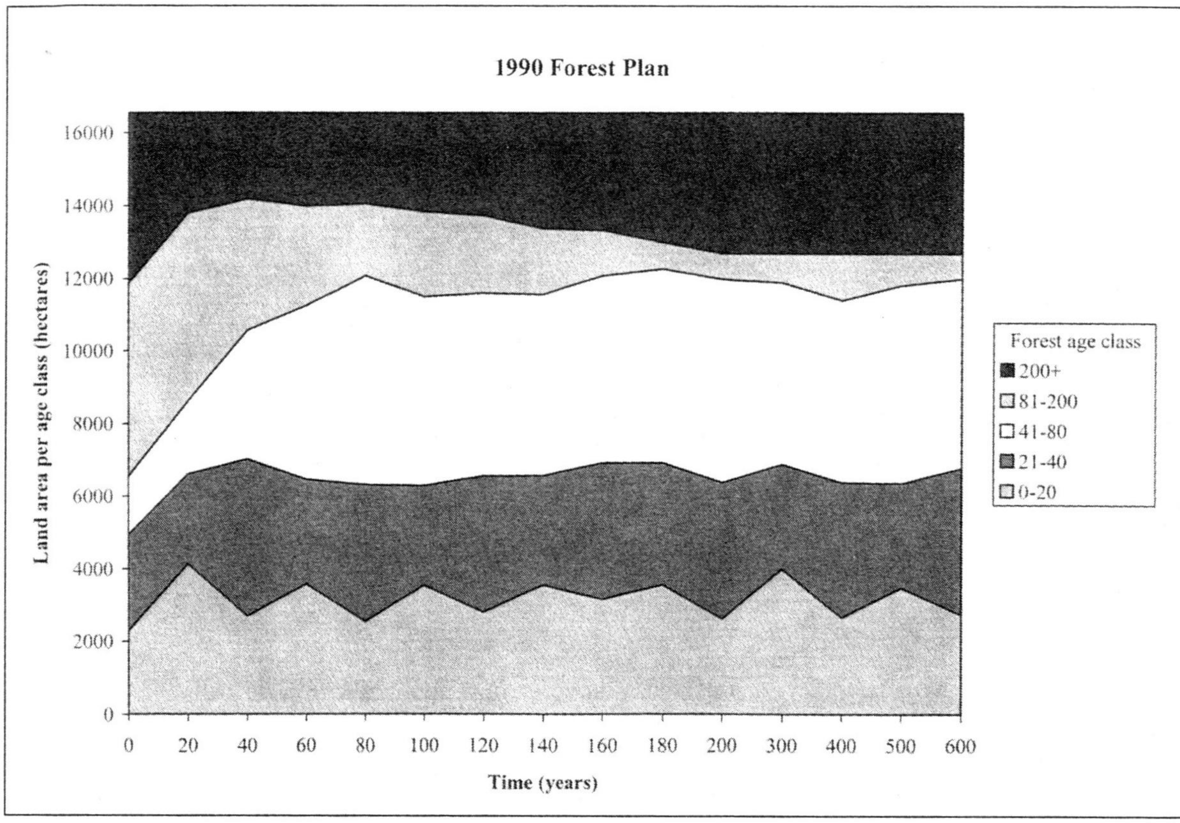

Figure 5. Distribution of forest vegetation age classes over the 600-year modeling timeframe based on the 1990 forest plan scenario (see Table 1 and text).

The *1990 forest plan scenario* yielded a landscape with extensive stands in age classes up to 80 years, the main rotation length used (Figure 5). The mature age class had a limited extent by year 180 of the simulation, producing a bifurcation in landscape structure with much of the landscape in stands either older than 200 years (22%) or less than 80 years (74%). Mean patch size under this scenario declined below the present size, and edge density increased about 30% by year 100.

The *NWFP scenario* also became dominated by stands less than 80 years (Figure 6). The mature age class was truncated to less than 4% of the landscape by year 200, and the landscape contained either old (44% of area greater than 200 years) or young (52% of area less than 80 years) forest age classes. This bifurcation of age class distributions over the landscape was expressed in absence of middle-age classes. The extensive network of riparian reserves in this scenario reduced mean patch size and increased edge density to levels similar to the 1990 forest plan.

The mix of rotation lengths used in the *AMA scenario* yielded a substantial area in the mature age class (Figure 7), unlike the other management scenarios. One consequence was that the AMA scenario produced the smallest area of forest less than 80 years old of the four active management scenarios. Mean patch size declined slightly over the first century and then grew slightly. Edge density declined 25% by year 100. Compared with other management scenarios,

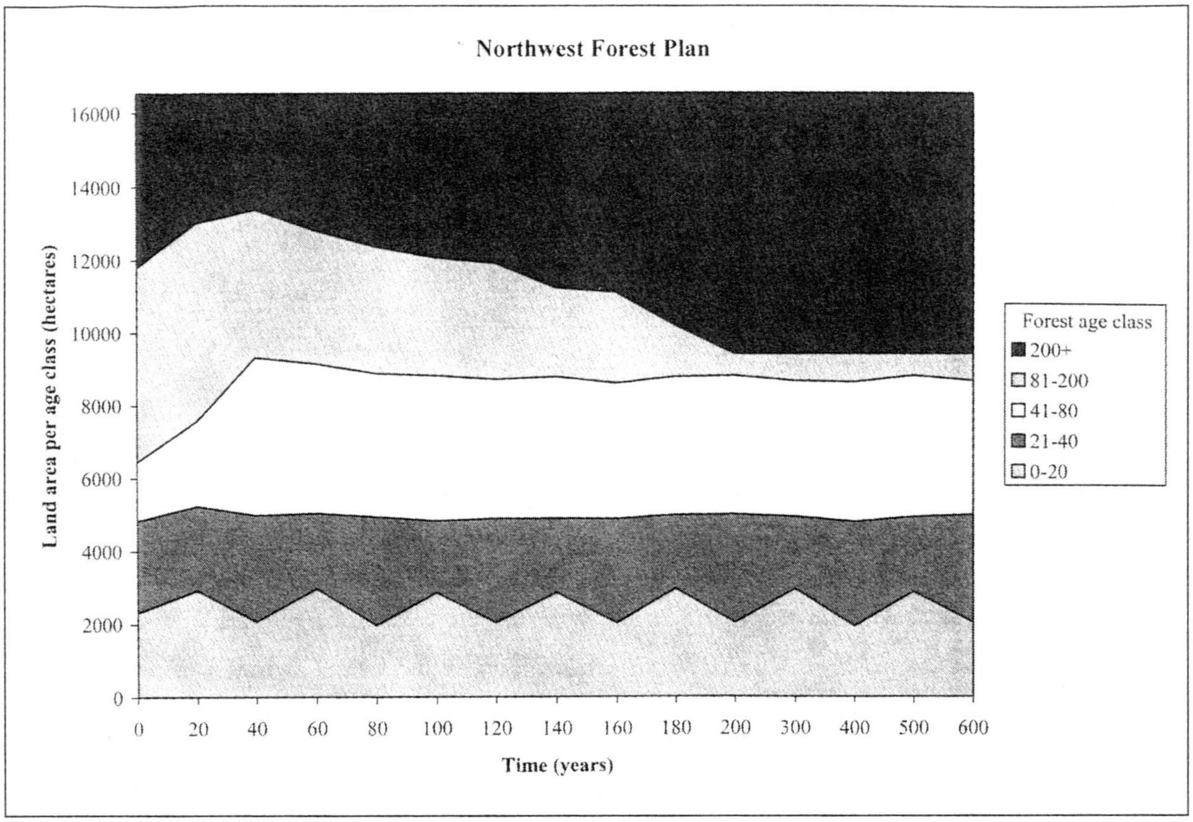

Figure 6. Distribution of forest vegetation age classes over the 600-year modeling timeframe based on the Northwest Forest Plan scenario (see Table 1 and text).

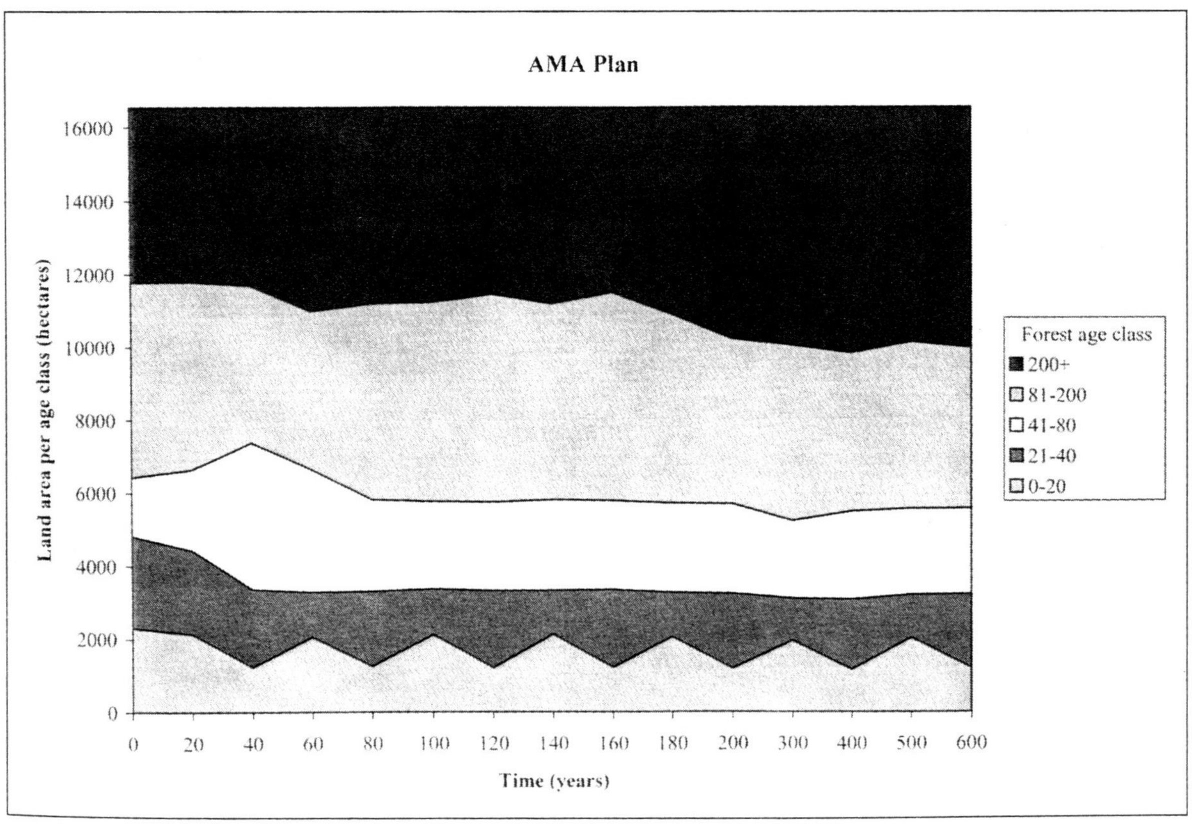

Figure 7. Distribution of forest vegetation age classes over the 600-year modeling timeframe based on the adaptive management area plan scenario (see Table 1 and text).

the AMA plan had more area in forest older than 80 years, larger patches, and more large, live trees in the young age classes. Somewhat surprising was the rapid equilibration of the AMA plan landscape despite the long rotations involved. This resulted, in part, because the current landscape, which involves a mixture of past clearcutting and wildfire-regenerated stands, is not very different in age-class distribution from that produced under this management scenario.

The *wildfire scenario* created the most complex distribution of age classes over time because of the variability in size and timing of fire disturbance (Figure 8). The youngest age classes (less than 40 years) can cover zero hectares after a 40-year period of no disturbance. On the other hand, a period of extensive fire can reduce the extent of old forest to less than 20% of the landscape. The mature age class appeared to be relatively stable across this simulation period, perhaps reflecting loss to fire and growth to the old age class balanced by growth of younger age classes. The wildfire scenario produced a modest increase in mean patch size and a substantial decrease in edge density, reaching a 45% reduction by year 100.

The *succession scenario* created a landscape that progressively lost the younger age classes (Figure 9) because no disturbances were planned and fire suppression was assumed to be completely effective. As stands aged, they entered older age classes and younger age classes gradually disappeared. The succession scenario sets an upper limit to mean patch size because patches grow together as edges become less distinct with the aging of adjacent stands. Mean patch size eventually reached 121 ha in this scenario, which in part represented the large number of small, persistent, nonforest patches scattered across the landscape. Edge density decreased accordingly.

2.4.2. Comparison of landscape composition and structure among scenarios—We compared the landscape-change scenarios in terms of distributions of age classes (Figures 2, 5 through 9), patch sizes (Figure 3), and edge density (Figure 4). A more complete comparison of the NWFP and AMA scenarios is provided in Cissel et al. (1999).

All management scenarios sustained classes up to age 40; the intensive plantation scenario maximized the area in these age classes. The 81 to 200 age class was nearly eliminated in the intensive plantation, 1990 forest plan, and NWFP scenarios, producing a landscape that was divided into old and young age classes with a broad gap in the middle age class. The ultimate extent of forest over 200 years was simply a matter of reserve area in each scenario, except in the AMA scenario where areas with a 260-year rotation contained some older, "managed" forest. The succession-only scenario was distinguished from the others by the absence of disturbance, which resulted in the younger age classes successively disappearing as stands aged and entered the next age class.

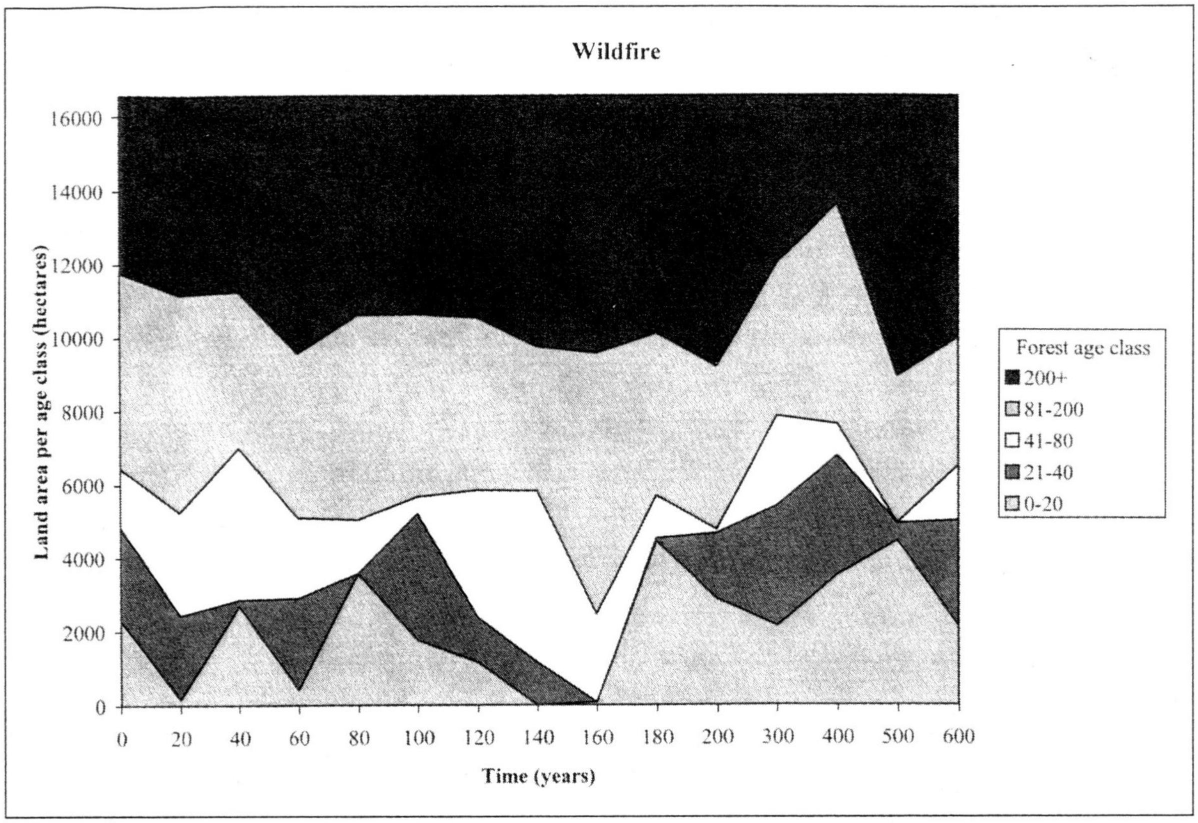

Figure 8. Distribution of forest vegetation age classes over the 600-year modeling timeframe based on the wildfire scenario (see Table 1 and text).

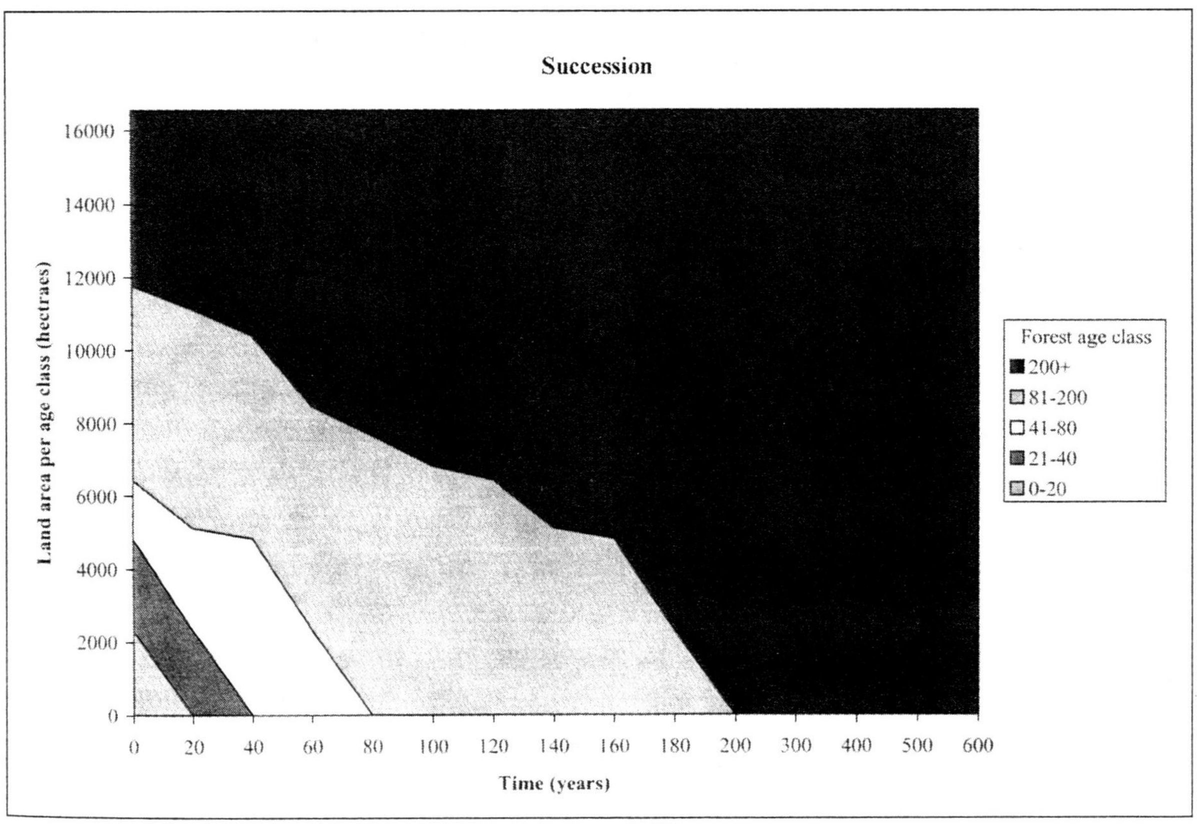

Figure 9. Distribution of forest vegetation age classes over the 600-year modeling timeframe based on the succession scenario (see Table 1 and text).

Table 2. Estimated properties and outputs of scenarios at year 100 for wood yield, extent of young and old forest habitat, annual water yield, and summer low stream flow. Carbon storage is estimated for the landscape once the scenario is fully implemented, based on modeling of Harmon and Marks (2002).

	Landscape-change scenarios					
Landscape properties	**Intensive plantation**	**1990 forest plan**	**NWFP**	**AMA**	**Wildfire**	**Succession**
Timber yield (10^6 m^3 y^{-1})	1.47	1.13	0.70	0.47	0	0
Carbon stored (Mg C ha^{-1})	272	447	686	769	581	830
Habitat (% of area):						
0-20 years	44	21	17	13	11	0
200+ years	11	16	27	32	36	59
Streamflow (proportion of old forest flow):						
Annual yield	1.28	1.13	1.10	1.07	1.09	1.0
Summer low flow	0.94	0.98	0.98	0.99	0.97	1.0

Note: NWFP = Northwest Forest Plan, AMA = adaptive management area, Mg C= megagrams of carbon.

The wildfire scenario resembled the management scenarios because it sustained a mixture of age classes over time. However, the irregular occurrence of fire, in contrast with regular cutting in management scenarios, produced greater temporal variability in the wildfire scenario. Wildfire was expected to produce a large range of patch sizes, high spatial variability, substantial retention of live trees (mean of 30% canopy cover) in disturbance patches, and abundant dead wood. The broad mature age class (81 to 200 years) showed less variability than the three youngest age classes, which spanned only 20 or 40 years each, simply as an artifact of length of the defined age class.

Mean patch sizes of the intensive plantation and AMA plan scenarios generally followed that of the wildfire scenario, exhibiting a slight upward trend after a small initial drop. These three scenarios eventually reached a mean patch size that was 32 to 40% of the mean patch size in the succession scenario. By design, the AMA plan followed the wildfire scenario with greater fidelity than the other scenarios (Figures 3, 4, 7, 8; Table 2). The fit was strongest for age-class distribution and less so for edge density and patch size because the large size of some wildfire patches was not considered socially feasible in a management scenario, even one as adventuresome as the AMA plan. The NWFP and 1990 forest plan scenarios followed a similar relatively level trend line. Mean patch size generally stayed within the range of 12 to 14% of that of the succession scenario over time for these scenarios, with the highest point (19%) reached after 600 years in the NWFP scenario. The timber harvesting in these two scenarios was done in smaller, widely spaces patches because of extensive riparian reserves and 80-year rotations. The net effect of the NWFP and 1990 forest plan scenarios was a highly fragmented landscape with high edge density, hence high vulnerability to windthrow and other edge-related phenomena.

2.4.3. Timber yield comparisons—Timber volume extracted, a traditional measure of wood production from a landscape, is one measure of economic value. The timber volume estimated for these scenarios reflects the vagaries of harvest scheduling models, including the representation of existing age classes in the model. Because harvest levels in this model were regulated to sustain the area harvested over time, volume fluctuations result. In particular, higher volumes resulted in the short term because many of the stands over 80 years carried greater volume than their replacements. This trend was most noticeable in the scenario that harvested on the shortest rotation (intensive plantation scenario), and was not significant for the AMA plan where very long rotations were used.

The volume produced by each scenario reflects the area available for timber harvest, the frequency of harvest, and the intensity of harvest (Table 1). Year 100 results are representative of future decades, and with one exception, reflect the relative differences among scenarios for the first century as well. Not surprisingly, the intensive plantation scenario produced the greatest annual amount (1.47×10^6 cubic meters in year 100), followed by the 1990 forest plan (1.13×10^6 cubic meters in year 100, or 77% of the intensive plantation scenario), the Northwest Forest Plan (0.70×10^6 cubic meters in year 100, or 48% of the intensive plantation scenario), and the AMA plan (0.47×10^6 cubic meters in year 100, or 32% of the intensive plantation scenario).

2.4.4. Carbon stores comparisons—Estimates of stored carbon for the scenarios were based on the final implementation of the landscape-change scenarios rather than carbon storage in landscape simulated at year 100 because the work of Harmon and Marks (2002) makes such an estimate possible and lag effects in stored carbon complicate the use of a year 100 analysis point. The estimated carbon stores on the landscape scenario ranged from 272 Mg C ha^{-1} in the intensive plantation scenario to 830 Mg C ha^{-1} in the succession landscape by the end of the simulations (Table 2). Both the extent of reserved area and the intensity of stand treatments in managed areas (rotation length and retention level) strongly affected carbon storage values for landscape scenarios as a whole. The reserve areas, which ranged from 16% of the intensive plantation scenario landscape to 42% of NWFP, were assumed to accumulate the maximum carbon storage for this landscape (830 Mg C ha^{-1}). The proportion of maximum storage sustained in managed parts of the simulated landscapes ranged from 20% for the high-utilization, 40-year rotation of the intensive plantation scenario to 90% for the high-retention, long-rotation AMA scenario. The wildfire scenario sustained lower carbon stores than either the NWFP or AMA scenarios as a result of the assumptions that no fire occurs in either reserve or managed parts of these scenarios, and that periodic wildfire suppresses carbon accumulation by burning it off and initiating young stands.

2.4.5. Biodiversity comparisons—The scenarios provided dramatically different extents of early (1 to 20 years) and late (80 plus years) seral habitat (Table 2). The intensive plantation scenario emphasized young stands, and the succession scenario was dominated by old forest. We looked to the wildfire scenario for an indication of the historical distribution of age classes and found early-seral stands over 11% and late seral stands over 36% of the landscape. These proportions are very similar to the AMA plan, but deviate by several hundred percent for young and old age classes of the intensive plantation scenario. The NWFP had about 50% more early and 25% less late seral forest than the wildfire scenario.

These management scenarios also differed in landscape pattern, retention levels of live trees in harvest areas, habitat distribution in time and space over the planning area, and regional context—all of which may strongly influence biological diversity. Landscape patterns in the NWFP scenario contained the unnatural aspect of extensive riparian reserves along all streams, which produced a landscape with high edge density and restricted size of individual opening. These conditions may favor some species but not others. Northern spotted owls, for example, may be more prone to predation by great horned owls *(Bubo virginianus)* in an edge-rich landscape, but riparian amphibian species that favor old-growth forest conditions may benefit by an extensive, old-forest riparian network. The AMA scenario was designed to provide patch size distributions and level of connectivity similar to the wildfire scenario. The wildlife scenario may provide the full spectrum of landscape conditions that native species have occupied over the past few millennia. Reserve systems of the NWFP and AMA scenarios differed with respect to riparian and aquatic systems. The AMA scenario had more diversity, which may benefit amphibian species. Landscape patterns of the other management scenarios involved less extensive reserve systems (unless we consider the succession-only scenario as a single, big reserve), which may prove detrimental to biodiversity, if we later learn that reserves are critical components of managed landscapes that sustain species.

Retention levels of live trees in harvest areas differed among some scenarios, with the AMA scenario providing the most diverse set of conditions. Field studies in this area reveal that bird communities shift in composition across a range of retention levels (Hansen et al. 1995), suggesting that a variety of stand structures and compositions may benefit from this type of habitat diversity. Other management scenarios provided a more restricted range of within-stand habitat complexity, which may limit habitat for some species.

Habitat distribution in time and space over the planning area varied substantially across the scenarios. Management scenarios underwent transitions from the current conditions to the simulated steady-state landscape patterns produced by the scenario. Some distinctive landscape structures emerged over the transition, such as the spatial bifurcation of the NWFP landscape with old forest near streams and stands less than 80 years in upslope areas. The wildfire and AMA scenarios, on the other hand, produced greater diversity of spatial patterns and forest age classes, with likely benefits to some species. In contrast to the modeled steady-state conditions of the management scenarios, wildfire produced irregular patterns in time and space. The complex role of wildfire in sustaining and also threatening native species in the landscape is worthy of further consideration.

The regional context of landscape analyses may influence the effects of a particular landscape on protection of biological diversity. Conservation strategies for some species, such as the northern spotted owl in the Douglas-fir region, involve broad-scale plans with networks of large reserves. The NWFP and AMA landscape-change scenarios in this study occur in matrix land nested among large reserves in the nearly 10 million ha, regional NWFP. Consequently, these scenarios may do a better job of protecting biodiversity in the region as a whole than the other management scenarios, which do not have those broader conservation elements.

2.4.6. Hydrology comparisons—The assessment of hydrologic effects of the different modeled scenarios is made in terms of annual flow and summer low-flow. We based this evaluation on extent of the 1 to 20 and 21 to 40 year age classes, which may exhibit increases in these flow parameters, based on long-term, experimental watershed studies in the nearby H.J. Andrews Experimental Forest. We estimated that annual flows would be approximately 10% higher under most management scenarios relative to the landscape fully forested in stands older than 40 years (the succession scenario) (Table 2). The one exception was the intensive plantation scenario, which was projected to have nearly 30% higher annual streamflow because of its extensive area of young forest. Annual water yield under the intensive plantation scenario was estimated as 17% higher than that of the wildfire scenario, and the other scenarios involving forest disturbance differ by only a small percent. Summer low-flow values were about 6% lower in the intensive plantation scenario than in the succession scenario and only 3% lower than in the wildfire scenario (Table 2). All other scenarios differed by only 1 to 2%.

As is the case with the biodiversity assessment, the effects of vegetation type and pattern on streamflow are poorly known. Recent studies in Watershed 1 on the H.J. Andrews Experimental Forest, for example, suggest that a vigorous riparian stand of red alder (*Alnus rubra* Bong.) can reduce summer low-flows more than a conifer-dominated riparian zone (Bond et al. 2002). The extent of alder-dominated riparian zones is, in part, a reflection of recent disturbance by management activities and flooding. Thus, riparian areas can have potential hydrologic effects disproportionate to their extent across a watershed, and they are sensitive to species shifts and disturbance. We have not attempted to account for these phenomena because their magnitude and geographic extent are unknown.

In most cases, the magnitude of effects on annual and summer low-flows were small relative to the succession scenario and even more similar to flows under the wildfire scenario.

2.4.7. Comparing scenarios: compatibility perspectives—Assessment of selected effects of the different landscape-change scenarios revealed tradeoffs between wood production and landscape properties that involve positive and negative, as well as weak and strong interactions. The amount of carbon stored in the landscape relates directly to the extent of older forest (80 plus years) with its associated high pools of live and dead carbon, and to rotation length and density of retained, live trees. For example, in the AMA scenario the long rotations produced a 68% lower timber yield, 2.8 times higher carbon stores, and nearly 3 times more old-forest habitat than the intensive plantation scenario. On the other hand, early seral habitat (1 to 20 years) is directly correlated with the rate of timber yield; it increases by a factor of 3.38 while timber yield increases by 3.13 in the intensive plantation scenario. The streamflow factors we examined were less sensitive to change in forest age-class structure, varying by less than 20% in the case of annual flow from small watersheds and less than a few percentage points for summer low-flow across the range of modeled management scenarios.

In narrow terms of compatibility between commodity and ecological objectives, wood that goes into the human use sector is not retained on the landscape where it can perform ecological functions. Currently, we cannot define with certainty specific thresholds of wood extraction that lead to unacceptable ecosystem consequences; current debate about species viability under different habitat conditions and management regulations is a prime example of attempts to identify such thresholds. Although we recognize this uncertainty, tradeoffs can be managed in several ways to maximize benefits. Modifications of stand-scale treatments can benefit ecological functions and carbon stores. For example, Harmon and Marks (2002) suggest there are substantial gains in carbon stores on the landscape when live and dead trees are retained within cutting units, and certain bird (Hansen et al. 1995) and lichen (Berryman 2002) species typical of older forest can be sustained in managed sites with retention of standing live trees.

Note that factors in addition to those considered in this analysis are at issue when considering tradeoffs between forest commodity extraction and ecological values of forests. Technical issues that we avoided in this modeling study include interactions of natural disturbance processes, such as wildfire and windstorms, with landscapes produced by the management plans; effects of roads on many ecosystem components, such as exotic plants and landslides; effects of forestry on floods; and habitat for threatened species. Social issues extend to public enjoyment of native landscapes through recreation and even simple perception of their existence. Operational landscape plans need to consider these interactions and integrate strategies with usable applications. Broader policy issues in regional forest management plans include shifts of wood production among regions, ownership, and nations with attendant social and ecological consequences.

Given the dynamic nature of landscapes in Oregon and Washington, maintaining future management options is an important consideration when comparing management approaches and taking a long-term perspective of compatibility. A detailed comparison of the AMA and NWFP plans led Cissel et al. (1999) to conclude that the more extensive mature (81 to 200 year) age class of the AMA plan may help maintain future options. For example, if shifts in policy dictate that more old forest should be grown and preserved, this can be accommodated more quickly from the mature age (81 to 200 year) age class than from the younger age classes that dominate the NWFP landscape. Furthermore, the mature age class provides many ecological functions characteristic of old forest, and is the source of future old forest.

3. Perspectives on Landscape Management

Reflections on this modeling work and past experiences working with public land management issues shape our perspectives on future land management. Over the years we have interacted with other scientists, managers, and policymakers on hundreds of field tours and workshops; attempted to implement the AMA plan (Cissel et al. 1999); observed the evolving relevance of science findings to forestry policy; and considered the history of change in forestry policy in the region and more broadly. These experiences lead us to make five general points concerning landscape management:

- Take the long view.
- Take a multiscale approach.
- Historical landscape conditions are a useful reference for considering compatibility.
- Landscape change is inevitable.
- Chart the future with multiple learning approaches, especially adaptive management.

These points are relevant to achieving compatibility among societal objectives for forest landscapes.

3.1. The Long View

Forest landscape management planning generally takes a 10- to 20-year view into the future, a small tick mark on the scale for forest development and ecological change. Landscape change reflects interactions among the slow processes of succession, climate change, cumulative effects of chronic disturbances, and legacies of past landscape structure, as well as abrupt changes due to biophysical or social disturbances. The pace of these phenomena influences outcomes. Distinctive attributes of old forest, for example, develop over centuries, and the legacy of dead wood from an old forest may persist for more than a century into the period of intensive forest management. Given the long time scales of forest stand and landscape change, taking the long view helps illuminate potential outcomes that would otherwise remain obscure.

Modeling future landscapes, is a valuable approach to understanding future landscape change. Examining the evolution of landscape structure over time can reveal unintended consequences of simple landscape-change rules. For example, elimination of the mature age class in the Northwest Forest Plan was not foreseen in the FEMAT analysis (FEMAT 1993). In another example, Franklin and Forman (1987) demonstrated some of the potential problems of dispersed patch clearcutting, partially represented in the 1990 forest plan scenario, through a simple, checkerboard conceptual model. Their analysis, which looked ahead several decades after the patch clearcutting system had been in use for only a fraction of the first rotation, was pivotal in framing the forest fragmentation issues of the late 20th century. We believe that similar modeling of future scenarios, such as we have begun here, is critical for understanding the ramifications of concepts across the landscape and across time. Given the slow pace of forest development through time and space, it is essential to model the future for more than one rotation. Critical challenges to carrying out long-term plans include change in private land ownership and political volatility in public lands policy. Regardless of context, the objective of the long view is to better understand concepts and their potential outcomes, and to communicate with others; these are essential ingredients in finding compatible forest uses.

3.2. A Multiscale Approach

Forest management is evolving from a focus on individual stands to a consideration of scales that range from the individual tree to landscapes, and their context at regional and even global scales (e.g., as influenced by commerce and certification) (Lindenmayer and Franklin 2002). This multiscale perspective is relevant to achieving compatibility because different management and ecological objectives must be addressed at appropriate scales. It is impossible to achieve compatibility across all objectives at a single scale, and many issues cannot be accommodated at only one scale. Protection of wide-ranging species, for example, is addressed at the scale of their range, but other species have smaller ranges. Wood supply issues operate in the global marketplace, yet local issues of wood supply are felt in timber-dependent communities. Efforts to efficiently link assessment and planning at multiple scales are still embryonic.

3.3. The Historical Landscape as Reference

Many short-term studies in ecology and hydrology use plots or small watersheds in stable, old-forest areas as controls or reference points. However, longer term and larger landscape views naturally lead to consideration of landscape dynamics. In disturbance-rich areas, such as Oregon and Washington, it is important to consider the role of disturbance regimes in sustaining native species and ecological processes (e.g., nitrogen fixation mediated by species present in particular successional stages). Many scientists and conservationists have argued for using historical disturbance regimes as a reference point to evaluate and chart future management in landscapes where the objective is to sustain native species and processes (Engstrom et al. 1999). As we discussed in the modeling exercise above, absence of disturbance in disturbance-prone landscapes can remove habitat conditions essential to some species.

Landscapes affected by historical disturbance regimes form useful, even essential, reference systems when considering compatibility among land use objectives. This is particularly true in the case of federal lands, which have high requirements for sustaining native species and some expectation for commercial wood production. Maintaining components of the natural disturbance regime is essential for maintaining some species; critical disturbance influences may include frequency, severity, and spatial pattern of disturbance as well as mechanisms, such as heat and sediment deposition. Whether for commodity extraction or ecological objectives, management actions can suppress, maintain, and augment native disturbance processes, or replace them with non-native processes. The consequences of any of these options should be considered in a compatibility assessment.

3.4. Inevitability of Landscape Change

Forest policy has experienced decades of relative stability punctuated by abrupt change, suggesting that surprising shifts in policy are an important component of landscape management. Forest Service management, for example, began with 50 years that emphasized stewardship while minimizing wood production. This was followed by rapid expansion of timber production in the post-World War II period until it was dramatically curtailed around 1990 as emphasis on species conservation began to dominate federal forest management. What does this policy volatility at the multi-decade time scale mean for landscape management? The planned and the realized future landscapes may differ substantially as a result of social and natural events. Policy shifts and natural processes, such as fire, wind, and insect outbreaks, create persistent and convulsive change in the drivers of landscape change and in the landscape itself. Land use legacies may be hard to erase with new policies because some landscape properties have substantial inertia (Wallin et al. 1994, Foster et al. 2003). Managed landscape patterns can form structures that are particularly vulnerable to disturbance by natural processes, such as windthrow at edges of cutting units (Gratkowski 1956, Sinton et al. 2000). Thus, natural processes commonly disrupt the planned course of landscape change.

In another example of the inevitability of landscape change, we note that each of the scenarios depicted here exists in Oregon and Washington, and each has experienced change or may do so in the near future: industrial forestry is pushed politically to reduce the intensity of management and be more spatially explicit in its application; the 1990 forest plan approach was declared illegal in litigation surrounding protection of the northern spotted owl; the Northwest Forest Plan, which revised the 1990 forest plan, has not approached the harvest levels projected; the AMA plan may require modification if future legislation sets an age limit on harvest; the historical wildfire regime has been thoroughly altered by fire suppression and other aspects of forest management; and the succession-only scenario will not be fully manifested on the landscape because of unsuppressible wildfire, windthrow, and other processes.

3.5. Charting the Future with Multiple Learning Approaches

Lessons about landscape change are best garnered by using multiple approaches: modeling, retrospective analysis of real landscapes, and sustained adaptive management in implementation of multiple management systems. Each of these approaches has strengths and weaknesses, but using them in concert builds a strong base for learning.

A critical approach to learning about landscape-change processes and consequences is to capitalize on the surprising diversity of landscape management systems operating within even restricted regions. Cohen et al. (2002) and Spies et al. (2002), for example, used remote sensing to examine pattern and rate of forest landscape change in western Oregon for mixed ownership and management systems. Most landscapes are hybrids of several approaches because of temporal or geographic factors. The current landscape of Blue River study area (Figure 1), for example, is a composite of wildfire and management similar to the 1990 forest plan scenario. Many landscapes, especially those covering larger areas, contain mixtures of land ownerships with associated landscape management approaches and resulting differences in pattern and function (Spies et al. 2002).

This landscape dynamism calls for us to accept our limited ability to predict the future and appreciate the value of taking an adaptive approach to management. Gunderson et al. (1995), for example, argue that failure to operate within adaptive, learning organizations may doom natural resource systems to operate in cycles punctuated by crisis. Formal adaptive management involves incremental learning through designed tests of alternative approaches to meeting management objectives, followed by monitoring and adaptation of future practices (Holling 1978, Walters and Holling 1990). This permits an incremental approach to seeking compatibility among societal expectations of forests.

Whereas explicit, formal adaptive management seems entirely appropriate for charting the future of landscape management systems, it is very difficult to carry out such programs. In Oregon and Washington, a system of ten Adaptive Management Areas designated by the NWFP met with limited success and ultimately lack of funding (Stankey et al. 2003). However, we persist in implementing the AMA landscape management scenario by using an adaptive management approach (Cissel et al. 1999) despite the challenges that have been raised over the years. Some land management agency (USDA Forest Service and Bureau of Land Management) biologists had difficulty appreciating the landscape perspective and chose to focus on achieving maximum species protection through stand-scale restrictions on harvest. Some agency leaders questioned exploring new options to the NWFP while it is in early stages of implementation despite the specific charge from the NWFP to test alternative approaches in AMAs (USDA and USDI 1994). Criticism of the AMA plan from outside the agency took many forms, including "this looks like a shallow excuse to cut more trees," and "this looks like another excuse to cut fewer trees." Others have viewed the testing of new ideas about landscape management with great interest and enthusiasm. The full spectrum of views is expressed in public discussions taking place in numerous field and workshop forums with the net effect of advancing collective understanding of the social and ecological dimensions of landscape management. A critical component of this process has been the close partnership of research and management, which is leading to new approaches to management with good credibility in both management and science arenas.

In summary, landscape science and management are at a critical juncture. Management and policy issues raise difficult challenges to which science can, at best, give only limited help. The new questions require greater integration across more disciplines than ever before, and new approaches to science beyond traditional, reductionist approaches (Holling 1995). Science needs to broaden its scales and degree of integration to address the challenge; however, science leads to no single, best, sustainable approach to maximizing compatibility among objectives, in part because the standards and objectives, both social and scientific, evolve over time. Ultimately, compatibility is a social choice.

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Compatible Forest Management

Edited by

Robert A. Monserud

USDA Forest Service Pacific Northwest Research,
Portland, Oregon, U.S.A.

Richard W. Haynes

USDA Forest Service Pacific Northwest Research,
Portland, Oregon, U.S.A.

and

Adelaide C. Johnson

USDA Forest Service Pacific Northwest Research,
Juneau, AK, U.S.A.

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