AN ABSTRACT OF THE DISSERTATION OF

Deana D. Pennington for the degree of Doctor of Philosophy in Geography presented on April 1, 2002.

Title: Structural and Functional Comparison of Human-impacted and Natural Forest Landscapes in the Western Cascades of Oregon

Abstract approved:

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Julia Allen Jones

This study compared effects of human and natural wildfire disturbance on age class distribution and associated ecosystem properties of forests in a 15,670 km^2 area of the western Cascades of Oregon. The study site is characterized by three forest use types: low elevation, intensively harvested private industrial lands; mid elevation partially harvested public forest lands; and high elevation wilderness lands. Hypothetical landscapes were constructed, representing wildfire conditions, the current (1995) condition, and forest management strategies. The spatial pattern of forests in each landscape was depicted by the distribution of four forest age classes (0-30, 31-80, 81-200, and 201+ years). Wildfire-affected forests were simulated for 3000-year periods using an existing model with six alternate parameterizations obtained from fire history studies. Forest patterns on the 1995 landscape were obtained from classified remotely sensed imagery. Three landscapes representing hypothetical forest management strategies were constructed: 1) riparian buffers, 2) reserve allocations, and 3) multi-age rotation harvests. Forest age class amounts, spatial distribution, and arrangement were compared between wildfire-affected, 1995, and managed landscapes. Wood production, carbon storage, water yield, and

species diversity of each landscape were evaluated using simple measures from empirical studies relating forest structural patterns to ecosystem properties. Comparison of the 1995 landscape with simulated wildfire-affected landscapes indicates that private industrial lands in 1995 had more young forest, whereas wilderness lands had more old forest, than most, or all, simulated wildfire conditions. Because private industrial and wilderness areas deviate from the range of natural (wildfire-affected) variability in opposite directions, the study area as a whole is within the probable range of natural variability over the past few millennia. Forest ages classes on public non-wilderness lands were within the range of simulated wildfire-affected landscapes. Ecosystem properties of the current and managed landscapes were within the range of variability of those properties in the simulated wildfire-affected landscapes. Given the caveats imposed by the simplistic assumptions, some ecosystem properties appear to be sensitive to the arrangement of forest age classes. Future studies would benefit from the use of structurally based, rather than age-based, forest classes, for evaluating forest pattern effects on ecosystem properties.

Structural and Functional Comparison of Human-impacted and Natural Forest Landscapes in the Western Cascades of Oregon

by
Deana D. Pennington

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APPROVED:

Major Professor, representing Geography

Chair of Department of Geosciences

Dean of Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Deana D. Pennington, Author

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Structural and Functional Comparison of Human-impacted and Natural Forest Landscapes in the Western Cascades of Oregon

Chapter 1 Introduction

Objective and Significance of the Study

Change is inherent in the earth system, resulting from causal agents that disturb some parts of the system, creating a cascade of cause and effect that may propagate throughout the remainder of the system and through time (Perry, 1994; Nakamura, 2000. While much current discussion centers on human disturbance, the landscapes around us have been profoundly disturbed in the past through purely natural (non-human) disturbance processes. Catastrophic processes such as severe weather systems, floods, wildfire, and volcanic eruptions have combined with the slower processes of erosion, uplift, vegetation succession, and ongoing climate change to produce a remarkable assortment of landscapes throughout time. Disturbance is normal for the system, and in fact, is essential to creating spatial and temporal variability that provides the complex template on which diverse species and ecosystem processes operate (Spies and Turner, 1999). Spatial and temporal variability produce patterns on the landscape, and those patterns influence both the spatial location and timing of subsequent disturbance processes (Turner, 1989).

The dynamics of changing landscapes have been paralleled with dynamically changing organisms, adjusting through migration and adapting through evolution to those landscapes. The interplay between changing landscapes, organisms and communities is complex, and includes feedback mechanisms such that organisms not only respond to changes in the environment, but also themselves alter the environment. Adaptation to changing landscapes also occurs in biophysical surface processes such as hydrology, soil development, and the flow of energy, soil, sediment, and nutrients through the system.

As we endeavor to understand the consequences of human actions, multidisciplinary, synthetic approaches to studying ecosystem processes become necessary (Gober, 2000). Decades of reductionist science have greatly enhanced our understanding of the details of many processes. Calls for broader-scale synthesis are based on the desire to study the interactions between different processes; to understand how processes work in concert (Landres et al., 1999; Holling, 2001). The challenge of synthesis is to determine which details are important at the broader, integrative scale, and which details may safely be ignored (Levin, 1992) or subsumed in simple metrics.

This study is a synthesis of interactions between human and natural disturbance agents and potential consequences of those interactions for the ecosystem in the western Cascades of Oregon (Figure 1.1). It was conducted at a broad landscape scale and the temporal scale of the past few millennia, incorporating disturbance history information from the past 500 years (Figure 1.2). In the Pacific Northwest, natural disturbance, harvest disturbance and vegetation succession operate simultaneously to create landscape patterns to which other processes respond. Some interactions are well understood, most are not, and their combined effects are largely unknown. This is complicated by nearly a century of fire suppression that has altered the natural fire cycle.

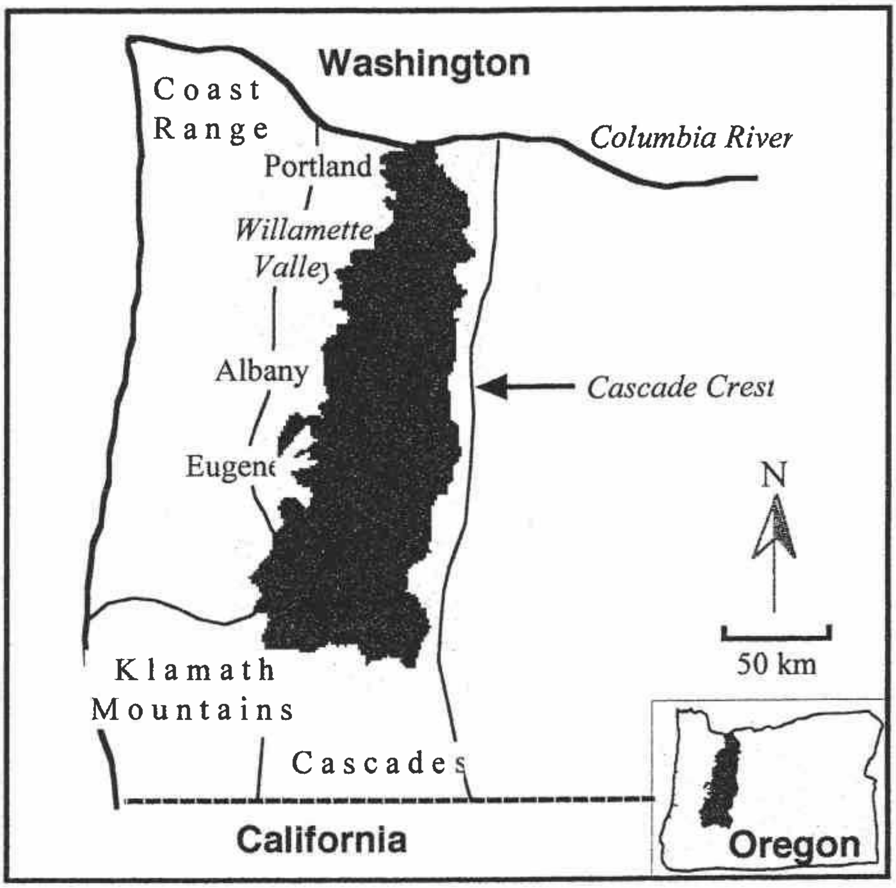


Figure 1.1. Study area: 15,670 km^2 in the western Cascades of Oregon. The study area is bounded on the west by the Willamette Valley and the east by the eastern edge of the Pacific silver fir zone, near the crest of the Cascade Range.

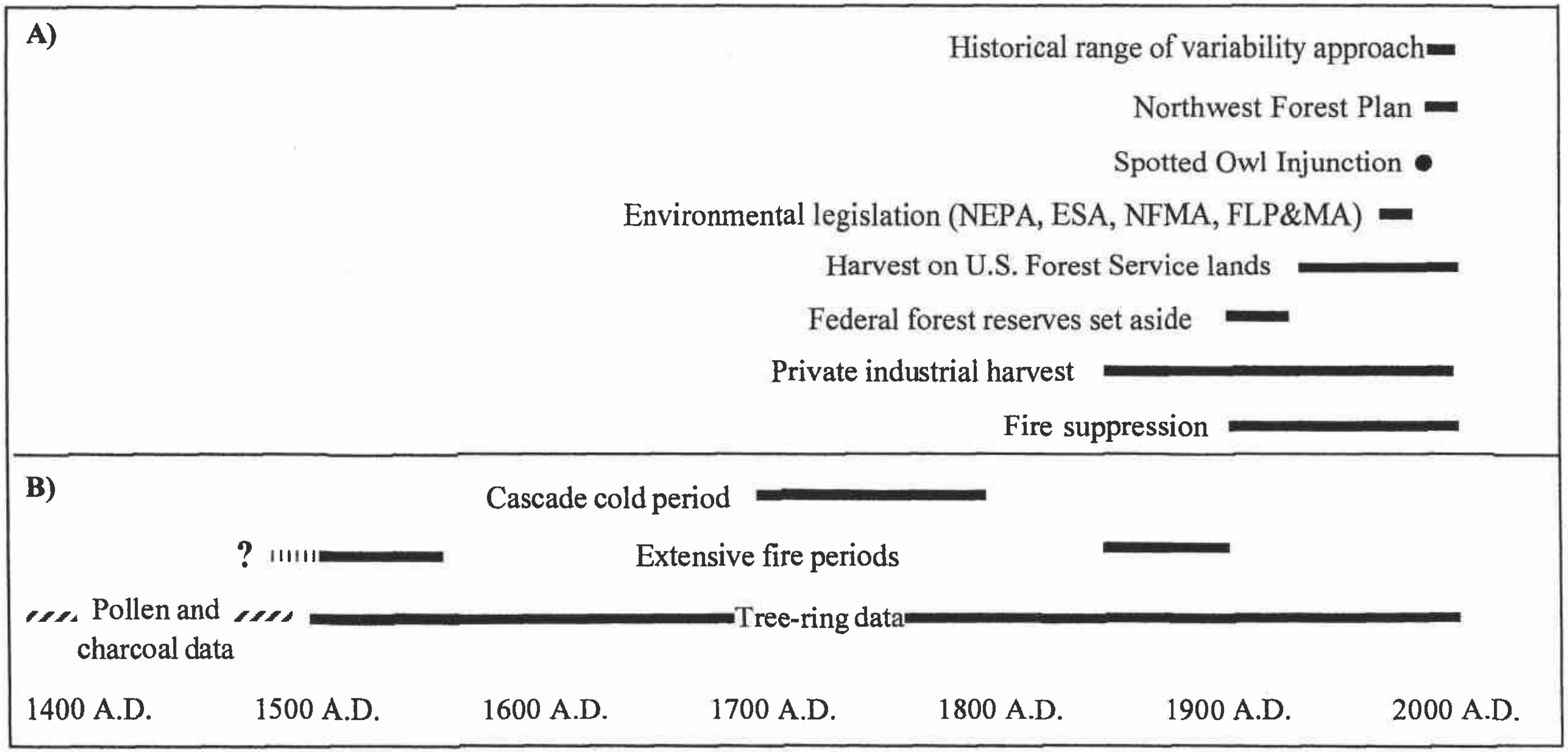


Figure 1.2. Time line of major events affecting forest disturbance in the Pacific Northwest since 1500 A.D. A) Human impacts: timber management events relevant to the study. NEPA = National Environmental Protection Act, ESA = Endangered Species Act, NFMA = National Forest Management Act, FLP&MA = Federal Land Policy and Management Act. B) Cold climate episode (Graumlich and Brubaker, 1986), periods of extensive fire (Weisberg and Swanson, in press), and temporal extent of tree ring and pollen/charcoal sources of information about fire history.

In the absence of explicit process understanding, measured properties may act as surrogates. A host of ecosystem properties could be incorporated into a study of landscape dynamics. A subset of properties was chosen that are most relevant for the questions of interest, "How does the western Cascades landscape under harvest disturbance differ from natural landscapes created from wildfire disturbance?" and "What are the potential consequences of those differences for key elements of biodiversity, hydrology, and carbon sequestration?"

Long-term forest management is an issue that affects numerous stakeholders, from numerous perspectives. Each perspective has an inherent agenda, based on the goals of that perspective. While each perspective may honestly believe theirs to be the best informed, in truth, many questions remain unanswered about the long-term consequences of any particular timber management approach and the aggregate effects of different approaches practiced across the geography of multiple land owner and land use classes. We simply do not have the understanding of interactions in the landscape to truly predict consequences. This study draws together data about a range of ecosystem properties and considers how they might work in concert, under different kinds of human and natural forest disturbance. Specific objectives were to:

1. Simulate wildfire disturbance and the range of landscape patterns likely to have occurred in the past few millennia,
2. Derive a representation of the current landscape from remotely sensed imagery,
3. Construct hypothetical managed landscape patterns under different management scenarios,
4. Compare coarse scale forest patterns from the wildfire, current and hypothetical managed landscapes, and
5. Investigate the effect of divergent patterns on selected ecosystem properties.

Background

Forest Management Policy

Systems theory suggests that socio-ecological systems develop along a cyclical trend from exploitation to conservation, with increasing regulation (Holling, 1973). Commodity production and technological issues surrounding access and transportation drove harvest on private lands in the mid-20th century. Timber harvest on both private and public lands in the latter part of the 20th century was strongly influenced by policy development concerning environmental conservation, particularly on federal lands, which constitute the vast majority of the study area.

Controversy over conservation issues on public lands began early in the 20th century and continued throughout the century. Six major policy enactments in the late 1960s played a pivotal role in the development of timber management policy affecting the area (Figure 1.2). The first was the National Environmental Policy Act (NEPA) of 1969. NEPA officially recognized the relationships of all of the components of the natural environment, and with society. It required detailed statements on any proposed actions that could affect the environment, both to inform decision makers and to inform the public. NEPA specifically required that alternatives be considered, and that the cumulative effects on all plant species and other biophysical entities be analyzed.

In the seven years following NEPA, three additional laws were enacted. The most well known was the Endangered Species Act of 1973, which required the conservation of fish, wildlife and plants on federal lands, and to some extent on private lands. The National Forest Management Act of 1976 specifically required management for diversity of plant and animal communities on national forest lands. And lastly, the 1976 Federal Land Policy and Management Act established guidelines for the management, protection, development and enhancement of public lands, with goals of multiple use and sustained yield. These four policies reflect the progression of scientific understanding about the ecosystem, from recognizing that some species were being lost, to acknowledging that all species should be considered and managed for, to a fuller understanding of the whole ecosystem and the trade-offs between ecosystem health and timber harvesting.

Although there was an understanding of the need for conservation and management, no studies indicated how those goals were to be accomplished. Federal forest managers were charged with managing habitat to maintain viable populations of fish and wildlife, even though there was limited knowledge of the species that were even present, of their habitat requirements, or of the population sizes needed to remain viable. Therefore, the Forest Service adopted a harvest strategy that accomplished a number of objectives, including attempting to minimize the effects of disturbance on the ecosystem, by harvesting at slower rates than on private industrial land, and in smaller patches that were dispersed across the landscape (Franklin and Forman, 1987).

In the late 1980s lawsuits were brought against the Forest Service and the Bureau of Land Management, charging that the above four laws were not being carried out with respect to the northern spotted owl and logging of old-growth forests in the Pacific Northwest. In 1991 a court injunction halted timber harvesting on all federal lands within the range of the spotted owl. Approximately 24 million acres were affected, including seventeen national forests across northern California and western Oregon and Washington. The court found that the Forest Service and Bureau of Land Management failed to meet a number of provisions of the law, by not considering recent studies of northern spotted owl demographics and consequent harvesting effects and not considering other old-growth dependent species.

After the court injunction and a lengthy period of debate between conservationists, timber harvesters, politicians and legal advisers, President Bill Clinton led a conference in Portland on April 2, 1993, and charged an interagency, interdisciplinary team (Forest Ecosystem Management Assessment Team, FEMAT) with crafting a balanced, long term policy that would provide for both ecosystem conservation and economic stability. The resulting policy, the Northwest Forest Plan (USDA, 1994), grew out of the work of FEMAT.

The Northwest Forest Plan divides public lands into seven land allocation areas (USDA, 1994). Congressionally withdrawn areas, such as national parks and wilderness areas, were not changed, and constitute 30 percent of the area. The remaining 70 percent, originally subject to timber harvest, was subdivided by the Northwest Forest Plan into late successional reserves (30 percent), riparian reserves (11 percent), administratively withdrawn reserves (6 percent), managed late successional reserves (1 percent), matrix (16 percent) and adaptive management areas (6 percent). Under the Northwest Forest Plan, 78 percent of the landscape is set aside as reserves, primarily intended to eventually mature into old growth forests, including large reserve areas connected by extensive riparian buffers. Programmed timber harvesting is allowed only on the other 22 percent of federal lands, in matrix and adaptive management areas. Under these guidelines, limited harvesting resumed on public lands, at much reduced volumes compared with pre-Northwest Forest Plan harvesting.

An alternative plan to the Northwest Forest Plan based on the historical range of variability approach has been proposed in the Blue River watershed in the central portion of the study area (Cissel et al., 1994). This plan pertains to management of matrix lands in Northwest Forest Plan. The Blue River plan reduces the area set aside as riparian reserves and sets cutting rotation lengths and levels of live tree retention based in part on the historic wildfire patterns. The goals of the plan are to maintain a constant timber yield, but redistribute harvesting such that harvest disturbance creates more natural stand and landscape conditions. By reducing the amount of land set aside as riparian reserves, the matrix area subject to cutting is increased, and the larger size enables the incorporation of longer rotations while maintaining harvest at approximately the same level. Additionally, harvest unit sizes are increased, creating larger blocks, more similar to disturbance patch sizes under natural fire regimes. Larger harvest sizes reduce the amount of edge and increase the amount of forest interior habitat, both criticisms of pre-1990 harvest practices (Franklin and Forman, 1987).

Private lands continue to be driven primarily by production of wood, but with some environmental policy constraints imposed by state law and regulation. In 1972, Oregon became the first state to regulate forest cutting through the Oregon Forest Practices Act (ODF, 2001). This act set minimum standards for reforestation, road construction and riparian buffer strips. It has subsequently been modified a number of times, but remains the singular legal constraint on private industrial lands, non-industrial owners and state lands.

Alternate Paradigms for Forest Management

The effect of the conversion of mature and old forest to young plantations on a variety of biophysical processes remains a hotly debated subject (Rochelle et al., 1999). Widespread harvesting has been implicated in a loss of biodiversity, as well as changes in a number of abiotic watershed processes, including those leading to elevated peak flows (Jones and Grant, 1996) and stream temperatures (Johnson and Jones, 2000). A prevalent paradigm guiding forest ecological research is that of forest fragmentation, the breaking up of large blocks of mature and old forest into a mosaic of pieces surrounded by young plantations or non-forest, analogous to an island of old forest in a "sea" of matrix (Harris, 1984). It is believed that forest fragmentation results in loss of habitat (Noss and Cooperider, 1994), the arrangement of habitat into smaller, disconnected pieces with little forest interior, and the creation of copious amounts of edge habitat (Franklin and Forman, 1987). These features are known to have adverse effects on species that favor interior forest habitat, such as the Northern Spotted Owl (*Strix occidentalis cauriana*; Thomas et al., 1990), and modify biophysical environments along the edges (Chen, 1993). The Northwest Forest Plan was based on this paradigm, with an emphasis on creating larger reserve areas connected by riparian corridors between reserves.

The forest fragmentation paradigm has been called into question (Rochelle et al., 1999). Its validity as a conceptual approach was the subject of a recent special issue of Ecological Applications (Villard, 2002), which questioned the appropriateness of the island metaphor for old-growth forest surrounded by a mixture of younger forest and non-forest types.

An alternative paradigm for forest management, the natural variability approach, was originally developed as a means of evaluating the potential for survival of native species in an environment that is being disturbed by humans, and for managing landscapes in the face of uncertainties about habitat needs of species. Its premise is that since native species have adapted to, and in part, evolved with the natural disturbance events of the historic past, their potential for survival is reduced if their environment is pushed outside of the range of variability characteristic of the natural system (Swanson et al., 1993; Morgan et al., 1994). It is sometimes referred to as a "coarse-filter" management strategy for sustaining the viability of diverse species about which we know little, through the maintenance of ecosystem variety similar to that of past landscapes (Hunter, 1988).

The natural variability approach and landscape management planning in general have led to assessments of the effects of different landscape management plans on a variety of ecosystem properties. The dynamic, diverse character of the natural landscape may be used as a frame of reference, since the spatial and temporal variability in the natural landscape may provide the stability and resilience to absorb the effects of any single disturbance. Although there are several important caveats to this approach (Landres et al., 1999), it is useful as a probabilistic approach in the absence of complete and explicit understanding of the effects of different landscapes. The combination of this approach with process understanding where it exists provides a powerful way to explore interactions between components of broad-scale natural resource systems. The historical range of variability approach has been proposed for guiding future forest management policy in public forests (Swanson et al., 1993; Cissel et al., 1994; Morgan et al., 1994; Swetnam et al., 1999).

This Study

Recent studies in landscape ecology use spatial pattern both to infer the processes that produce the pattern and to examine the effect of spatial patterning on processes; i.e., invoking spatial pattern as a causative force in ecosystem processes (Turner, 1989; Pickett, 1995). Studies typically contain one or more of the following elements: 1) describing landscape patterns, including the size, shape, number and arrangement of components, 2) flows of energy, matter or organisms between landscape elements, especially with respect to the effect of landscape patterning on those flows, and 3) processes that change the landscape, alter its pattern, and thus alter flows. This study contains elements from all three approaches. Landscape patterns produced by wildfire and harvest processes will be described and compared, the effect of those different patterns on landscape properties will be considered, and the findings will be placed in a context of changing drivers through space and time.

This study used the historical range of variability approach to compare current and hypothetical western Cascades landscapes with the range of landscapes that may have existed in the past prior to Euro-American settlement, fire management and forestry practices. Wildfire-affected landscapes are simulated using empirical data from field studies, combined with theoretical understanding of spatio-temporal trends in fire characteristics. Remotely sensed data were used to identify current landscape conditions. GIS models were used to construct hypothetical landscapes emphasizing selected features from various management approaches. Wildfire-affected, current, and hypothetical managed landscapes were compared by measuring age class amounts, the distribution of age classes across the landscape, and selected measures of arrangement of age classes. Simple response models were used to calculate ecosystem property differences between landscapes. Measures of wood volume, potential species richness and water yield were quantified as surrogates of carbon sequestration, biodiversity and hydrologic ecosystem function.

Studies of alternative forest management scenarios in the Pacific Northwest are under way using combinations of stochastic simulation techniques and process models (Cissel et al., 1999; Spies et al, in press). The Cissel et al. (1999) study is being conducted in the central portion of this study area at the extent of a watershed. The Spies et al (in press) is a province scale study to the west of this study area in the Coast Range. These studies are conducted at relatively fine spatial resolutions: 30 meters or less, and focus on detailed description of forest structural patterns and effects.

Since the Cissel et al. (1999) study considered forest patterns and processes at fine resolution, this project attempted to investigate coarser scale questions regarding the implications of alternative landscapes along environmental gradients. The study was conducted primarily at the province scale along with a smaller scale associated with major land owner/land use types, although some analyses were conducted at the watershed scale in order to link with studies in the Blue River watershed. In order to accomplish a broad scale analysis, many details that are very important at finer scales were either abstracted to simple conceptual models or ignored entirely. This study painted the landscape with a broad brush, highlighting differences between natural and managed landscapes that seem to be most important at the broad scale. These differences reflect the following general statements:

1. Natural processes result in patterns through space and time that may sometimes occur as discrete boundaries and events, but are often less sharply defined. Representation of past landscapes is difficult because our measurements of these patterns are limited, discrete, and biased by the discontinuous nature of the record, our simulation techniques are limited, and neither adequately captures the continuous nature of many processes. Wildfire simulations were modeled as discrete, steady-state systems, but the more continuous nature of wildfire processes was captured by simulating a range of parameters and using those results to interpret how more continuous, transient wildfire landscapes may have occurred.
2. Human processes tend to result in patterns that are simpler than natural processes. Often management actions occur as discrete events and boundaries that are more easily represented and conceptualized. The contrast between more continuous, less defined natural patterns and discrete, simpler human patterns was emphasized in the approach of this study, which conceptualized simple management patterns with discrete, sharp-edged boundaries.
3. The current landscape is a mixture of both natural and human patterns. As such, it displays characteristics of both. At the landscape scale,

human disturbance processes have largely replaced natural disturbance, although natural processes can never be eradicated entirely. At best, they can be controlled for long periods of time, with the substantial caveats of human error. Therefore, while there remain legacies of natural disturbance on the landscape (Wallin, 1994), most disturbances now occurring and likely in the future are human-related. Over the long term, mixed natural and managed landscapes will probably gradually be replaced by the simpler landscape patterns reflecting human processes. However, natural disturbance processes will continue to leave a footprint on the landscape, and the potential impact of climate change is yet to be adequately understood.

4. Although forest managers are actively engaged in exploring management plans that retain features of more natural landscapes, this study represents managed landscapes as simple landscape patterns for the explicit purpose of considering the implications of simpler landscape structure. The hypothetical landscapes are not intended to represent all of the features of managed landscapes; rather, they capture a few patterns that may be most important at the broader scale and present "clean" representations of those patterns. They represent the extremes that could occur if specific, well-defined management strategies were carried out consistently across the landscape. Therefore, they indicate the direction and farthest point to which a particular management strategy could move the landscape. Since the effect of pattern on ecosystem property may be subtle, increasing variability in these landscape representations to more realistic levels would obscure relationships between pattern and measured ecosystem property. Hypothetical managed landscape scenarios represented in this study are not in any way real landscapes; they capture and abstract certain features of managed landscapes in order to investigate potential effects of management patterns under the simplest parameterization.

Chapter 2 Methods

Approach

Except where indicated, all analyses were conducted on a Windows NT system, using ESRI ArcInfo 7.2. Many of the analyses were conducted by writing Arc Macro Language scripts, included on a compact disc in the back of this dissertation (Appendix A). Layers were retrieved from publicly available sources, and include land cover and cultural information (Appendix B). Base layers were projected to UTM coordinates, co-registered, and clipped to the desired extent.

The study area in the western Cascades of Oregon (Figure 1.1) was selected to scale up from similar work in a mid-sized landscape and watershed (Andrews/Blue River work of Cissel et al., 1999) and to provide a Cascade Province view for comparison with parallel work in the Coastal Landscape analysis and Modeling Study (CLAMS) in the Coast Range Province. Maps of public and private land owners and federal reserves were compiled and analyzed to determine characteristics of major owner and land allocation types. Landscapes representing different disturbance regimes were created (Table 2.1). A predominantly wildfire disturbance regime, typical of the past, was simulated with a fire model, producing wildfire-affected landscapes. More recent landscapes have resulted from a mixed disturbance regime, including effects from both fire and harvest disturbance. Thematic Mapper imagery from 1995 was used to represent the mixed disturbance regime landscapes. Hypothetical managed landscapes were created in ArcInfo based on selected forest policies in the actively managed parts of the forest landscape and anticipated forest succession in no cut/no burn areas.

Table 2.1. Terminology and subdivisions used in this study to indicate landscapes produced by differing combinations of wildfire and harvest disturbance, and fire suppression. Details of the selection, simulation and construction of these landscapes are described throughout the methods section. Figures use these abbreviations in the legends.

Disturbance Regime	Landscape Pattern	Disturbance Scenario	Abbrev-iation
Wildfire	Wildfire-affected landscapes	Very infrequent fire	N/A
		Infrequent fire	
		Average fire	
		Frequent fire	
		Very frequent fire	
		Empirical fire (past 500 years)	
Mixed	Current landscape	Fire/human mixed, as on the 1995 landscape	1995
Harvest	Hypothetical managed landscapes	Riparian rule. Riparian buffers + general federal guidelines + federal wilderness	RIP
		Riparian-rule plus reserves. Riparian buffers and reserves from the Northwest Forest Plan + federal wilderness	RIP/RES
		Riparian/reserve/mixed-rotation. Riparian buffers, reserves and harvest allocation goals from the Blue River Plan + federal wilderness	RIP/RES/ROT

Structural comparisons were made between wildfire-affected, current and managed landscapes. Comparisons were made of age class amounts, patch characteristics, and disturbance patch/stream adjacency measures. The landscapes were subdivided by owner/allocation type; characteristics of individual owner/allocation types were extracted and compared.

Landscape patterns were used to approximate several ecosystem properties for each landscape. Investigated properties included selections from three broad ecosystem properties: carbon storage (converted wood bole volume, standing wood bole volume and total ecosystem carbon), biodiversity (species richness) and hydrology (annual and summer water yield). Between-landscape comparisons of the properties were made, and trends with increasing disturbance were identified.

Study Area

Biophysical characteristics

The study area is located in the western Cascades of Oregon (Figure 1.1), and includes the H.J. Andrews Experimental Forest, a National Science Foundation sponsored Long-Term Ecological Research Site. The area encompasses a mixture of owner/allocation types, characterized in part by classified, remotely sensed imagery and a number of fire history studies. The study area ranges from the northern Oregon border to the northern edge of the Klamath Mountains. Elevation increases from west to east, and ranges from 200 to over 1800 meters. The western edge of the study area is bounded by the limit of hardwood/conifer forest in the Cascade foothills along the Willamette Valley and to the east, runs nearly to the crest of the Cascades. The crest area itself is not included in the classified remotely sensed imagery.

Seven fire history studies in the area have been conducted with similar techniques (Weisberg, 1997a, 1997b, 1998; Van Norman, 1998; Cissel et al., 1998;

Kertis, 2000; Agee and Krusemark, 2001). The locations of sample plots within each study site were obtained as a GIS layer from Berkley (2000; Figure 2.1).

The vegetation is divided into two major zones that transition at approximately 1050 meters elevation: the western hemlock (*Tsuga heterophylla*) zone, which predominates at low elevation through much of the study area, and at high elevations, the Pacific silver fir (*Abies amabilis*) zone (Franklin and Dyrness, 1973). Within the western hemlock zone the principal seral tree species are western hemlock and Douglas-fir (*Pseuotsuga menziesii*). Douglas-fir predominates, and is an early-seral species that regenerates after wildfire disturbance and may live for centuries. Douglas-fir is the preferred species for timber production, and is typically re-planted following harvesting. The Pacific silver fir zone contains a mixture of species, dominated by Pacific silver fir, Douglas-fir, noble fir (*Abies procera*), and western hemlock.

Pacific silver fir and western hemlock are more susceptible to fire than Douglas-fir (Minore, 1979). Douglas-fir, with thick bark, is the most fire resistant of the conifers, although it is vulnerable to fire until it matures. Although cool, moist, high elevation forests are less susceptible to fire, when climatic conditions allow them to dry out they can burn intensively because of their relatively high proportion of fire-susceptible species and high fuel build-ups in cool, moist sites.

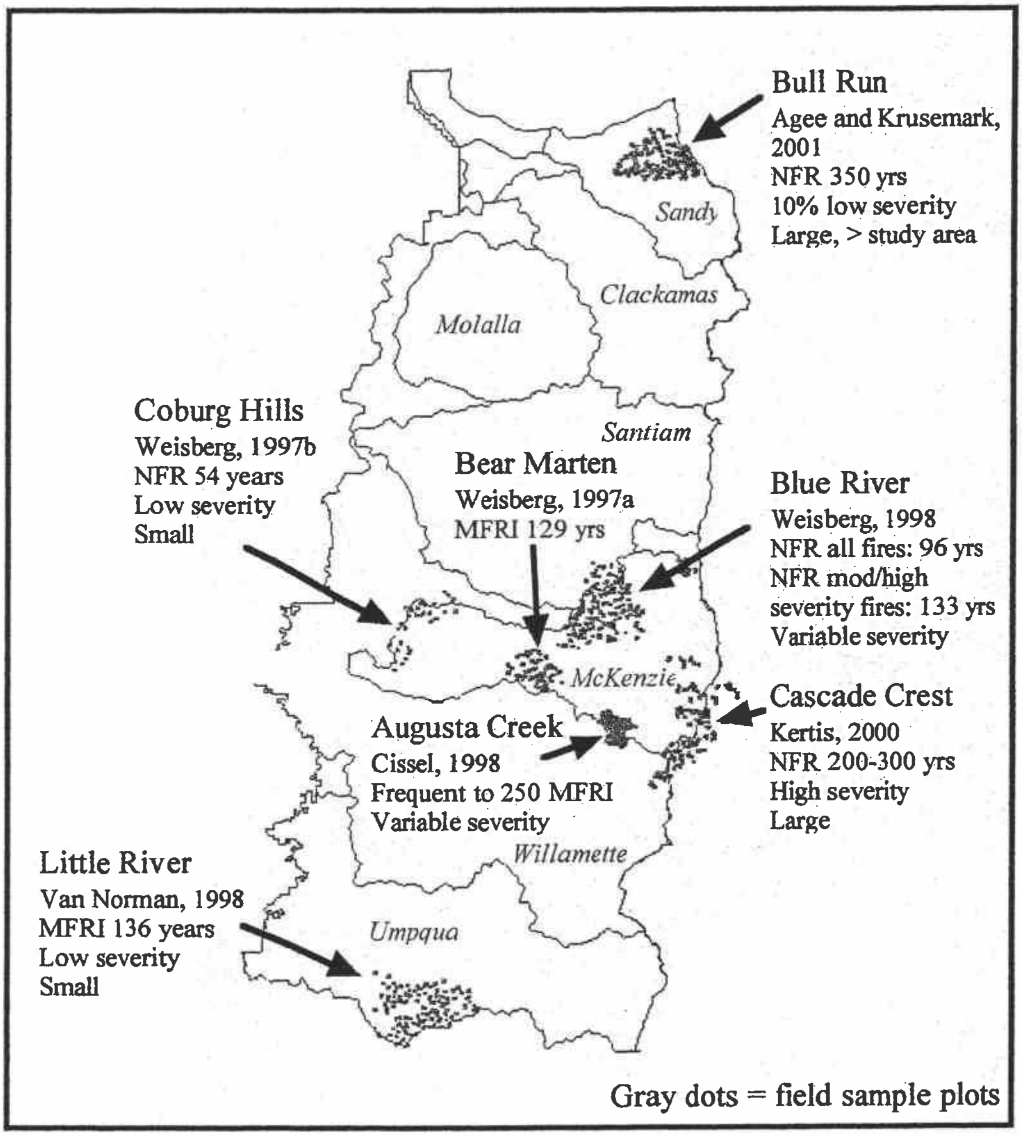


Figure 2.1. Locations and major findings of dendrochronological fire history studies in the study area that used comparable techniques (Berkley, 2000). The area is subdivided into major watersheds. Fire frequency is reported as natural fire rotation (NFR) or mean fire return interval (MFRI).

The study area has a temperate, maritime climate with cool, wet winters and warm, dry summers (Bieirimaier and McKee, 1989; Greenland, 1994). Most of the precipitation occurs between November and March. Precipitation increases from west to east with increasing elevation, averaging about 2300 mm at the H.J. Andrews Experimental Forest in an approximately central location within the study area. Precipitation falls primarily as rain at the lower elevations and snow at the higher elevations. A persistent snow pack up to 4 meters deep may form and last until June in high elevation sites.

Dry, warm summers are conducive to wildfire, particularly in the lower portions of the Cascades that do not receive spring snowmelt to maintain moisture. The predominant summer wind direction is from the southwest, however, occasional east winds occur when thermal low-pressure cells develop along the coast and a high pressure ridge settles over eastern Oregon. At these times, dry, desiccating winds blow westward across the Cascades, further reducing fuel moisture and creating favorable conditions for fire.

Land Owner Characteristics

A polygon layer of owners (OWNER_ATT), compiled in 1994, and a layer of federal timber reserves (FEDRES1) were retrieved from the U.S. Forest Service databank (Appendix B). The owner layer included individual owner names and owner classes from the 1990-91 ACI ownership database. The owner layer was combined with the reserves layer to create a map showing land tracts of both private owners and federal congressionally designated wilderness and non-wilderness lands (Appendix C). This information will be referred to as owner/allocation type.

A study area of 22,650 km^2 was initially selected for a preliminary analysis of owner/allocation type characteristics. Fragstats 2.0 (McGarigal and Marks, 1995) was run on the combined owner/allocation layer to analyze tract characteristics. Based on that analysis, the study area was reduced to 15,670 km^2, eliminating an area of low elevation, private non-industrial land along the Willamette Valley and a large area to the south that contained Crater Lake National Park (Table 2.2) because these were land use types beyond the scope of this study.

Both public and private land owners occur in the study area, with private lands dominating at low elevations, public lands at high elevations and public wilderness lands at the highest elevations (Figure 2.2). Major owner/allocation types were reclassified into four primary types for analysis: Bureau of Land Management/private industrial alternating sections (checkerboard; CHECK), private industrial (PI), U.S. Forest Service non-wilderness (USFS) and U.S. Forest Service wilderness (WILD). The Bureau of Land Management/private industrial checkerboard region includes both public and private acreage originally subdivided into one square mile sections for railroad land grants. These tracts were too small for discrete analysis at the sub-province scale, and because of the checkerboard pattern, were likely to display properties that differed from Bureau of Land Management or private industrial acreage separately. State, private non-industrial and miscellaneous ownership tracts comprised a small proportion of the landscape and were not analyzed further.

Table 2.2. Characteristics of land owner holdings, for an initial, larger study area on which land owner analyses were conducted and the final, reduced-size study area.

Owner/Allocation Type		Initial analysis area		Reduced study area	
		Class Area (ha)	Percent of Total	Class Area (ha)	Percent of Total
Public	U.S. Forest Service multiusage	1,256,746	55.5	862,592	55.0
	Wilderness & Nation Park	250,923	11.1	87,408	5.6
	State	35,828	1.6	28,113	1.8
Mixed	Bureau of Land Mgmt./Private Industrial	179,569	7.9	223,820*	14.3*
Private Industrial	Weyerhaeuser	154,689	6.8	Not measured separately in new area	
	Timber Service	59,251	2.6		
	Willamette Ind	42,401	1.9		
	Champion	36,735	1.6		
	Fibre	28,801	1.3		
	Giustina	23,505	1.0		
	Seneca	20,283	0.9		
	R Brothers	19,537	0.9		
	Roseboro	15,979	0.7		
	Cavendish	14,046	0.6		
	Ford	6085	0.3		
	Other	156	2.9		
	Total private industrial	487,468	21.5	335,704	21.4
Private Non-Ind.		33302	1.5	29,487	1.9
Misc.		20820	0.9		
Totals		2,264,655	100	1,567,124	100

*Bureau of Land Management lands were combined with adjacent private industrial checkerboard tracts to create a Bureau of Land Management/private industrial checkerboard owner/allocation type.

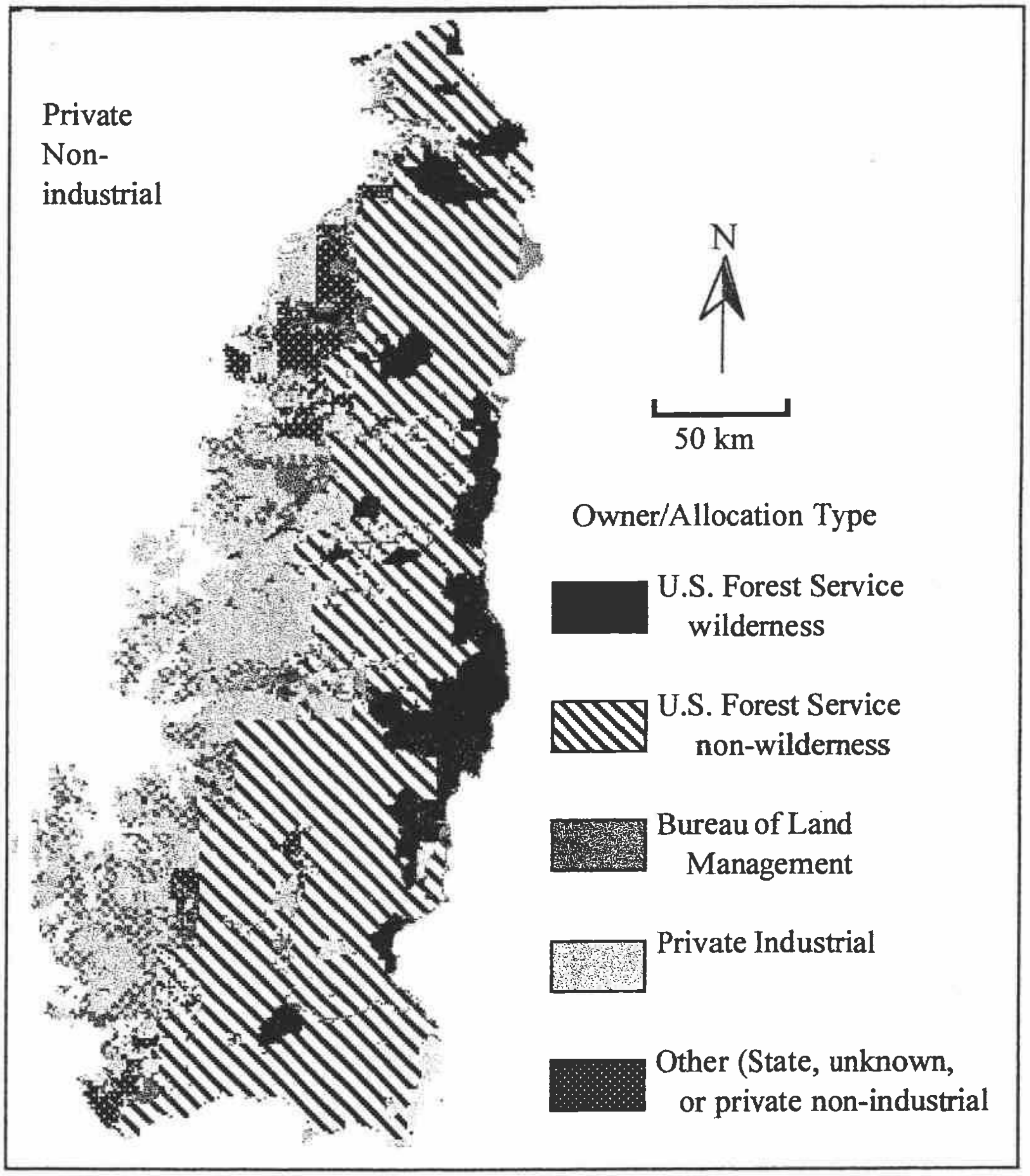


Figure 2.2. Map of major owner/allocation types. Elevation increases from west to east. Note that private industrial acreage dominates at low elevations, U. S. Forest Service non-wilderness at mid to high elevation, and U.S. Forest Service wilderness areas at the highest elevations along the Cascade crest.

Creation of Digital Landscapes Representing Wildfire, 1995 and Managed Regimes

Wildfire Disturbance Regime: Simulation of Wildfire-Affected Landscapes

Approach

A fire model was selected that was appropriate for the scale of the study. Model input layers were constructed in Arc/Info. Fire frequency, severity and size parameters were compiled from the fire history studies from the past 500 years. These data were used as a reference for postulating a range of parameter values that might have occurred over the past few millennia, incorporating more climatic variation than observed in the past 500 years. The fire model was run multiple times, using the range of parameters. Output from the model was in the form of forest age class maps at 50 year time steps for each model run. These landscapes were analyzed for basic statistical properties of each age class. Based on these statistical characteristics, a reduced number of landscapes were selected for comparative analysis.

The Landscape Age-class Dynamics Simulator (LADS) Fire Model

Wildfire throughout the study area was simulated using the Landscape Age-class Dynamics Simulator (LADS) model developed by Wimberly (2000). This model was chosen because it was designed for large scale, grid-based studies, and was developed for a sister research project in the Oregon Coast Range, facilitating regional comparisons.

The LADS model simulates the spread of randomly initiated fire across the landscape and resultant distribution of vegetation classes. For each cell, the LADS model tracks two values: 1) the length of time since the last fire, and 2) the length of time since the last high-severity fire. High severity fires are stand-replacing and result in both values being reset to zero. Low severity fires are not stand-replacing, and only the first value is reset. Results are classified into age/structural classes based on these two values. Output consists of classified grids at user-specified time steps.

The LADS model allows the user to designate areas within which different fire regimes may operate. Each fire regime is assigned differing fire frequency and severity parameters. Fires that initiate in a given fire regime are assigned characteristics based on that regime, but are allowed to burn into adjacent regimes.

LADS Model Input Layers

The model requires input study area buffer zone, fire regime and fire susceptibility layers. Creation of these layers is described in detail here and in

Appendix D. A 200 meter spatial resolution was selected for the simulations, consistent with the design of the model and study objectives.

The buffer zone (Figure 2.3A) allows fires to initiate outside of the study area and burn into the study area, reducing edge effects. The width of the buffer zone is arbitrary, since only the actual study area is included in the final output. For this study, a narrow buffer zone was constructed on the eastern edge along the Cascade crest, where a natural edge truly exists due to the steep topography and sparse vegetation. A broader zone was constructed along the western edge of the study area.

Four fire regimes were designated, based on extrapolation of fire regimes identified by Weisberg (1998) in his fire history reconstruction in the central portion of this study area. Weisberg's regimes were defined using a statistical linear combination model relating topographic variables to fire frequency characteristics. The model used was:

$$\text{Fire Frequency} = -0.99 + (0.0015 * \text{elevation}) + (0.30 * \text{northness}) + (-0.85 * \text{midslope}) + (-0.71 * \text{upperslope})$$

where elevation is a continuous variable, northness is a continuous variable quantifying topographic aspect, and midslope and upperslope are indicator variables designating the position of each pixel on a hillslope. The response variable is a continuous variable reflecting fire frequency, which Weisberg (1998) classified into three regimes: high, mid, and low frequency.

In this study I extrapolated Weisberg's model to the entire study area (Figure 2.4A). The explanatory variables were determined from a digital elevation model (DEM), from which elevation could be directly measured and from which slope, aspect, and hillslope position could be derived (Appendix D).

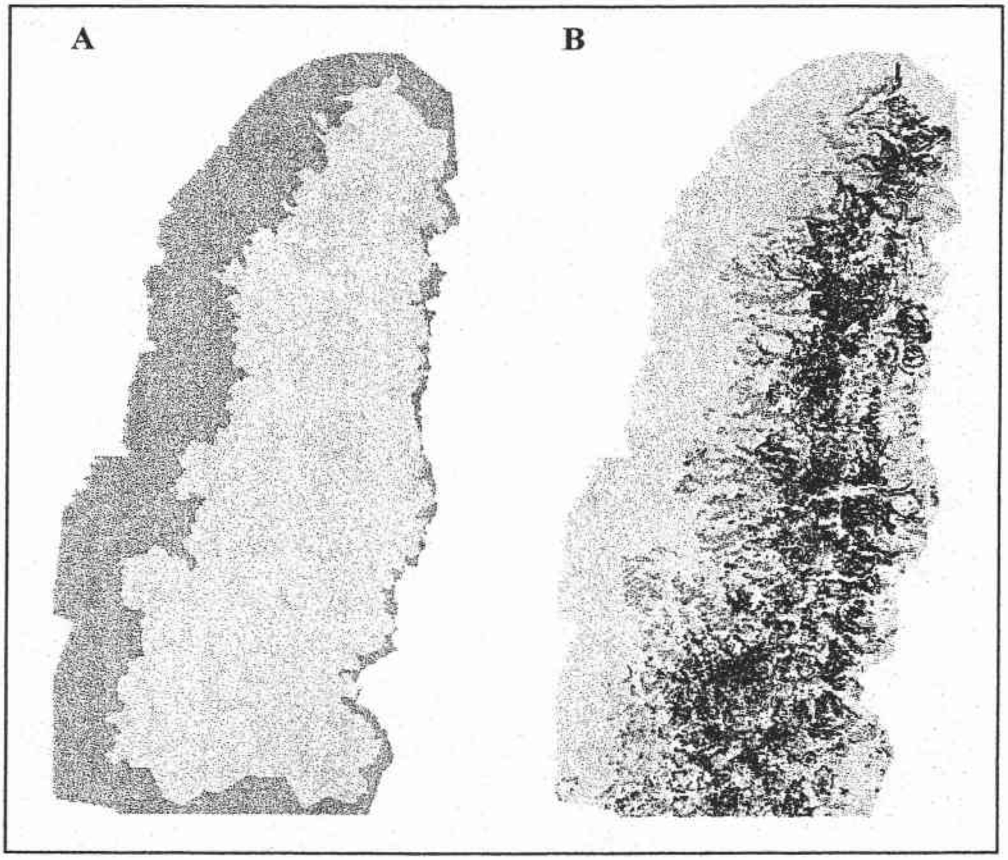


Figure 2.3. Layers constructed for use with the LADS fire model. A) Buffer layer, showing analysis area (light gray) and buffer zone (dark gray) in which fires are allowing to ignite and/or spread, but which is excluded from the analysis. B) Topographic susceptibility layer, indicating areas highly susceptible to fire (black) versus those less susceptible (light gray), constructed from a statistical model relating maximum fire interval to topographic variables (Weisberg, 1998). Mid to upper hillslopes on steep, southerly aspects are most susceptible to wildfire.

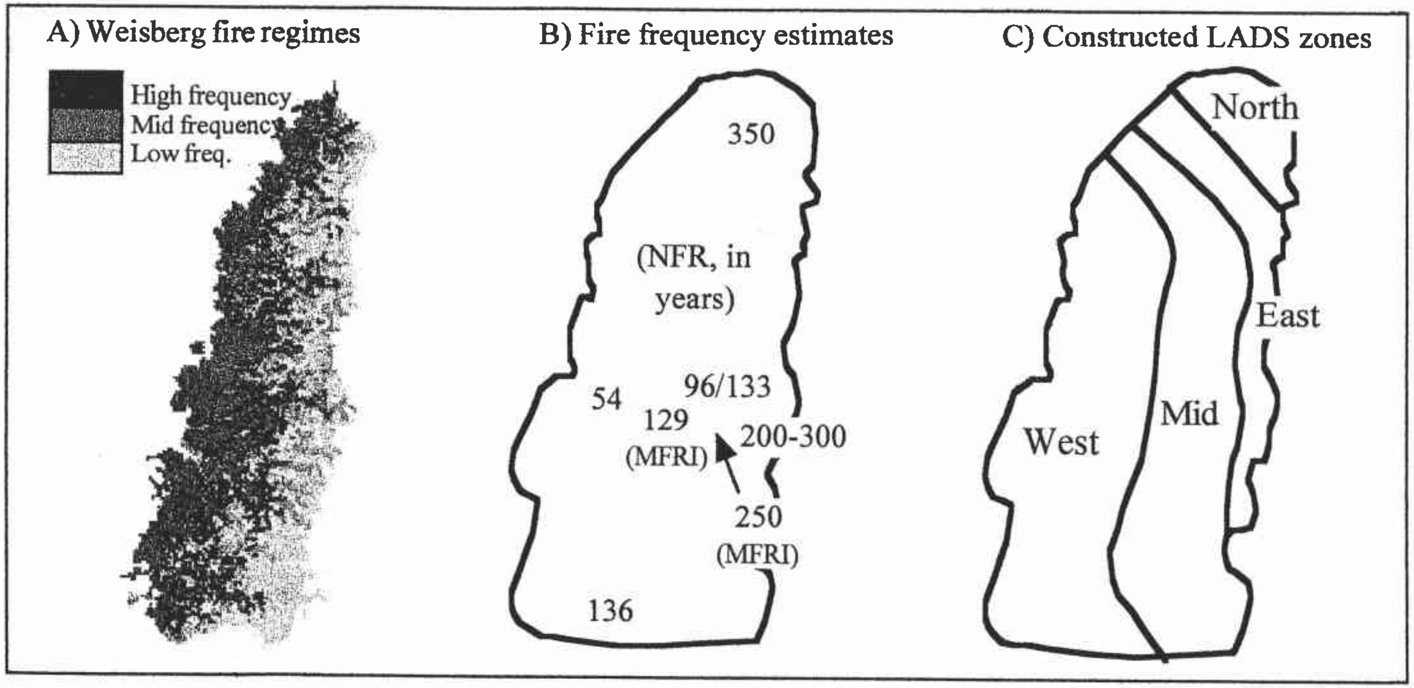


Figure 2.4. Steps in the construction of the fire regimes used in the LADS model. A) The statistical model reported by Weisberg (1998) in the Blue River study (Figure 2.3) in the central portion of study area, relating fire frequency regimes to topographical variables, spread across the study area. B) Fire frequency data from multiple studies shown in Figure 2.3, reported as natural fire rotation (NFR) in years, except where noted as mean fire return interval (MFRI). C) Constructed LADS zones of differing fire regimes, following trends identified by the Weisberg model except in the north zone, which reflects longer fire frequencies reported in Bull Run to the north, not represented well by the Weisberg model.

After the model was extrapolated, Weisberg's break points were used to extend his three fire regimes across the study area. Figure 2.4A displays the Weisberg fire model results spread across the landscape. The mid-frequency regime defined by Weisberg and shown in Figure 2.4A was useful in his more localized study for delineating valley bottoms. At the broader scale, that regime occurs as a narrow band that occupies only a small portion of the landscape. Because of the way the LADS model operates, the Weisberg mid-frequency zone is too narrow to have an effect on the model output. Therefore Weisberg's three regimes were combined into two broader fire regimes for input into the LADS model. The boundary between the two zones coincided with the boundary between Weisberg's high and mid frequency regimes. These two zones were designated the west and middle fire regimes. A third, east zone along the Cascade crest was included to delineate between the highly variable fire characteristics of the majority of the studies in the central portion of the study area, including both high and low severity burns, and a predominately low frequency, stand-replacing regime that occurs at the highest elevations (Kertis, 2001).

These results were compared with the natural fire rotations from the empirical data, and were manually modified to agree with apparent fire frequency from the work of Agee and Krusemark (2001) in the Bull Run watershed to the north, and Van Norman (1998) in the Little River watershed to the south (Figure 2.4B). The Bull Run study at the northern end of the study area indicated fire return intervals that were longer than the stand-replacing events identified in the High Cascades. Agee and Krusemark (2001) believed that the influence of the Columbia River Gorge on precipitation patterns was responsible for the observed long rotation period; therefore a separate fire regime was constructed for that area, the north zone.

To the south, the study conducted in the Little River area (Van Norman, 1998) identified low size and severity patterns not typical of other study sites in the region. This site is located just outside of the larger Willamette River watershed and is in a different geographic province (Klamath Mountains). Therefore, it may represent a transition to a different fire disturbance regime representative of warmer and drier conditions that is likely to have had more frequent fire. Hence, the fire regime boundaries were slightly modified on the southern end of the study area to represent this transition. The final fire regime layer that was used in the LADS model is shown in Figure 2.4C.

The model uses the fire susceptibility layer (Figure 2.3B) on a cell-by-cell basis to determine the direction of fire spread. The fire spread algorithm combines fire susceptibility based on vegetation age, the user-specified predominant wind direction, and this susceptibility layer to determine the direction of spread. This layer was created based on a statistical model of maximum fire interval developed by Weisberg (1998). Weisberg found that maximum fire interval was more strongly influenced by topographic characteristics, especially to slope steepness, than was mean fire interval. His statistical model was:

$$\text{Maximum Fire Interval} = 376.70 + (0.005 * \text{elevation}) + (30.65 * \text{northness}) + (-72.44 * \text{midslope}) + (-68.59 * \text{upperslope}) + (-186.83 * \text{moderately steep}) + (-310.01 * \text{very steep}) + (0.1401 * \text{elevation:moderately steep}) + (0.2642 * \text{elevation:very steep})$$

where elevation is a continuous variable, northness is a continuous variable quantifying topographic aspect, and midslope and upperslope are indicator variables designating the position of each pixel in the watershed, and moderately steep and very steep are indicator variables designating relative slope steepness. The model includes two interaction terms between elevation and the steepness variables. The response variable is a continuous variable reflecting the maximum interval between fires at each specific place.

Weisberg found that north-facing, gentle slopes along valley bottoms had longer maximum fire intervals than south-facing, steep slopes along ridges. On the basis of his findings, I inferred that maximum fire interval could be a surrogate for relative fire susceptibility, since areas having longer intervals were more likely to be protected from fire. The maximum fire interval model was applied across the entire area, and then reclassified into three susceptibility categories (Figure 2.3B). Using this method, steep, highly dissected terrain in the middle Cascades was modeled with higher fire susceptibility than the gentler slopes of the high and low Cascades, consistent with some field observations.

LADS Model Input Parameters

Wildfire disturbance may be characterized in terms of fire frequency, severity and size (Weisberg, 1998). Fire frequency is typically measured by the fire return interval, which may be calculated as the natural fire rotation (NFR), a measure of the time required to burn an accumulated area equal to the size of the whole landscape. Some studies report the mean fire return interval (MFRI), the mean number of years between fires at a given study site, without reference to the area burned. Fire severity is a measure of tree mortality. Fire extent is determined by correlation of fire events between sample sites, and is most accurate if cross-correlation techniques are used (Weisberg, 1998). In practice, fire frequency, severity and size parameters are very difficult to establish for historical times due to limited evidence of low severity fires, erasure of evidence by subsequent fires and the continuous variation in parameters related to ongoing climatic change (Weisberg and Swanson, in press; Long, 1998). Fire frequency measures are generally believed to be more accurate than severity and size measures (Weisberg, 1998). Fire size, in particular, may be difficult to determine.

Because of the uncertainty in measurements and observed variability in empirical data, along with the knowledge that the empirical data represent a relatively narrow range of climatic conditions, a wide range of parameters was selected for simulation, loosely based on available studies. The goal was to illustrate the range of landscape conditions that could have occurred over the past few millennia, given the uncertainty in the relationship between fire frequency, severity and size parameters and longer-term climate change.

The approach used was to simulate a range of postulated wildfire scenarios based on assumptions constructed from wildfire theory, constrained by empirical fire data. Assumptions included:

A1: Fire frequency at a given site varies through time related to changing climate.

A2: Fire frequency varies through space related to topography and latitude.

A3: Fire severity and size increase with decreasing fire frequency.

Multiple simulations were conducted representing different fire frequencies (Assumption 1; Figure 2.5: x-axis). Since the empirical data represent the past 500 years and climate is known to vary substantially over longer time periods, the range of fire frequencies used (Figure 2.5A) was selected to represent a wider range of conditions than represented by the empirical data. Within each simulation, spatial variation was incorporated (Assumption 2; Figure 2.5: four fire regimes). The four fire regimes prescribed different fire frequency, size and severity characteristics. Fire severity and size parameters were varied to represent a gradient from very low frequency, high severity and size to very high frequency, low severity and size (Assumption 3).

For each fire regime, the model requires: 1) the natural fire rotation (NFR) and 2) the percentage of fires that are high severity. The mean fire size for high and low severity fires is specified by the user, and are constant for the entire landscape. Fire size is modeled as a geometric random variable with a negatively skewed distribution (Wimberly, 1998). This results in a fire size distribution that consists of many small fires but only a few large fires. High severity fires, as defined by the model, reset all vegetation in the cell to age 0, and roughly correspond to high severity fires as defined by Morrison and Swanson (1990) and used by most of the field studies, with greater than 70 percent mortality. All other fires in the model are incorporated into a low severity category, and would include both moderate (30-70 percent canopy mortality) and low (< 30 percent canopy mortality) severity fires, as used in the field and associated photo interpretation studies. Very low severity fires, with little or no mortality of the canopy but removal of the underbrush, are not modeled (and also are not easily identifiable in fire history studies).

The range of NFRs used within each fire regime (Table 2.3) exceeds the observed range from the past 500 years, but is intended to represent potential fire frequencies under more extreme climatic conditions, observed earlier in the Holocene (Long et al., 1998). It was assumed that under extremely cool and wet conditions in the north regime, fires would rarely occur (NFR 1000 years), and fuel loads would be excessive. Therefore, once ignited, the fire would be extremely large, with 100 percent tree mortality. The selected mean high severity fire size (100,000 ha) represents an approximate size of 5th order drainage basins in the area, such as the North Santiam basin (138,500 ha) or the South Santiam basin (76,100 ha). At the other extreme, under extremely warm, dry conditions in the lowest elevations, recurrent fires at short intervals (NFR 10 years) would remove most of the fuels, therefore 100 percent of fires would be low severity, and would be of small extent, typically less than the size of a 3rd order watershed (100 ha). The parameters used on each simulation run were distributed between these extremes (Table 2.3).

A final, "empirical" simulation attempted to create a best fit to the empirical data, which suggests fire frequencies intermediate to those used for the moderate to infrequent fire simulations. However, relatively small fire sizes were used in the empirical scenario compared with those used in the postulated parameter range, since field studies in the central portion of the study area have identified few large fires. Small fire sizes may accurately reflect conditions over the past 500 years, but may also be indicative of difficulties correlating specific fires between study sites and the relatively small area of most fire history studies. An 1865 fire in the central portion of the study area (Silverton) was reported to have burned approximately 400,000 ha (ODF, 1993). Therefore, the mean fire sizes used in the simulations are clearly feasible, even if our studies have not been able to distinguish fires of large size.

The larger fire sizes used in the full range of fire frequency simulations have the effect of simulating more variable landscapes (see the sensitivity analysis below), and therefore more effectively represent the potential range of conditions. The small fire sizes based on the empirical data produced less variable landscapes. Since fire size is the most difficult parameter to estimate, the values selected for the postulated parameter range err on the side of producing greater landscape variability than probably actually occurred.

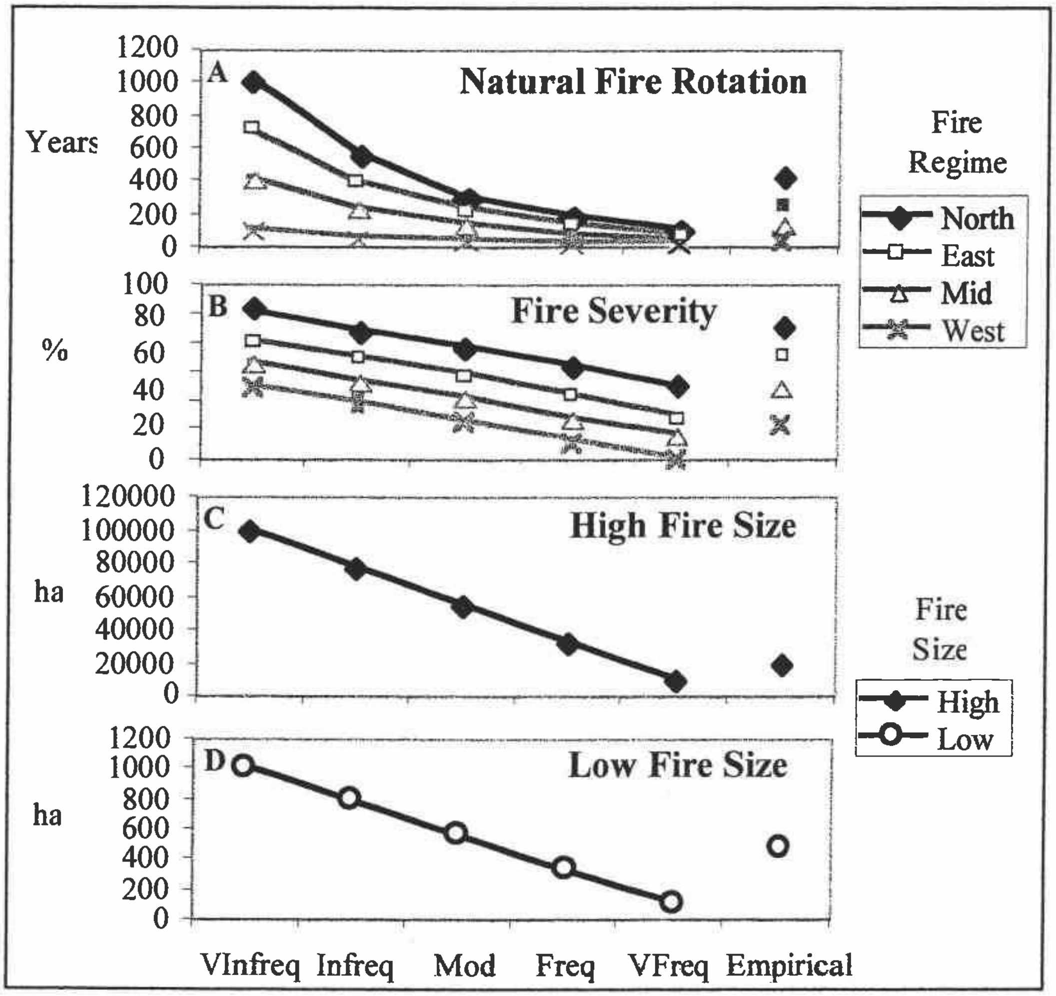


Figure 2.5. Parameters used in fire simulations. A range of five parameter sets along a fire frequency progression (very infrequent, infrequent, moderate frequency, frequent, very frequent) were simulated. Parameters were postulated based on fire theory, empirical data and assumed longer-term variation with climate change. The very frequent fire simulation was conducted for 1000 year sensitivity tests, but due to long run times, was not included in the 3000 year simulations. A sixth simulation run, based primarily on the empirical dendrochronological fire history studies from the past 500 years, was also conducted. The empirical fire frequency, severity and low fire size parameters were comparable to those used in the moderate to infrequent fire simulations. The high fire size parameter was reduced in the empirical simulation based on the paucity of field evidence for large fire sizes. See the text for a discussion of fire sizes.

Table 2.3. Simulation fire frequency, severity, and size parameters used in the LADs model, for six fire frequency scenarios and four fire regimes.

Climatic Conditions: inferred fire frequency	Size (ha) By severity	Regime Area	Frequency (NFR; years)	Severity (% of fires that are high severity)
Cold & wet: very infrequent fire	High severity: 100,000 ha Low/Mod severity: 1000 ha	North	1000	100%
		East	700	80%
		Middle	400	65%
		West	100	50%
Cool & wet: infrequent fire	High severity: 77,500 ha Low/Mod severity: 775 ha	North	562	87%
		East	394	68%
		Middle	225	53%
		West	56	37%
Moderate climate: moderate frequency fire	High severity: 55,000 ha Low/Mod severity: 550 ha	North	300	75%
		East	221	59%
		Middle	126	42%
		West	32	25%
Warm & dry: frequent fire	High severity: 32,500 ha Low/Mod severity: 325 ha	North	178	63%
		East	124	43%
		Middle	71	27%
		West	18	12%
Hot & dry: very frequent fire	High severity: 10,000 ha Low/Mod severity: 100 ha	North	100	50%
		East	72	33%
		Middle	41	17%
		West	10	0%
Past 500 years, moderate to cool; empirical parameters	High severity: 20,000 ha Low/Mod severity: 500 ha	North	450	85%
		East	250	70%
		Middle	125	50%
		West	75	25%

LADS Model Output Classification

This study used an output classification scheme comparable to one being used in a sister project in the Oregon Coast Range (Wimberly, submitted; Wimberly et al., 2000) and discussed in detail in those studies. Output values 1 to 7 (Table 2.4) were assigned to age and structural complexity classes that may be interpreted based on known vegetation succession rates in the area (Franklin et al., 2002; Nesje, 1996). The seven age/structural classes were used for comparison with results in the Coast Range. Then, the structural classes were combined for this study, and only the age class information was used, resulting in four age classes: early seral (0 –30 years), young forest (31-80 years), mature forest (81-200 years) and old forest (over 200 years).

LADS Model Runs

Sensitivity analyses of the effect of fire frequency, severity and size parameters on fire disturbance characteristics were conducted by varying the parameters one at a time while holding all of the other parameters constant at average (base) values (Table 2.5). Seven, 1000 year simulations were run, varying frequency, severity and size parameters from the highest to lowest values used in the simulations (Table 2.5). Gridded landscapes were output every 50 years. The fire disturbance characteristics of the resultant landscapes, as measured by the amount of early seral vegetation on each, were exported to Excel. The mean and standard deviation of early seral vegetation were calculated and graphed to identify trends in the output related to each specific variable.

Table 2.4. Modeled vegetation classes (Wimberly, 2000). At any given time step, the model output consists of cells with values 1 to 7, indicating the time since the last high severity fire (AGE) and the time since the last fire of any severity (TFIRE). The age of the oldest trees in the cell is given by AGE; the youngest by TFIRE. Open, semi-open and young classes are classified based on the age of the youngest trees (TFIRE); mature, old and very old classes are based on the age of the oldest trees (AGE).

LADS Class	TFIRE: Time since last fire (years)	AGE: Time since stand replacement (years)	Inferred vegetation type, Wimberly (2000?)	Age class used for analysis in this study
1	< 30	< 30	Open	1: Early seral
2	< 30	> 30	Semi-open	
3	30-80	30-80	Young, single story	2: Young forest
4	30-80	>80	Young, multistory	
5	80-200	80-200	Mature	3: Mature forest
6	80-500	200-500	Old	4: Old forest
7	>80	>500	Very Old	

Table 2.5. Sensitivity analysis of fire frequency, severity, and size parameters used in the LADS model. The values listed as "base" were the average values held constant for tests of other variables. Parameters values tested are shown.

Test Variable	Size (ha) By severity	Regime	Frequency (NFR, yrs)	Severity (% high)
Base	High size: 55,000 ha Low size: 550 ha	North	300	75%
		High	221	59%
		Middle	126	42%
		Low	32	25%
High Frequency	High size: Base Low size: Base	North	**100**	Base
		High	**70**	Base
		Middle	**40**	Base
		Low	**10**	Base
Low Frequency	High size: Base Low size: Base	North	**1000**	Base
		High	**700**	Base
		Middle	**400**	Base
		Low	**100**	Base
High Size	High size: **100,000 ha** Low size: **1000 ha**	North	Base	Base
		High	Base	Base
		Middle	Base	Base
		Low	Base	Base
Low Size	High Size: **10,000 ha** Low Size: **100 ha**	North	Base	Base
		High	Base	Base
		Middle	Base	Base
		Low	Base	Base
High Severity	High severity: Base Low/Mod severity: Base	North	Base	**100%**
		High	Base	**80%**
		Middle	Base	**65%**
		Low	Base	**50%**
Low Severity	High size: Base Low size: Base	North	Base	**50%**
		High	Base	**30%**
		Middle	Base	**10%**
		Low	Base	**0%**

The sensitivity analysis indicates that the mean amount of landscape in the disturbed (early seral) age class is most sensitive to fire frequency, while disturbance variability is sensitive to both fire frequency and fire size (Figure 2.6). Decreasing the natural fire rotation from the very infrequent fire simulation (NFR 1000, 700, 400, and 100 years for the four zones) to the frequent fire simulation (NFR 100, 70, 40 and 10 years for the four zones) resulted in a corresponding increase in the mean amount of early seral forest from 9.7 percent to 53.7 percent. The standard deviation increased from 3.5 to 6.5 percent. Conversely, decreasing the fire size from high and low severity average sizes of 100,000 ha and 1000 ha to 20,000 ha and 500 ha, respectively, resulted in little change in mean percentages of disturbed forest (25.2 percent to 24.5 percent), but a large decrease in the variability (standard deviation from 7.5 to 2.5 percent). For a given natural fire rotation, incorporating a higher proportion of disturbance in a few, larger events, results in a corresponding decrease in the amount of disturbance occurring in the remaining events. Therefore, under those conditions, there are a few, highly disturbed landscapes and many less disturbed landscapes, thus displaying high variability, but the mean remains the same.

Because the LADS model correlates severity with size, changing the severity results in a change in the proportion of fire sizes, but not the fire frequency. Therefore, sensitivity to severity is similar to sensitivity to size, affecting primarily variability (analysis not shown). In summary, varying the natural fire rotation primarily affects mean age class amounts and secondarily variability, while varying the fire size and/or severity characteristics affects only variability.

Based on the sensitivity analysis, simulations were run for 3000 years, to allow the high fire size simulations adequate time to express the full range of variability on the landscape. Each simulation was preceded by a 500 year burn-in period that was not included in the analysis. Gridded landscapes were output by the model in 50 year time steps.

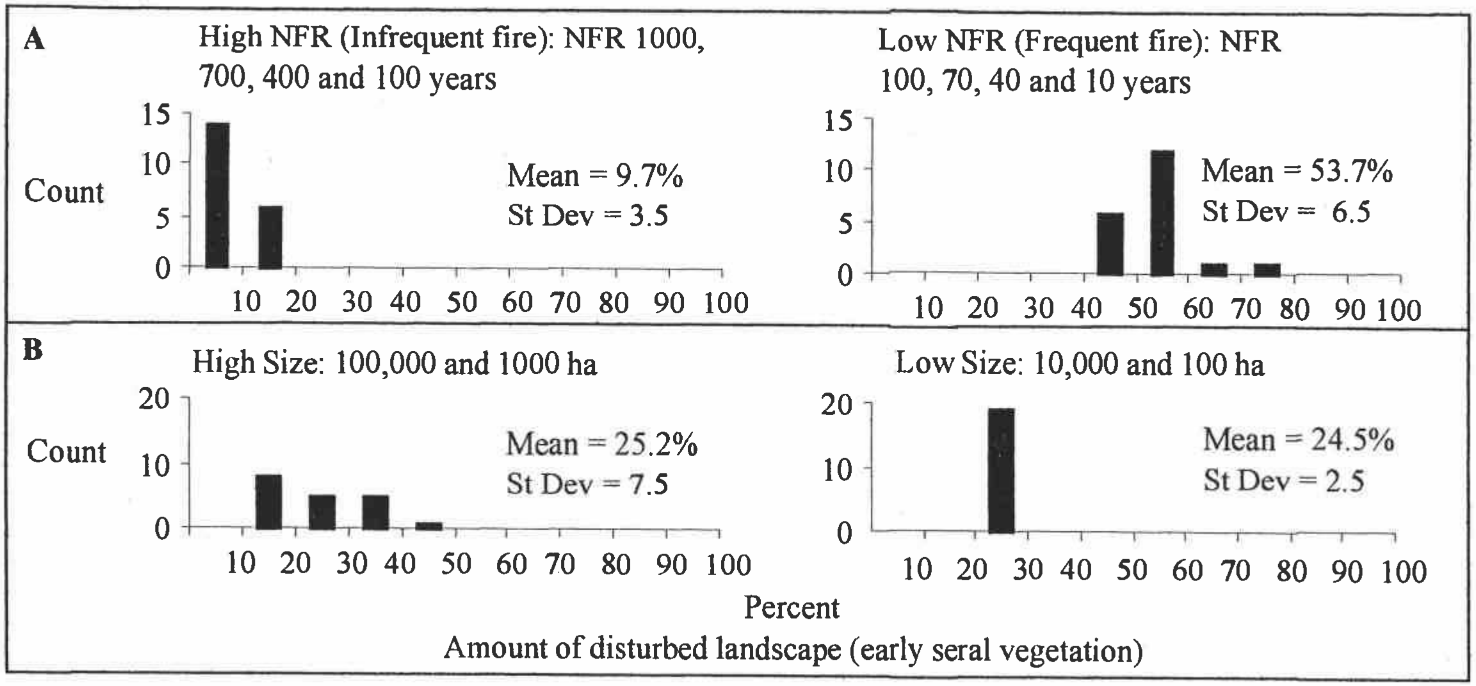


Figure 2.6. Histograms from the sensitivity analysis of fire frequency and size parameters. For natural fire rotation (NFR), size and severity parameters were held constant while NFR was varied from the extremes used in the simulations. For the size test, NFR and severity were held constant while size was varied from the extremes used in the simulations. Severity parameters were also tested. Note that changing the fire frequency affects both the mean disturbance amount and the standard deviation, while fire size affects only the standard deviation.

Five fire scenarios were simulated. Four used parameters from the postulated range of very infrequent to frequent fire conditions through time. A simulation of very frequent fire (and hence, very small fire size), used in the sensitivity analysis, was not conducted for the 3000 years due to excessive run times (more than 8 days for the 1000 year sensitivity simulation). The fifth simulation used parameters based solely on the empirical field data.

LADS Model Output Landscapes

Output consisted of 60 landscapes for each of five simulations, for a total of 300 wildfire-affected landscapes. Cells in each landscape were classified as values 1 through 7, representing age and structural classes (Table 2.4). These seven classes were re-grouped into four age classes, and age class amounts were imported into Excel. The percentage of the study area in each age class was graphed over time. The mean, standard deviation and error, maximum and minimum percentage of area over time were computed for each age class. Histograms were created of the class amounts. The results from the five simulations were contrasted, especially with reference to the simulation based on the empirical data.

Five landscapes from each fire scenario were selected for further analysis. Three of the selected landscapes represented mean amounts of fire disturbance on the landscape as measured by the amount of early seral vegetation present. The remaining two selected landscapes represented the extremes of the range of fire disturbance variability: the 5- and 95-percentiles of the early seral age class distribution. Therefore, twenty-five of the original 300 landscapes were selected for additional analysis.

Mixed Disturbance Regime: Characterization of the 1995 Landscape

Three classified land cover base maps derived from 30 m Thematic Mapper remotely sensed imagery were combined to create an age class layer (Appendix E):

1) LARS95DISTURB, a disturbance map created using change analysis from 1972-1995,
2) LARS88CONAGE, a map of conifer stand age derived from 1988 Thematic Mapper imagery, and
3) LARS88VEGMAP, a vegetation class map, also derived from 1988 Thematic Mapper imagery, including seven structural classifications.

Cohen et al. (1995a; 1995b; 1998; 2001) and Cohen and Spies (1992) describe details regarding the creation of these base maps. LARS95DISTURB was created from six Landsat Multi-spectral Scanner images dated 1972, 1977, 1984, 1988, 1991 and 1995. The six images were classified as closed canopy forest, water, or other using unsupervised techniques. Consecutive images were overlain to identify pixels that had changed from closed canopy forest to the other category. Hence, this map identifies stand-replacement forest disturbance by fire or cutting from 1972 to 1995.

LARS88CONAGE and LARS88VEGMAP are maps derived from 1988 Thematic Mapper imagery. A Tasselled Cap transformation was used to determine brightness, greenness and wetness components of the remotely sensed data. Those components were analyzed along with field data and aerial photographs to create a regression relationship that predicted vegetation class and conifer age from the remotely sensed data. Ages are presented as continuous; however, the standard error is 102 years (Cohen, personal communication). The vegetation class map used standard supervised and unsupervised classification techniques to identify seven vegetation classes:

1) Open (<30 percent green vegetation cover),
2) Semi-open (30-70 percent green vegetation cover),
3) Broadleaf (> 70 percent broadleaf cover),
4) Mixed (> 70 percent green vegetation cover, < 70 percent broadleaf and < 70 percent conifer),
5) Young conifer (> 70 percent conifer cover, < 80 years),
6) Mature conifer (> 70 percent conifer cover, 80-200 years) and
7) Old conifer (> 70 percent conifer cover, > 200 years).

An error assessment was conducted between the three layers before combining them. The conifer age and vegetation class maps were 100 percent consistent (e.g. everything assigned a conifer age was classified as conifer forest with consistent ages), since they were derived concurrently during the same analysis. Conifer age and vegetation class were each compared with the disturbance map. Two assumptions were made: 1) cells identified as disturbed after 1972 on the disturbance map would have had less than sixteen years to regenerate to conifer closure at the time the 1988 Thematic Mapper data were obtained, and therefore should be classified as either early seral vegetation or young conifer on the vegetation class map, and as less than 16 years old on the conifer age map, and 2) cells undisturbed between 1972 and 1995, in most cases, should not be classified as open or semi-open on the vegetation class map, given that small, naturally open areas (such as rock outcrops) are a very small percentage of the landscape. Using these assumptions, approximately 2 percent of cells on the disturbance map are inconsistently classified on at least one of the other maps. Note that this analysis did not identify all sources of error. The classification accuracy for the disturbance map was estimated at 91 percent (Cohen et al., 1995a).

The conifer age and vegetation class maps have estimated classification accuracy of 70 to 75 percent and 82 percent, respectively (Cohen et al., 2001).

The disturbance, vegetation class and conifer age maps all provide information regarding disturbance history, but with different temporal extents and resolutions. The three maps were combined to produce an age class layer at 30 m resolution assigning pixels to one of four broad age classes (DISTAGECLASS; Table 2.6): 0-30 years (early seral), 31-80 years (young forest), 81-200 years (mature forest), and > 200 years (old forest). Time of disturbance is measured most directly and accurately by the disturbance map, which was used as the primary source for assigning pixels to the 0 to 30 year age class (Table 2.6). However, only roughly 30 percent of cells throughout the study area were disturbed in that 23 year period. Pixels that were assigned a value on the conifer age map were assigned to an age class based on that age. Because there is an average lag of approximately 33 years from the time of disturbance until conifer canopy closure (Nesje, 1996), stands disturbed more recently than about 1960 are less likely to have achieved canopy closure by 1988, and could not be classified by this method. The age class of pixels not classified from the disturbance or conifer age maps was inferred from the vegetation class map. Of these, pixels classified as early seral in 1988 (open, semi-open or broadleaf) were likely to have been disturbed just prior to the 1972 date covered by the disturbance map. These were assigned to the 0 to 30 year age class in DISTAGECLASS.

Pixels classified as mixed conifer/broadleaf that were not disturbed after 1972 could not be assigned to an age class with confidence. Mixed forest pixels could occur as early as 20 years post disturbance, in the 0 to 30 year age class. However, wilderness areas contain approximately 20 percent mixed conifer/broadleaf pixels. These areas have not been disturbed in nearly a century, demonstrating that mixed conifer/broadleaf pixels could be more than 100 years old, in the mature forest age class. Since mixed conifer/broadleaf pixels could be assigned to at least three of the four age classes, they were left unassigned.

Table 2.6. Comparison of age class information derived from the disturbance (LARS95DISTURB), conifer age (LARS95CONAGE), and the vegetation class (LARS95VEGMAP) maps (Cohen et al., 2001) to produce the final age class map (DISTAGECLASS). Age classes were assigned from the disturbance or conifer age maps, where possible. Otherwise, vegetation class was used. The disturbance map was considered to be most accurate, but only applies to stands initiated since 1972. The conifer age map was secondary and was most useful for stands initiated prior to 1960, which were likely to have fully regenerated to conifer by 1988. The intervening period, from 1960 to 1972 is not well represented in either data set. Pixels not classified by either of these two data sets were classified based on the vegetation class map from the 1988 imagery, with open, semi-open and broadleaf vegetation classes assigned to the 0 to 30 year age class.

Year	LARS95-DISTURB	LARS88CONAGE			LARS88-VEGMAP	DISTAGE-CLASS
	Value	Value (yrs)	Count (30 m pixels)	Information	Class	Class
1995	1-Harvest 2-Fire			No conifer age signal	Open, Semi-open, Broadleaf	Age Class 1 < 30 years Early seral Includes all pixels from post-1972 disturbance + conifer age values 1-23 + Pixels identified as open, semi-open or broadleaf on vegetation class map
1994						
1993						
1992						
1991	3-Harvest 4-Fire					
1990						
1989						
1988	5-Harvest 6-Fire	1	1624	Weak, possibly erroneous conifer age signal		
1987		2	1140			
1986		3	1347			
1985		4	1044			
1984	7-Harvest	5	1121			
1983		6	1110			
1982		7	681			
1981		8	1174			
1980		9	870			
1979		10	3258			
1978		11	685			

Table 2.6, continued.

1977	8-Harvest	12	898			
1976		13	3541			
1975		14	622			
1974		15	1097			
1973		16	2719			
1972		17	781			
1971	9- Undisturbed	18	3599			
1970		19	2690			
1969		20	5441			
1968		21	7249			
1967		22	5733			
1966		23	7722			
1965 1950		24 39	14998 54913	Transitional conifer age signal, probably from the most productive sites	Young Forest	Age Class 2 31-80 years Young Conifer Forest Includes conifer age map values 24-74
1949 1915		40 74	197966	Strong conifer age signal, most pre-1950 harvested sites are fully regenerated, given 38+ years		

Table 2.6, continued.

1914 1795		75 194			Mature Forest	Age Class 3 81-200 years Mature Conifer Forest
1794		195			Old Forest	Age Class 4 > 201 years Old Conifer Forest

Harvest Disturbance Regime: Construction of Hypothetical Managed Landscapes

Hypothetical managed landscapes were created with the goal of representing a limited number of features of timber management plans as they might exist in the future if those features entirely replaced the current, mixed-impact landscape. If the future is consistent with the past, timber management may vary considerably in time and across ownerships. However, it is likely that forest disturbance will continue to be driven by a combination of economic incentives for timber harvest along with environmental protection issues. Three hypothetical managed landscapes were created, representing selected elements from several management strategies on federal lands (Table 2.7). These landscapes combine simplified assumptions regarding harvest rotation length, size and severity and the location of undisturbed forest reserves. For simplicity, landscape names refer to only the primary features in the landscape:

- A riparian-rule landscape (RIP). Harvest strategies in the mid-20th century, during the peak of timber harvest, were used as a guideline in constructing a largely economically driven hypothetical landscape. This landscape was constructed using 40 year rotations with aggregated patches on private industrial lands based on target practices for larger industrial firms (Spies et al., 1994), 80 year rotations, and smaller, dispersed harvest patches on federal lands based on target practices on federal lands during that time period, and old forest in the wilderness areas. Average riparian buffer rules from the Oregon Forest Practices Act were applied,
- A riparian-rule plus reserves landscape (RIP/RES), similar to the riparian-rule landscape but with increased riparian and late successional reserves and a 15 percent green tree retention level on public lands, based loosely on targets from the Northwest Forest Plan,
- A riparian-rule plus reserves plus mixed-rotation landscape (RIP/RES/ROT) based on the approach proposed by Cissel et al. (1999) for the Blue River watershed in the central portion of the study area. This landscape prescribes more limited riparian reserves than the Northwest Forest Plan, maintains large areas of late successional reserves from the Northwest Forest Plan, but modifies the harvest rotations, cutting sizes and green tree retention to be more consistent with disturbance characteristics of the natural fire regime.

Private industrial lands were modeled similarly in all three scenarios, with larger, aggregated harvest patches and shorter rotations (40 years). Wilderness areas were modeled as all old forest in all three scenarios, assuming long term continued lack of disturbance. Bureau of Land Management/private industrial checkerboard lands were modeled with 80 year dispersed patterns, rather than a mixture of patterns because the land owner boundaries were not retained in the GIS layers representing these areas and thus it was not possible to assign a mixture of characteristics. The harvest patterns applied to the hypothetical landscapes were constructed as a one-time pattern allocation whereas the wildfire landscapes were simulated over time, had inertia, but were steady-state.

Table 2.7. Elements of managed landscapes representing three timber management strategies: riparian reserves, late successional reserves and harvest rotations based on natural fire regimes, on four owner/allocation types: Bureau of Land Management/private industrial checkerboard lands (BLM/PI Checkerboard), private industrial, U.S. Forest Service non-wilderness and U.S. Forest Service wilderness. YR = rotation years, AG = aggregated pattern, DSP = dispersed pattern.

Scenario	Owner/Allocation Type			
	BLM/PI Checkerboard	Private Industrial	U.S. Forest Service non-wilderness	U.S. Forest Service Wilderness
Riparian-rule	80 YR, DSP State riparian	40 YR, AG State riparian	80 YR, DSP State riparian	All Old
Riparian/ Reserves	80 YR, DSP NWFP riparian	40 YR, AG State riparian	80 YR, DSP NWFP riparian	All Old
Riparian/ Reserves/ Mixed-Rotation	80 YR, DSP HRV riparian	40 YR, AG State riparian	100-260 YR, AG, MD, DSP HRV riparian	All Old

These landscapes were constructed in three steps. First, layers of a single harvest pattern were created. Second, layers of riparian buffers were created, using three different rule sets consistent with the three different management strategies. Third, selected single patterns were combined with riparian layers to construct compound landscapes, also tracking green tree retention rates. Each of these steps is described below.

Construction of single pattern layers

Harvest landscapes consisting of a single pattern were simulated with the SIMMAP 2.0 model (Saura, 1999; Saura and Martínez-Millán, 2000). A range of harvest rotations and aggregation patterns were used, spanning the observed 20th century rates and proposed future rates on federal lands (Table 2.8; Appendix F). The model distributes age classes randomly, with a user-defined aggregation factor (Appendix F) that groups cells of a given class according to a normal distribution around a mean cluster size. The SIMMAP model creates a one-time pattern allocation whereas the LADS wildfire model was simulated over time, had inertia, but was steady-state. The class percentages used in single pattern landscapes were calculated at given rotations as the number of years represented in the class divided by the number of years in the rotation. Each rotation was simulated five times using progressively increasing aggregation factors (0.05 to 0.55, Appendix F), producing samples of a progression of patch aggregation patterns along with a progression of harvest frequencies. Simulated patterns were imported into ArcInfo, registered, reclassified for consistency, and clipped to the study area boundary. Additionally, a landscape consisting of all old forest was constructed.

Table 2.8. Simulated age class percentages in single pattern landscapes. The layer name consisted of HARV + the rotation + the aggregation pattern, where AG = aggregated pattern, MD = intermediate pattern, and DSP = dispersed pattern.

Rota-tion	Early Seral 0-30 years	Young 30-80 years	Mature 80-200 years	Old > 200 years	Layer Names
40	75%	25%			HARV40AG HARV40MD HARV40DSP
80	38%	62%			HARV80AG HARV80MD HARV80DSP
100	30%	50%	20%		HARV100AG HARV100MD HARV100DSP
120	25%	42%	33%		HARV120AG HARV120MD HARV120DSP
160	19%	31%	50%		HARV160AG HARV160MD HARV160DSP
180	17%	28%	55%		HARV180AG HARV180MD HARV180DSP
200	15%	25%	60%		HARV200AG HARV200MD HARV200DSP
240	13%	21%	50%	16%	HARV240AG HARV240MD HARV240DSP
260	12%	19%	46%	23%	HARV260AG HARV260MD HARV260DSP
All old				100%	ALLOLD

The SIMMAP model outputs mean patch sizes in terms of numbers of cells. This output was recalculated for a 4 ha cell area. The resultant patch sizes were compared with target aggregation patterns for the three landscape scenarios to select appropriate aggregated, moderate and dispersed patterns for each landscape (Figure 2.7). Although mean patch sizes differed for different samples, in general these produced landscapes with early seral mean patch sizes of 10, 30 and 60 ha, respectively. Private industrial lands have typical harvest rates of 40 years and large, aggregated patterns, while public lands have longer harvest rotations (typically 80 years in the past) and smaller, dispersed patterns (Spies et al., 1994). Therefore, the 40 year rotation layer with an aggregated pattern (HARV40AG) was used to represent private industrial harvest patterns on all three landscapes. The 80 year rotation layer with a dispersed pattern (HARV80DSP) was used to represent harvest patterns on U.S. Forest Service lands in riparian- and riparian/reserve-rule landscapes. Three additional rotations with all three aggregation patterns were required for creation of the riparian-rule plus reserves and mixed-rotation landscape: the 100, 180 and 260 year rotations. The ALLOLD layer was used for wilderness areas, and for federal reserves in riparian-rule plus reserves and riparian-rule plus reserves and mixed-rotation scenarios.

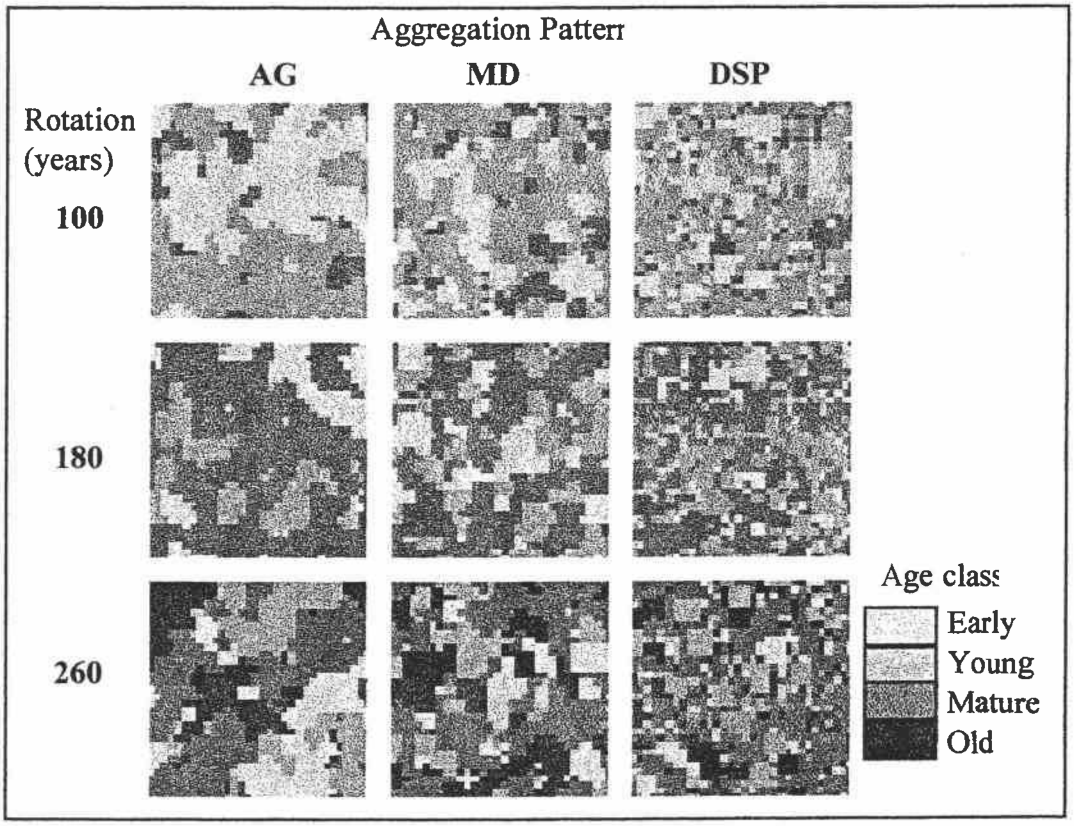


Figure 2.7. Examples of single pattern landscapes created in Simmap 2.0, using different rotations (in years) and aggregation factors (unitless). Aggregation factors: Aggregated (AG) = 0.45, moderate (MD) = 0.25 and dispersed (DSP) = 0.05. These patterns were used to construct compound landscape areas in the historical range of variability scenario.

Construction of riparian buffer layers

Riparian buffers were modeled according to three policies: the Oregon Forest Practices Act, the Northwest Forest Plan, and as proposed in the Blue River Plan (Cissel et al., 1999). These models required special techniques due to small sized buffers (< 100 meters) relative to the coarser resolution of the simulation data (200 meter). The goal was to develop a method by which the portion of each cell occupied by riparian buffer could be estimated under the three different rule sets. A fuzzy approach (Fisher et al., 1999; Wilson and Burrough, 1999; Zadeh, 1994) was used to accomplish this. Fuzzy approaches are methods by which a given cell, rather than being assigned to a single class, has percentages assigned to multiple classes. It is an attempt to more explicitly quantify cells that do not consist of a single constituent.

All three rule sets distinguish between fish-bearing and non fish-bearing streams. However, there is no data set containing information regarding the fish-bearing status of most Cascade stream segments. Although the Oregon Department of Forestry has initiated a survey of streams, it is not expected to be finished for a number of years (ODF, 2001b). Therefore, a means of approximating a likely subset of fish-bearing streams from the set of all streams had to be devised. To accomplish this, methods were established in the Blue River watershed, where the fish-bearing status of streams is known and digital layers exist. A 30 meter DEM was used to develop a set of rules that predicted (to a reasonable degree) the fish-bearing status of streams in the Blue River, then that set of rules was applied across the entire study area. It is notable that this is a major source of uncertainty, since not only does this procedure only approximate conditions in Blue River, Blue River itself is only a small portion of the study area, and does not represent the range of conditions throughout the entire area. However, the difference between rules for fish- and non fish-bearing streams is small, except for the riparian-rule plus reserves and mixed-rotation scenario, which contains numerous uncertainties in addition to the riparian analysis.

In the initial step (see Appendix G for additional details), stream layers were created using a range of drainage cutoffs, producing a series of layers that were compared with the Blue River streams. A layer representing all streams draining more than 90 ha (100 30 m cells) nearly identified the same streams identified at for the Blue River area under the Northwest Forest Plan (Figure 2.8). Known fish-bearing streams were approximated with a layer of streams draining 900 ha (1000 30 m cells) or more.

Three sets of rules were applied against the fish-bearing and non fish-bearing stream layers (Table 2.9). State rules (ODF, 2001b) apply a range of buffer sizes within which no harvesting is allowed, depending on the stream size. For simplicity, average buffer widths were applied. An average of 75 foot buffers (23m) are required by state law on each side of fish bearing streams, 60 feet (18 m) for non-fish bearing streams. The full buffer widths of 46 m and 36 m were approximated as two 30 m cell widths and one 30 m cell width, respectively. The Northwest Forest Plan (USDA and BLM, 1994) mandates buffers two tree heights wide along each side of fish-bearing streams, and one tree height along each side of non fish-bearing streams. Since tree height varies with site potential and cannot be derived from remotely sensed imagery, an average value of 52 m was used, estimated in the Blue River (Cissel, 1994), yielding full buffer widths of 208 m (6 cell widths) and 104 m (3 cell widths). The Blue River Plan (Cissel et al., 1999) proposes 70-200 m buffers along each side of fish-bearing streams (averaging 270 m total width, 9 cell widths), with no buffers required for non fish-bearing streams. Hence six buffer layers were created, for each combination of rule set (Oregon Forest Practices Act, Northwest Forest Plan, or Blue River Plan) and fish-bearing status. Errors were introduced where the buffer did not exactly correspond to the 30 meter cell widths.

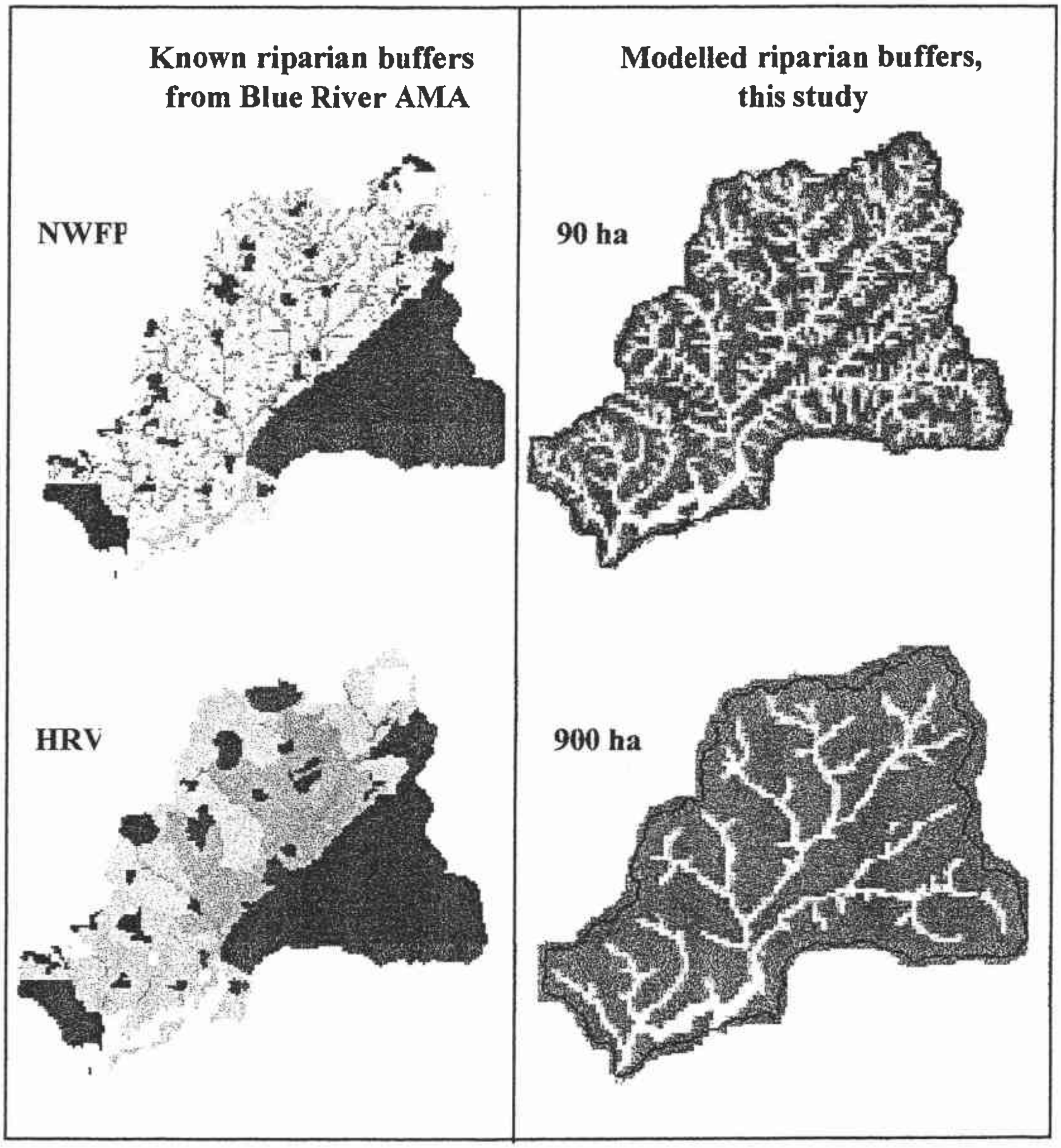


Figure 2.8. Comparison of known and modelled riparian buffers for the Northwest Forest Plan and historical range of variability scenario, for streams in the Blue River watershed. Modelled layers were created by selecting cells based on drainage area, using cutoffs of 90 ha and 900 ha.

Table 2.9. Oregon Forest Practices Act, Northwest Forest Plan and Blue River Plan (Cissel et al., 1999) riparian rules for fish-bearing and non fish-bearing streams. Stated buffer width is applied to each side of the stream.

	Fish-bearing	Non fish-bearing
Oregon Forest Practices Act	50, 70 or 100 feet, depending on stream size (average: 75 feet = 23 meters)	50 or 70 feet, depending on stream size (average: 60 feet = 18 meters)
Northwest Forest Plan	2 tree heights = 104 meters	1 tree height = 52 meters
Blue River Plan	70-200 meters (average: 135 meters)	No buffer required

Because the required buffer sizes were smaller than the cell resolution of the simulations (200 m), riparian percentages of the larger cell were estimated by using the ArcInfo AGGREGATE function to increase the riparian layers cell size from the initial 30 meter resolution to the 200 meter resolution of the simulations. The AGGREGATE function allows the grouping of smaller cells into larger ones and offers a variety of functions for the resulting cell value. In this case, 30 meter cells were flagged with a binary 1 or 0, depending on whether or not they contributed to a specific riparian rule set. The smaller, binary cells were then grouped, counting the number of riparian cells in the larger group, yielding a count of 30 meter riparian cells within a larger 180 meter cell resolution. The 180 meter resolution layer then had to be resampled using the nearest neighbor technique to the 200 meter resolution of the simulation layers, introducing additional errors. Fuzzy classification methods were used to track both the age class of the cell and the percentage of that cell that consisted of riparian buffer in each of the harvest landscapes. Specifically, the first character of the cell value was assigned the original age class; the 2nd and 3rd characters were assigned the riparian percentage.

The three riparian layers were compared for the entire study area, and stratified by elevation zone. Elevation zone was determined from the digital elevation model using three groups: 0 to 700, 700 to 1200, and greater than 1200 meters (Appendix H). Data from the riparian layers were exported to Excel, where total riparian area, and area by elevation zone was compiled.

Construction of hypothetical managed landscapes

Single pattern layers were combined with riparian layers to create three hypothetical managed landscapes (Appendix I). In all three scenarios, wilderness areas were prescribed using the all-old forest pattern (ALLOLD), the long-term targeted condition for these areas. Private industrial lands were prescribed a 40 year rotation and aggregated patterns (HARV40AG) in all three cases. The scenarios differed in the treatment of U.S. Forest Service non-wilderness land. These differences are described below.

The riparian-rule scenario (RIP) is based on the period of most intense harvesting on public lands, from about 1960 to 1990, prior to enactment of the Northwest Forest Plan. The riparian-rule landscape uses harvest rates and patterns typical of that time period combined with riparian buffer zones located according to the Oregon Forest Practices Act, which governed the location of harvest patches relative to the stream network at that time. It was created by overlaying three single pattern landscapes: the 40 year rotation/aggregated pattern landscape (HARV40AG) on private industrial lands, the 80 year rotation/dispersed pattern (HARV80DSP) on Bureau of Land Management/private industrial checkerboard lands and U.S. Forest Service non-wilderness lands and the all old landscape (ALLOLD) in the wilderness areas. That landscape was overlain by the state-mandated riparian buffer zones, which were prescribed as old forest within the buffer, assuming that disturbance within the riparian areas would be suppressed indefinitely. Standard practice at this time was to completely clearcut harvest, so no green tree retention was tracked in this scenario.

The riparian/reserve scenario (RIP/RES) represents selected forest management policies from the 1994 Northwest Forest Plan (USDA and BLM, 1994), which imposed stricter riparian buffer requirements and set aside substantial area in late successional reserves on public lands. Remaining acreage on public land, designated as matrix, retained the potential for 80 year rotation target rates with mandatory 15 percent green tree retention. The initial landscape was created with the 40 year rotation/aggregated pattern (HARV40AG) on private industrial lands, the all old landscape (ALLOLD) on wilderness lands and the 80 year rotation/dispersed (HARV80DSP) pattern on U.S. Forest Service non-wilderness lands. These were identical to the riparian scenario. Then, old forest from the all-old landscape (ALLOLD) was overlain in the newly designated late successional reserve areas. Northwest Forest Plan rules were used to designate the riparian overlays, and the 15 percent green tree retention rates were allocated to matrix areas on a per cell basis, using similar fuzzy classification methods as used to track riparian buffers, namely, the 4th and 5th characters of each cell value consisted of the green tree retention percentage for that cell, either 0 or 15 percent in this scenario.

The riparian-rule plus reserves and mixed-rotation scenario (RIP/RES/ROT) represents selected elements from a new management proposal for the future, using historical range of variability concepts. The management strategy has been worked out in detail by the U.S. Forest Service in the Blue River watershed. Creation of this landscape was complex, and is described in detail in Appendix I. Conceptually, the strategy consists of identifying natural wildfire regimes on the landscape, and attempting to incorporate the frequency, size, and severity characteristics of the natural fire regime into harvest management goals through the use of multiple rotation lengths, cut-disturbance patch sizes and retention levels

(Cissel et al., 1999). The goal of the riparian-rule plus reserves and mixed-rotation scenario was to attempt to spread some elements of the Blue River strategy across the broader landscape. In practice, this was difficult to accomplish because the rules used in the Blue River Plan are site specific, and require substantial field-based information and site specific interpretation. Additionally, the Blue River watershed is only a small portion of the larger study area and is not representative of the full range of conditions. The methodology presented here attempted to capture the main features of the Blue River approach without the site specific details.

The plan consists of two general management classes: reserves that are not subject to harvest, and landscape areas that are subject to varying degrees and types of harvest. Reserves consist of discrete areas set aside as late successional reserves by the Northwest Forest Plan, as special area (unique) reserves, and as aquatic reserves designated around streams and reservoirs. The latter two are flexible, depending on management objectives as part of the Aquatic Conservation Strategy of the Northwest Forest Plan for late successional forest conditions rather than on an identifiable set of rules, and may include entire small watersheds, where desired, to meet site specific habitat objectives. Landscape areas consist of blocks that are harvested on different rotations and a range of patch sizes. In the Blue River Plan, landscape areas were designated partly based on a fire regime study that was accomplished in the area (Weisberg, 1998), and partly based on known ecological conditions and identifiable landforms.

Therefore, a method had to be developed that would approximate the concepts prescribed by the Blue River Plan over the full Cascade study area, without the site specific, field-based knowledge that is an integral part of that plan. The approach used was to create a rule set based on those discrete rules that are stated by the plan, combined with rules that approximate some of the field-based knowledge. The rules were developed conceptually, then applied to the local Blue River area and adjusted until the resultant distribution of age classes matched the

Blue River Plan. The rules were then spread across the study area. "Unique", "scenic", or other subjective criteria could not be incorporated, and would change the results that were obtained. However, this is a first attempt at establishing a base rule set that could then be modified as desired by managers using site level knowledge.

The Blue River Plan identified large, contiguous blocks on the ground and used the fire regimes identified by Weisberg (1998) as a reference in assigning harvest characteristics to each block. The Weisberg fire regime model was spread across the entire landscape in this study for the fire simulation work (page 26; Appendix D). A digital elevation model was used to delineate broad landform elements (ridge, valley, north, south, east and west hillslopes; see Appendix H for details) for which the model output could be generalized. Each topographic landform element contained a range of output values from the Weisberg model for each cell in the element, which were averaged for the whole landform element. The average was then used to assign the entire landform element to one of the three landscape areas from the Blue River Plan (Table 2.10; Figure 2.9), representing three harvest frequencies, each with unique retention levels, and each with three harvest patch sizes occurring in variable amounts.

Table 2.10. Landscape area prescription elements from the Blue River Plan (Cissel et al., 1999) used in the riparian-rule plus reserves and rotation scenario. Topographic landform elements identified from a digital elevation model were assigned to one of the 3 landscape areas based on average wildfire characteristics, estimated from a statistical model developed by Weisberg (1998).

	Rotation age (years)	Percentage of landscape area			Retention level (%)
		Small patch (< 40 ha)	Medium patch (40-80 ha)	Large patch (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

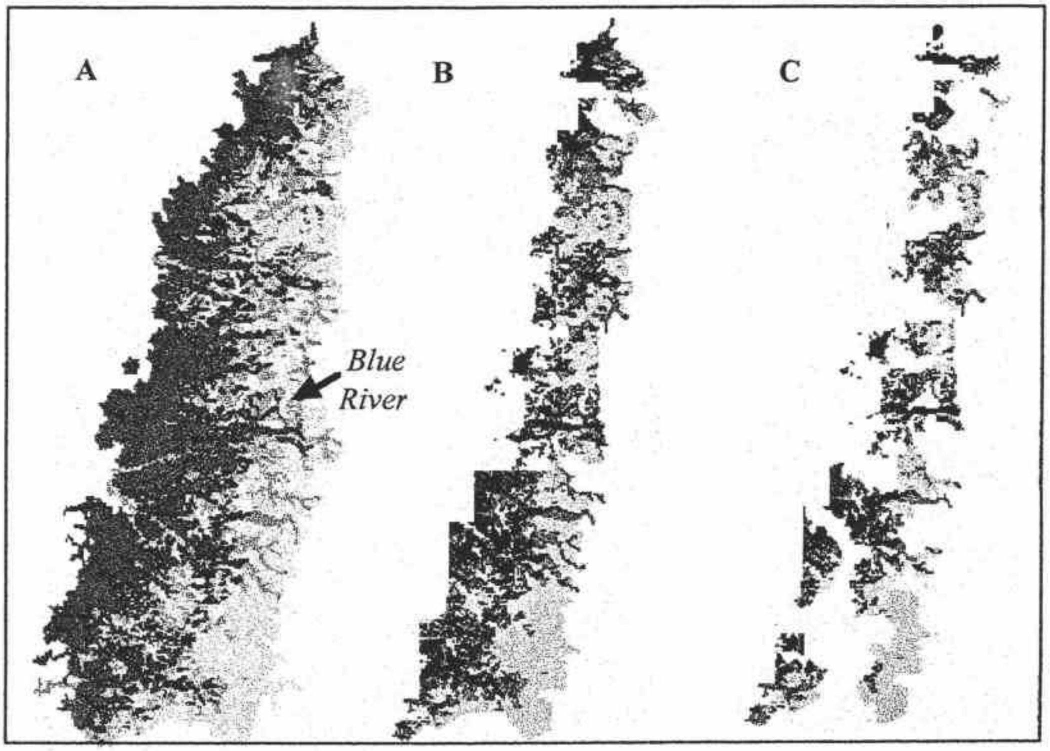


Figure 2.9. Progressive creation of U.S. Forest Service matrix landscape areas for the historical range of variability landscape. A) Fire regimes identified by the Weisberg model were averaged over topographic components for the entire study area. B) Same as A, for U.S. Forest Service owner/allocation types only. C) Same as B, with areas designated as wilderness or late successional reserves removed, yielding the final landscape areas used in the landscape creation.

Landform elements from each landscape area were selected at random to meet the percentage requirements for the different patch patterns. The assigned rotation age and aggregation patterns were applied by overlaying the appropriate single pattern layer for the different prescriptions. For instance, according to Table 2.10, 60 percent of landscape area 1 is comprised of small patches on 100 year rotations with a 50 percent retention level. Therefore, 60 percent of the landform elements in landscape area 1 were selected at random and prescribed the 100 year rotation small patch single pattern with a 50 percent retention level.

After the single patterns and retention levels had been applied, riparian buffers were overlain. Late successional reserves and wilderness areas were overlain using the ALLOLD layer. The resultant landscape consisted of a mixture of patch patterns assigned to whole landform elements based on their average natural fire regime characteristics, embedded in old-age classed riparian, late successional and wilderness reserves. This layer was then combined with the appropriate layers for BLM/PI checkerboard and private industrial lands (Figure 2.10).

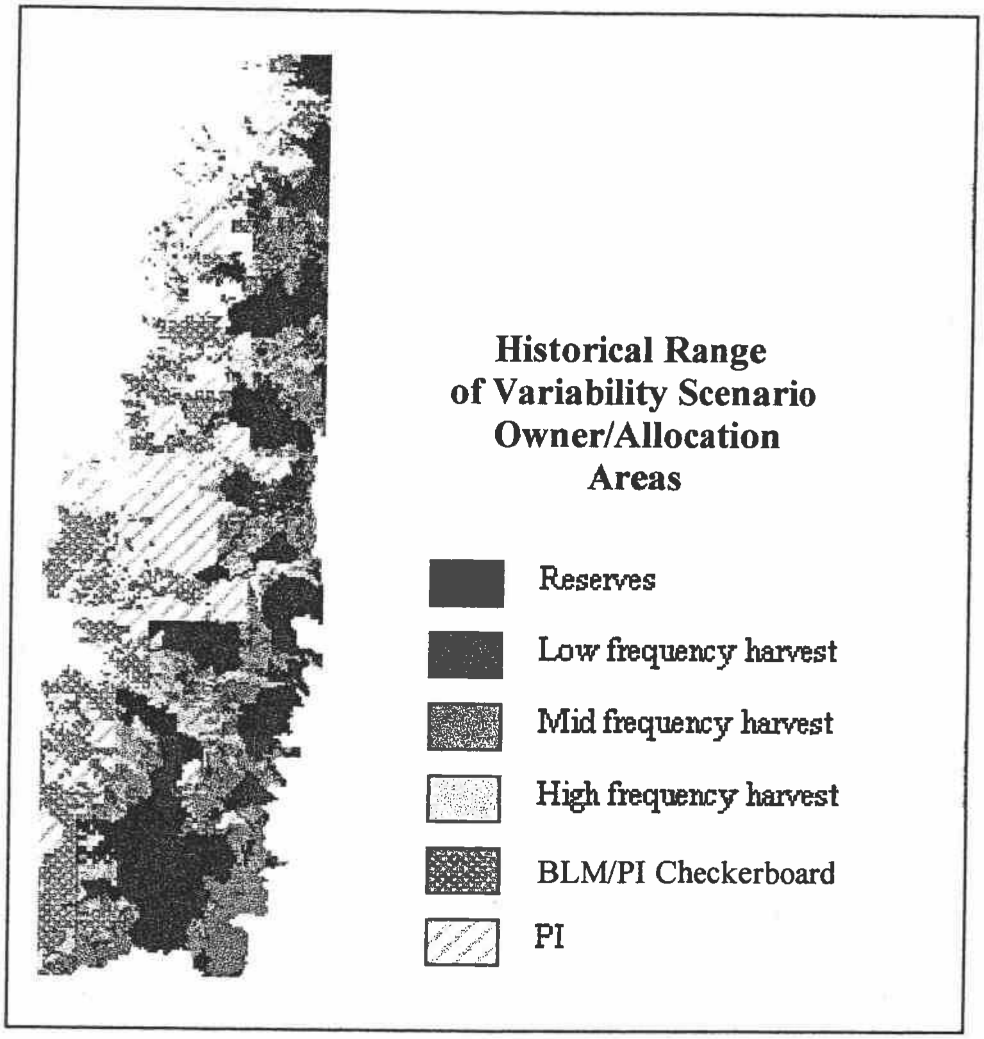


Figure 2.10. Allocation areas used to create historical range of variability landscape. Low, mid and high frequency harvest areas were assigned rotations, block sizes, and retention levels according to Cissel et al. (1999) prescriptions (Table 2.10). Bureau of Land Management/private industrial checkerboard lands were assigned 80 year rotations, 15% retention and dispersed patterns. Private industrial lands were assigned 40 year rotations and aggregated patterns.

Historical range of variability landscape - Blue River watershed comparison

The distribution of age classes in the riparian-rule plus reserves and mixed-rotation scenario was compared with the simulated age class distribution from the Blue River Plan, compiled from Table 5 in Cissel et al. (1999). That table lists the percentage of area in each age class subdivided by retention level. For example, the table lists the number of cells consisting of young (41-80 year) forest with a 30 percent retention rate. To simplify comparison, both Table 5 and the data from this study were input into Excel and recalculated as the percentage of the landscape in a given age class, assuming that all green-tree retention/overstory would be in the old forest age class. Since the average rotation in the riparian-rule plus reserves and mixed-rotation scenario is 180 years, the average age of retained trees would exceed that figure, and would consist of old forest. Age class amounts were then compared graphically.

The Cissel et al. (1999) study did not distinguish between age class amounts in the matrix area and amounts in the Blue River watershed as a whole, which contains approximately 20 percent special area reserves in the H. J. Andrews Experimental Forest which was not subject to logging in the Blue River Plan. The reported numbers are skewed by the large percentage of old forest on the H.J. Andrews site. Age class amounts for the Blue River Plan were recalculated by subtracting the acreage amount associated with the H.J. Andrews from the old forest age class for comparison with the non-reserves (matrix) area of the larger Cascades study area.

Structural Comparison of Wildfire-affected, 1995 and Hypothetical Managed Landscapes

Analyses of landscape structure were conducted on twenty-nine landscapes: the twenty-five selected wildfire-affected landscapes, the 1995 landscape and three hypothetical landscapes (riparian-rule, riparian-rule plus reserves, and riparian-rule plus reserves and mixed-rotation scenarios). One of the analyses was computationally intensive and was only conducted on one of the wildfire landscapes, as noted below.

Analyses were conducted on the whole landscape and stratified by owner/allocation type. An ArcInfo Macro Language (AML) script was written (Appendix A) to overlay each of the masks on each landscape, and export the appropriate information for the whole landscape and for each owner/allocation strata.

Comparison of Age Class Types and Amounts

Differences in forest age class types and amounts were compiled from the ArcInfo database. Age class counts, along with riparian and green tree retention levels for each landscape, were exported from ArcInfo into Excel. The riparian percentage of the cell was calculated in hectares and counted as old forest. The non-riparian percentage of the cell was further subdivided into the number of hectares of retained green trees. The equivalent area of green tree retention was also counted as old forest, with the remaining area counted as the matrix age class. These amounts were divided by the appropriate area (whole landscape or strata area) to obtain the landscape percent. Percentages were graphed for visual analysis.

Comparison of Patch Characteristics

The landscapes were analyzed for patch characteristics with APACK 2.0 (Mladenoff et al., 1995). Number of patches, mean patch size, largest patch and edge density sizes were calculated for the landscapes as a whole. Since the owner/allocation strata are of unequally sized areas, only mean patch size and edge density were calculated by owner/allocation type. The APACK results were imported into Excel, and graphed.

Comparison of Patch Arrangement: Patch Proximity Analysis

Patch arrangement with respect to other patch types was analyzed using a patch proximity analysis. The goal was to determine for each target cell what age class proportions occurred around that cell at different distance classes. The pair-wise (target cell age class and surrounding age class) counts by distance class were averaged for each landscape and imported into Excel. Graphs were created in Excel for each pair-wise age class combination, of the increase in age class area with increasing sample radius. Graphs were compared between landscapes. This analysis was computationally intensive, so that although layers were created for all of the landscapes, only one of the wildfire-affected landscapes was included in the Excel analysis along with the 1995 and hypothetical managed landscapes. The statistical significance of differences between landscapes could not be assessed without permutations of each landscape to create a statistical sample, and the time and resources were not available to create and analyze 100 permutations of each landscape. Details of this analysis are provided in Appendix J.

An additional thirty two landscapes were created for each of the thirty two fire and harvest landscapes for this analysis. Because of the volume of data generated, graphical analysis of patch arrangement by distance class was conducted for only four of the landscapes: the 1995, riparian-rule plus reserves- and riparian-rule plus reserves and mixed-rotation landscapes, and one fire landscape from the empirical simulation (FH700). The remainder of the constructed layers were used in analysis described in the next chapter.

Comparison of Disturbed Patch Arrangement Relative to the Stream Network

Appendix K details methodology used to analyze the position of disturbed (early seral) patches relative to the stream network. Not all streams can be identified at this resolution; rather, the stream analysis identified larger streams, draining more than 200 ha (4 ha cells, 50 cell flow accumulation cut off). For each pixel in each landscape, a layer was created that contained the distance class to the nearest identified stream segment. Zones within 200, 500, 1000, 2000 and 3000 meters distance from the stream network were delineated, which captured the range of distances identified at this resolution. Because drainage networks are self-similar, pixels that are far from larger streams are also likely to be relatively far from smaller streams, so that this methodology is useful for comparing relative changes in proximity to the stream network across the landscape, although the absolute distances are not meaningful. The number of early seral pixels in each distance class was counted for each landscape and by elevation zone. Because the elevation zones consist of different sized areas, the counts were normalized by dividing by the number of stream pixels in that zone, to obtain a count of the number of early seral pixels per stream pixel. These counts were imported into Excel for graphing.

Ecosystem Property Comparison

Approach

A set of properties acting as surrogates of ecosystem processes was identified. Site-specific data were collected on the relationship of these landscape properties to three factors: age class, elevation and patch arrangement. Sets of rules were developed for converting age class to ecosystem property response. For each property and rule set, cell values were calculated for each landscape and output to maps. The cell values for each map were averaged by landscape and by owner/allocation type. The resulting values were compared as a function of disturbance amount, owner/allocation type and disturbance regime (fire or harvest).

Thirty six landscapes were used for this analysis: the twenty five wildfire-affected landscapes, the 1995 landscape, the three hypothetical managed landscapes and seven single pattern landscapes used in the creation of the hypothetical landscapes. The single patterns were incorporated to demonstrate effects in the simplest of cases, with uniform patterns of varying age class amounts.

Selected ecosystem properties and rule sets to estimate their response to landscape structure are shown in Table 2.11. Rule sets were developed for each of three factors. The first rule set assumed that only the age class had an effect on the ecosystem property. The second rule set incorporated spatial complexity introduced by elevation. The third rule set incorporated complexity introduced by arrangement, in the cases where relevant pattern effects at this scale could be quantified. The development of these rule sets is described in detail below. The purpose of this approach was to extract the effect of spatial factors (elevation and patch arrangement) on the ecosystem property response relative to a base response where only age class is considered.

The thirty-six landscapes used four different cell value formats with varying complexity (Table 2.12). The first format was used in the 1995 landscape and the single patterns, consisting of a single numerical value representing four age class types (1 to 4, respectively): early seral (0-30 years), young forest (30-80 years), mature forest (80-200 years) and old forest (> 200 years). The second format was used in the riparian-based hypothetical landscape, and incorporated riparian buffer zone information. This consisted of three digit values, where the first digit corresponded to the four age classes identified above, and the second and third digits corresponded to the percentage of the cell in riparian buffer zones (e.g. a value of 130 is age class 1, 30 percent riparian). The third format incorporated both the percentage of the cell in riparian buffer zones, and green tree retention information. These were five digit values, the first three identical to the three digit values described above. The last two digits represented the percentage of green trees retained during harvest (0, 15, 30 or 50 percent). Landscapes from the wildfire simulations consisted of seven, single digit values: open (value 1) and semi-open (value 2), which were equivalent to the 0-30 year age class in the harvest data, young single cohort (value 3) and young multicohort (value 4), which were equivalent to the 31-80 years age class, mature (value 5), equivalent to the 81-200 year age class, and old (value 6, 200-500 years) and very old (value 7, > 500 years), equivalent to the greater than 200 year age class in the harvest data.

Table 2.11. List of ecosystem properties for which landscape effects were calculated. Three rule sets, with increasing consideration of spatial complexity, were used to convert age class landscapes to the magnitude of a property response. The three rule sets are shown across the top of the chart, based on the age class of the forest, elevation gradient and spatial arrangement.

Property	Rule set 1: Age class area	Rule set 2: Elevation	Rule set 3: Spatial Arrangement
Converted Wood Bole Volume	Not quantified	Based on estimated age of wood produced and average wood bole increment rate[1] for different site productivities[2] times the age of the cell	No known spatial arrangement constraints. Not quantified
Standing Wood Bole Volume	Not quantified	Based on average wood bole increment rates[1] for different site productivities[2] times the age of the cell.	No quantifiable spatial arrangement constraints. Edge effects likely, but not quantified.
Total Ecosystem Carbon (TEC)	For all age classes, as percentage of old forest TEC[3]. percentage derived from a secondary succession model[4].	Likely to decrease with increasing elevation, but amounts unknown, so not quantified.	No known spatial arrangement constraints. Possible edge effects when adjacent to 0-30 year age class. Not quantified.
Biodiversity	Potential species richness for amphibians, birds, mammals and reptiles, and their total[5]	Potential species richness reduced by elevation constraints on specific species[5]	Potential species richness reduced based on absence of other required patch types within range of species[5]

Table 2.11, continued.

Annual Water Yield	Average water yield increase for 0-30 and 30-80 year age classes[6]	High and low elevation water yield differences for 0-30 and 30-80 year age classes[6]	Water yield increases modified based on distance to stream (buffering action of intervening vegetation)
Summer water yield	Average water yield increase for 0-30 year age class[6]	High and low elevation water yield changes for 0-30 year age class[6]	Water yield changes modified based on distance to stream (buffering action of intervening vegetation)

1 Ohmann, J., U.S. Forest Service, personal communication.

2 Isaac, L.A.., U.S. Forest Service, unpublished map of site productivity classes, *ca.* 1945.

3 Smithwick (in press).

4 Harmon (2001).

5 Johnson and O'Neill (2001).

6 Jones, J., Oregon State University Department of Geography, unpublished data.

Table 2.12. Variations in the representation of landscape information in each cell for thirty-six landscapes.

Landscape Type	N	Class	Age	percent in Riparian Buffer Zone	percent of Green Tree Retention	Comments
1995; single patterns	8	1	0-30	n/a	n/a	
		2	31-80	n/a	n/a	
		3	81-200	n/a	n/a	
		4	> 200	n/a	n/a	
Riparian scenario	1	1	0-30	0-100	n/a	130 = age class 1, 30 percent riparian
		2	31-80	0-100	n/a	
		3	81-200	0-100	n/a	
		4	> 200	0-100	n/a	
Riparian/ reserves and Riparian/ reserves/ mixed-rotation scenarios	2	1	0-30	0-100	0, 15, 30, 50	13030 = age class 1, 30 percent riparian, 30 green tree retention
		2	31-80	0-100	0, 15, 30, 50	
		3	81-200	0-100	0, 15, 30, 50	
		4	> 200	0-100	0, 15, 30, 50	
Wildfire-affected	25	1	0-30	n/a	n/a	Open
		2	0-30	n/a	n/a	Semi-open
		3	31-80	n/a	n/a	Single cohort
		4	31-80	n/a	n/a	Multicohort
		5	80-200	n/a	n/a	
		6	201-500	n/a	n/a	
		7	> 500	n/a	n/a	

For each ecosystem property rule set, cells that were partially riparian and/or had green tree retention were area-weighted, assuming that these areas would remain old forest (Equation 5.1). For each property and rule set, calculated cell values were output to maps. These data were summed for the landscape as a whole and by owner/allocation type, and divided by the number of cells in the relevant area to obtain an average value. For each property rule set, the average cell value for each response map was calculated as:

$$R_i = \frac{\sum_{i=1}^{3} \sum_{j=1}^{N} \sum_{k=1}^{4} [\alpha_o r_j + \alpha_o (1 - r_j) g_j + \alpha_k (1 - r_j)(1 - g_j)]}{N} \qquad \text{(Equation 5.1)}$$

where

i = number of rule sets, j = number of cells, k = number of age classes, N = number of cells in area of interest (landscape or owner/allocation type), R_k = average response for rule set i and cell j, r_j = riparian percent of cell j, g_j = retention percent of harvest area for cell j, α_j = response multiplier for age class k, and α_o = response multiplier for the old forest age class.

Response multipliers (α) for each property are detailed below (Table 2.13). The averaged results were exported to Excel. Histograms were created for each property for the wildfire-affected landscapes and values from the other landscapes were overlain. Values were plotted against the amount of disturbance in the stratum, as measured by the percentage of the 0 to 30 year age class, for landscapes as a whole, and by owner/allocation type. Trend lines were graphed in Excel. Trend lines were compared in terms of the overall character of the relationship between the amount of disturbance and the process of interest, differences between fire and harvest landscapes, and the effect of adding elevation and arrangement into the analysis.

Table 2.13. Multipliers substituted for α in Equation 5.1, for quantifying ecosystem process response by age class, elevation and arrangement rule sets. Species counts compiled from Johnson and O'Neill (2001). See Appendices L through O for a list of species, their elevation ranges and the areal range of individuals. Summer water yield variation was calculated as a percentage of the original, 100 percent yield, based on stream flow data (Jones, unpublished data). Annual water yield was calculated as an increase in mm, based on stream flow data (Jones, unpublished data). Total ecosystem carbon was modeled (Harmon, 2001) as a percentage of the old forest value, given by empirical data (Smithwick et al., in press). Removed and standing wood were estimated based on site indices of productivity (Isaac, *ca.* 1945) and average growth rates (Ohmann, personal communication). Where cells were partially riparian or had green tree retention, that area was assumed to be old forest and the count was area-weighted.

<table>
<tr><th colspan="2">Process</th><th>Rule Set</th><th>Early seral</th><th>Young Forest</th><th>Mature Forest</th><th>Old Forest</th></tr>
<tr><td rowspan="6">Biodiversity</td><td>Amphibians</td><td rowspan="4">Age class only</td><td>26</td><td>31</td><td>32</td><td>32</td></tr>
<tr><td>Birds</td><td>167</td><td>118</td><td>127</td><td>131</td></tr>
<tr><td>Mammals</td><td>198</td><td>66</td><td>71</td><td>74</td></tr>
<tr><td>Reptiles</td><td>25</td><td>9</td><td>9</td><td>8</td></tr>
<tr><td>Species Richness</td><td>Elevation range</td><td colspan="4">See Figure 2.12</td></tr>
<tr><td>Species Richness</td><td>Patch proximity</td><td colspan="4">$\alpha = \sum_{i=1}^{n} R_2 - 1$, for $x_{dn} < P_d$

where R_2 = cell response under rule set 2,
n = number of species at this elevation range that are closely associated with specific age classes,
P_d = number of cells of closely associated age classes required at range distance d,
x_{dn} = number of cells within distance d of closely associated age class n</td></tr>
</table>

Table 2.13, continued.

Hydrology	Summer Water Yield	Age class only	108 percent	100 percent	100 percent	100 percent
		High elevation	126 percent	100 percent	100 percent	100 percent
		Low elevation	72 percent	100 percent	100 percent	100 percent
		Distance from stream	$\alpha = p_d(1-r)R_2$ where R_2 = cell response under rule set 2, p_d = proportion of flow that reaches stream from distance d, r = riparian percent of cell			
	Annual Water Yield	Age class only	300 mm	51 mm	0 mm	0 mm
		High elevation	350 mm	112 mm	0 mm	0 mm
		Low elevation	161 mm	3 mm	0 mm	0 mm
		Distance from stream	$\alpha = p_d(1-r)R2$ where R_2 = cell response under rule set 2, p_d = proportion of flow that reaches stream from distance d, r = riparian percent of cell			
Carbon	Total ecosystem carbon	Age class only; no initial detritus	539 Mg C/ha	522 Mg C/ha	738 Mg C/ha	829 Mg C/ha
		Age class only; 15 percent initial detritus	547 Mg C/ha	522 Mg C/ha	738 Mg C/ha	829 Mg C/ha
		Age class only; 30 percent initial detritus	555 Mg C/ha	531 Mg C/ha	738 Mg C/ha	829 Mg C/ha
		Age class only; 50 percent initial detritus	555 Mg C/ha	531 Mg C/ha	738 Mg C/ha	829 Mg C/ha

Table 2.13, continued.

	Removed Wood	Age class only; harvest disturbance	Assume age of removed wood based on owner/allocation type: private industrial = 40 years, public = 80 years			
		Age class only; fire disturbance	20 * c Mg C/ha	60 * c Mg C/ha	140 * c Mg C/ha	400 * c Mg C/ha
			Where c = growth rate based on site productivity			
	Standing Wood	Age class only	20 * c Mg C/ha	60 * c Mg C/ha	140 * c Mg C/ha	400 * c Mg C/ha
			Where c = growth rate based on site productivity			

Derivation of Converted Wood Bole Volume α

Estimates were made of the amount of wood converted from wood boles to other carbon products (e.g. on-site debris or lumber). The prior age class of early seral cells was determined from the prior landscape and simple assumptions were made about the volume of wood contained in different age classes. In the case of the managed landscapes the age class of the cell prior to disturbance was estimated from the target harvest rotation (e.g. private industrial lands on 40 year rotations were assumed to remove 40 year old forest, 80 year for public lands). For wildfire-affected landscapes the age of the converted wood bole volume was retrieved from the prior landscape in the wildfire simulations.

A linear relationship was assumed between the age class of the cell and the volume of wood that it would have contained. A U.S. Forest Service map of site productivity class created *ca.* 1945 by Isaac was combined with average annual wood bole increment rates per hectare for different productivity classes (Ohmann, personal communication) to establish the relationship (Table 2.14).

Table 2.14. Wood bole increment rates per hectare for productivity classes.

Productivity Class	Wood Bole Growth Rate m^3/ha per year
1	15.75
2	13.6
3	10.0
4	7.2
5	4.7
6	2.4
7	0.7

The first rule set (age class amounts only) was not included since the data on which this calculation was based, productivity classes, incorporate elevation. Site productivity is roughly correlated with elevation in the study area, so this calculation included variation with elevation. The site-specific increment rates were multiplied by the age of the wood prior to conversion, to determine an increment that could be applied to each age class and substituted for α in Equation 5.1 (Table 2.13). Although there is probably a decrease in the amount of removed wood with increasing elevation corresponding to decreased site productivity with elevation, no additional empirical data are available to quantify this trend. Additionally, there is no known patch arrangement effect at this scale. Some research suggests that edge effects where open and forested conditions are juxtaposed alter microclimates and can modify decomposition rates (Chen et al., 1993). However, this process has an effect at the stand scale, and is not easily quantified at the broader scale. Therefore, no spatial interactions were tested.

Derivation of Standing Wood Bole Volume α

Standing wood bole volume calculations were very similar to removed wood calculations, except in this case, the cells of interest are young, mature and old forest cells (Table 2.13).

Derivation of Total Ecosystem Carbon α

Estimates of total ecosystem carbon (TEC) in old-growth forests, including live, dead and below ground stores, have recently been made in the Pacific Northwest (Smithwick et al., in press). Mean carbon stores for 14 old-growth stands of 450-460 years in the west-central portion of the study area were 829 Mg C / ha, of which 64 percent occurred above ground in live stores and 36 percent as detritus and in soil. Other studies have established that carbon stores in younger forest age classes are substantially less than old-growth stores (Harmon et al., 1990).

In this study, I ran a secondary succession model (Harmon, 2001) to estimate total carbon stores by age class. The model calculates total stores at each time step as a percentage of maximum live biomass (100 percent at 300 years), which was assumed to be equivalent to the measured old-growth TEC of 829.4 Mg C / ha

(Smithwick et al., in press). The modeled data were calculated at annual time steps, and then were averaged for each of the four age classes.

The model was run using a range of initial detrital fractions representative of the range of harvest practices and wildfire severity. Only a portion of above ground biomass is removed from the site during harvest; some green trees are often retained, and smaller branches and debris are left on site as slash and in some cases burned. Harmon et al. (1996) found that in 1990, roughly 20 to 40 percent of above ground biomass left on site post-harvest. Harmon and Marks (submitted) found that moderate severity burns retain 71.8 percent of maximum above ground C-stores. Agee and Huff (1987) found that severe burns retain approximately 50 percent of above ground biomass. Estimated initial detrital fractions were input into the secondary succession model, and live, detrital and soil carbon stores were modeled for 300 years, as a percent of maximum live biomass (Figure 2.11). The results were then scaled, assuming TEC of 829 Mg C / ha for old forest. The calculated TEC was applied as α in Equation 5.1 (Table 2.13).

As with removed and standing wood, other elevation and spatial arrangement constraints likely exist, but are not presently quantifiable.

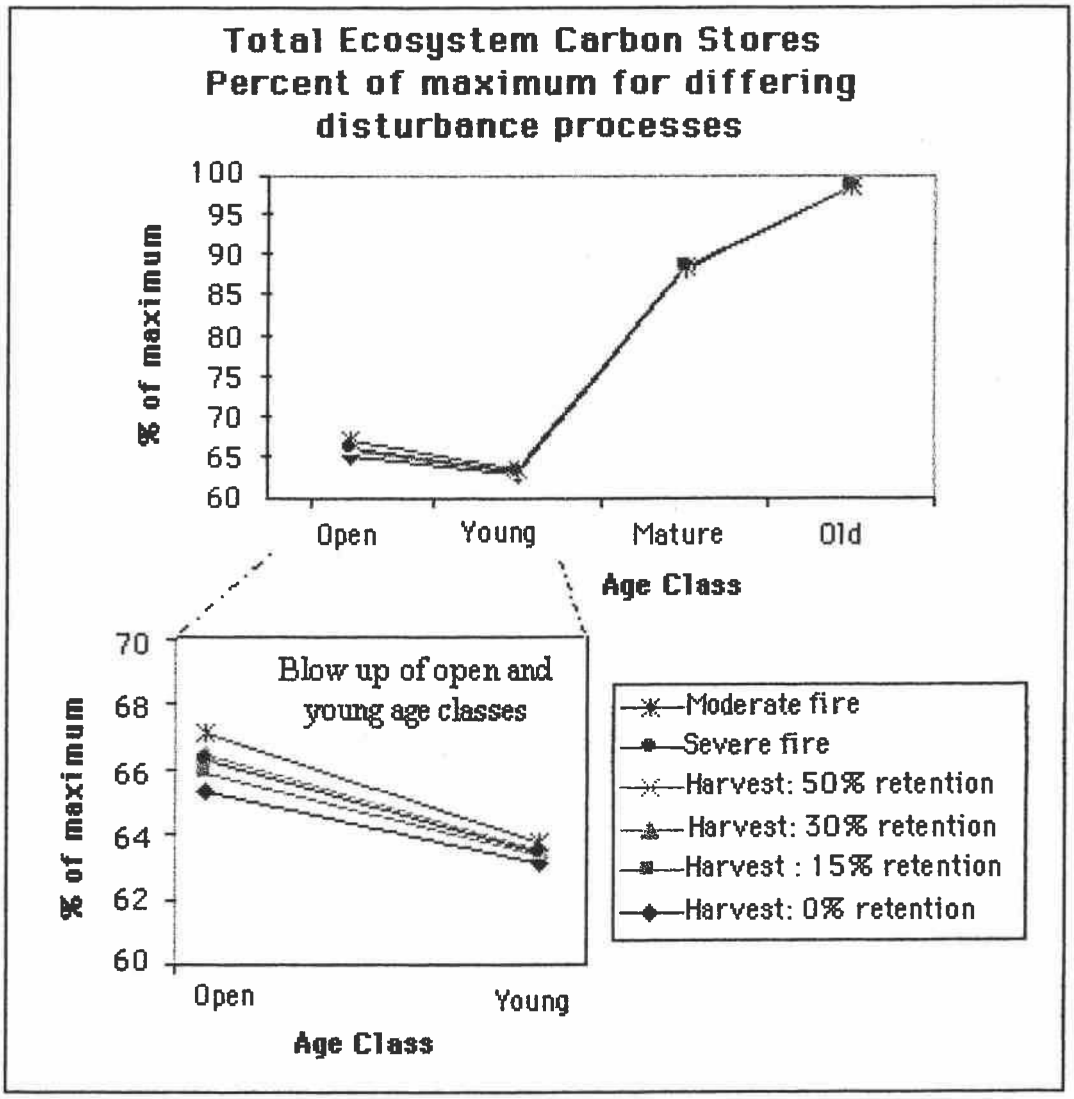


Figure 2.11. Modeled total carbon stores (live, detrital and soil) as a percent of maximum stores. The secondary succession model used (Harmon, 2001) calculates carbon stores at annual increments, which were averaged for four age classes. The model allows for different input parameters for the amount of post-disturbance detritus and live biomass left on site. That parameter was varied for the type of disturbance (fire or harvest) and for harvest, percent of green trees retained during harvest. Modeled output exhibited differences in carbon stores between disturbance types only in the open and young age classes, with lower values for harvest disturbance than for fire disturbance.

Derivation of Biodiversity α

Lists of vertebrate species in Oregon and Washington forests have recently been compiled by panels of species-experts and made available on CD-ROM (Johnson and O'Neil, 2001). These data are subdivided by locale; the study area is in the Westside Lowland Conifer-Hardwood Forest locale. Information on each species includes forest structural conditions in which the species may be found (habitat associations) and for obligates, those structural conditions with which the species is most closely associated. Data on the CD were compiled for more specific structural conditions than the age classes used in this study, hence were grouped into the most closely corresponding age class (Table 2.15; Appendices L through O). Also listed is the elevation range of the species and where known, the approximate area of an individual's range.

Table 2.15. Habitats for which associated vertebrate species were compiled by Johnson and O'Neill (2001), and the corresponding age class used in this study.

Habitat types designated by Johnson and O'Neill (2001)	Age class used in this study
Grass/forb Shrub/seedling Sapling/pole	0-30 (Early seral)
Small trees: single and multicohort, open, moderate and closed canopy	30-80 (Young Forest)
Medium trees: single and multicohort, open, moderate and closed canopy	80-200 (Mature Forest)
Large trees: single and multicohort, open, moderate and closed canopy	> 200 (Old Forest)

In the first rule set, the effect of forest age class amounts on potential species richness was quantified by counting the number of species associated with each of the four age classes and assigning the count as α, calculating the value of each cell based its age class, riparian proportion and percent green tree retention (Table 2.13; Equation 5.1). Counts were compiled for four vertebrate types (amphibians, birds, mammals and reptiles) with a total count for all four.

Spatial complexity was added in the second rule set by limiting the number of species counted in a given cell by elevation range. Counts of the number of species present at each elevation range were compiled from the CD-ROM (Figure 2.12), which specified the range for most species (Johnson and O'Neill, 2001). For each cell, the elevation was derived from DEM, and the appropriate species count for that elevation range substituted for α in Equation 5.1.

In the third rule set, patch arrangement and area constraints were added to limit the number of species counted in a given pixel based on its proximity to cell types required by a given species (Table 2.13; Appendices L through O). For instance, some birds are most closely associated with early seral conditions where they hunt and breed, but they are also associated with other forest conditions. The counts of these birds were only included in a cell if a given number of early seral cells occurred within the range of each bird. The patch arrangement rule set was only applied to counts of mammals and birds, since reptiles and amphibians have ranges that are typically less than the cell size of the study (4 ha).

The patch proximity layers introduced and described above (page 69) were used to conduct this test. Briefly, for each cell in each landscape (the target cell), maps of counts of the number of cells of each of the four age classes within distance classes were created. Because of the computationally intensive nature of the calculation, this test was conducted on only ten of the selected landscapes: five wildfire-affected landscapes (one from each fire frequency simulation), the 1995 landscape, the riparian, riparian/reserve, and riparian/reserve/rotation landscapes, and the single pattern consisting of all old forest.

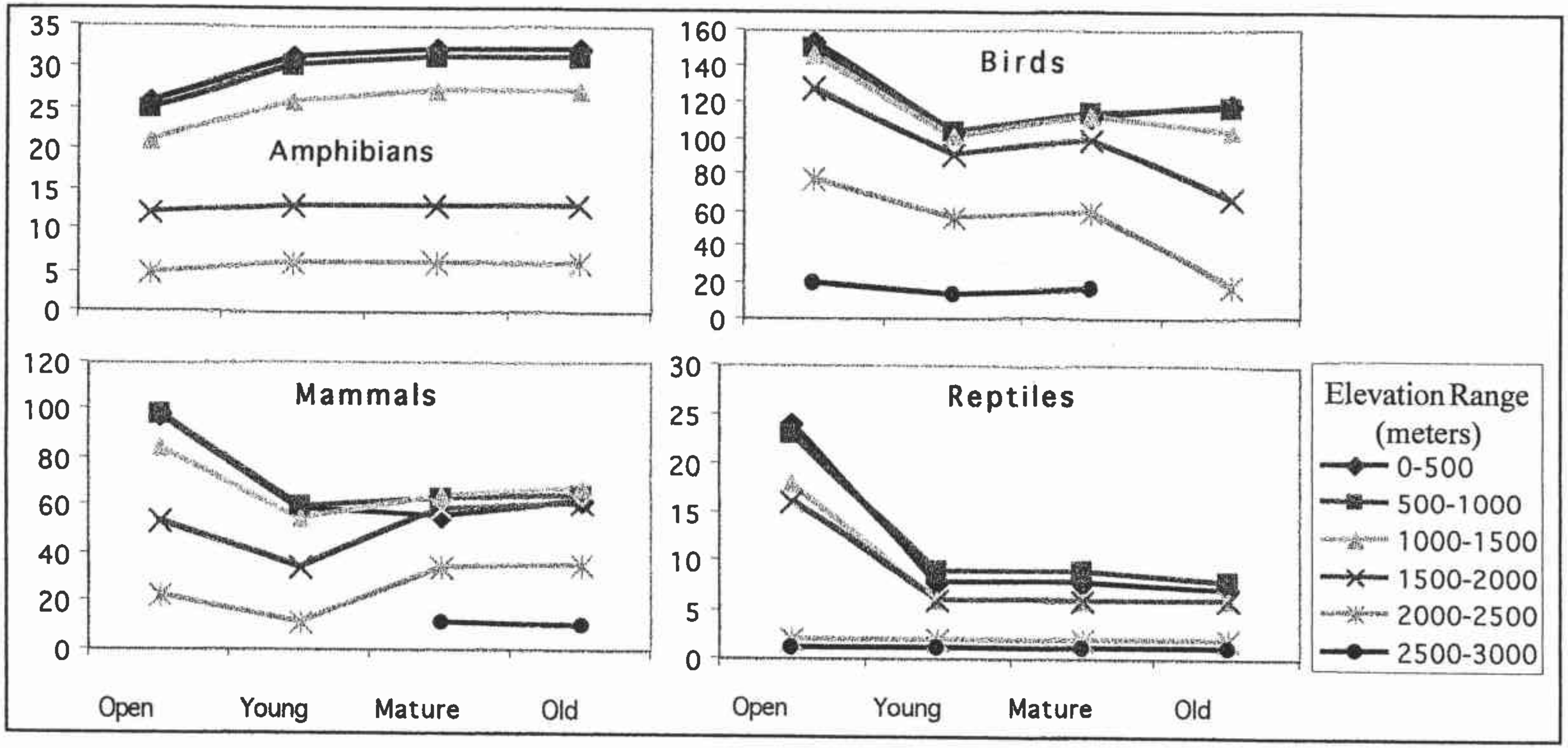


Figure 2.12. The number of vertebrate species occuring in western Cascade forests, by age class and at different elevation ranges. Species counts at elevation ranges were compiled from Johnson and O'Neill (2001). All species counts decrease with elevation, for all age classes, but the pattern of decrease varies. For example, note the transition from more mammal species in open forest at low elevations, to more in closed forest conditions at high elevations.

For the third rule set, a cell was counted as having suitable habitat for a species if:

1) The species is associated with that forest type at that elevation range,
2) Any age classes with which the species is closely associated, occurred within an area defined as the average range of an individual (Johnson and O'Neill (2001; Appendices M and N), centered on the target cell, and
3) The required age classes exceeded a given percentage of the area in (2).

The required percentages of area were arbitrarily defined, and were higher for individuals with small ranges (Table 2.16). It was assumed that if an individual had only a 10 ha range, that individual would only encounter the four nearest neighboring cells to the target cell (a 16 ha area), and at least one of those four cells (25 percent, or 4 ha) would have to be the required cell type. At the other extreme, for an individual with a range of 10,000 ha (mostly birds), it was assumed a lower proportion of that area would need to be the required age class type because of the high mobility of the individual. For an individual with a 10,000 ha range, it was assumed that the largest sample size, 7840 ha, would need to have 10 percent of the required age class. Since area requirements are unknown for most species, this value was arbitrarily chosen. Hence, the results of this calculation are speculative, but since the same assumptions were applied consistently to all of the landscapes, relative differences in response may be compared. Cell requirements for ranges in between these two extremes were interpolated assuming a logarithmic reduction in the proportion of required cells with increasing range.

Table 2.16. Minimum area required of age classes with which a species is closely associated, for different individual ranges.

Estimated ranges of individual mammals and birds, in logarithmic categories	Number of 4 ha cells in the radius of a circle with an area approximately equivalent to the individuals' estimated range	Area (ha) of the resulting polygon	Percent of the polygon area assumed to be needed in a given age class in order for the mammal or bird to be present	Equivalent number of 4 ha cells required
10	1	16	25	1
50	2	48	21.5	3
500	5	360	16.5	13
1000	10	1264	15	47
10000	25	7840	10	196

Derivation of Annual Water Yield α

Water yield responses were estimated using stream flow records from paired-basins with and without experimental forest harvest (Jones and Post, in prep; Jones, 2000). None of the tested watersheds, 20 to 30 years after treatment, have returned to their pre-treatment annual water yield values (Figure 2.13). Andrews watersheds 1 and 2, for which the longest term data exist, follows a fairly well-defined trend that was projected for this analysis, resulting in an estimated return to pre-treatment values in year 52. The remaining two paired watershed sets (6-8, 9-10) are much more variable. For these, a trend was plotted from the highest value to the last reported value, then projected, resulting in a return to pre-treatment conditions at years 35 (low elevation) and 61 (high elevation), bracketing the 52 year return of the mixed elevation watershed. Projected trends were averaged for the 0-30 and 30-80 year age classes.

Annual data based on a five year moving average, were averaged for each age class, and this number (Table 2.13) was applied as α in Equation 5.1 to every cell in each landscape. For the first rule set, based on age class amounts only, the mixed elevation values for Andrews watersheds 1 and 2 were applied to each cell (Table 2.13). In the second rule set, values from the low and high watersheds (Andrews watersheds 10 and 9 and Andrews watersheds 6 and 8, respectively) were applied to cells based on their elevation (Table 2.13).

In the third rule set, spatial arrangement effects were considered by developing a procedure that restricted the effect of forest age and elevation with increasing distance from the stream network. It would be expected that disturbance in less dense parts of the stream network would have a lesser effect on stream flow than disturbance near highly developed parts of the stream system. This effect would be especially pronounced in the summer, when drought conditions would imply that intervening vegetation would be likely to capture excess runoff before it reached the stream, but would likely have an effect throughout the remainder of the year as well. There are no empirical data to parameterize this variability. It is likely to vary substantially across the landscape with topographic variation in hillslope lengths and slopes, soil types, soil moisture and productivity. A truly representative parameterization would involve creating and coupling a complex hydrogeomorphic model with this analysis. In the absence of such a model arbitrary breakpoints were selected, recognizing that the absolute number obtained is only an approximation, perhaps adequate for comparing the relative response between landscapes.

The stream distance data analyzed above (page 69) suggested that the less than 200 m distance class had a different spatial distribution across the landscape than the 201 to 500 m class. Therefore I selected 200 m as the first breakpoint, in order to interpret the results with reference to the stream distance analysis. I assumed that disturbance within 200 m of a major stream would contribute the full effect, and that the contribution would dissipate at greater distances (Table 2.17). Disturbance 201-500 m from the identified stream network was assumed to contribute only 50 percent of the full effect, 500-1000 m 25 percent of the effect, and disturbance farther than 1000 m from a major stream was assumed to have no effect on the stream system at all.

Table 2.17. Patch arrangement effects on annual water yield after disturbance.

Distance from stream	Value Computation
< 200 m	100 percent of value
200-500 m	50 percent of elevation value
500-1000 m	25 percent of elevation value
> 1000 m	0 percent of elevation value

Cells adjacent to the stream with riparian buffers, which would contribute 100 percent based on the distance cut off, were further modified since these cells would have significantly different effects with and without a riparian buffer. For simplicity, it was assumed the effect was inversely proportional to the amount of riparian buffer. Therefore, if a disturbed cell consisted of 75 percent riparian buffer, the annual water yield effect would be 25 percent of that for a disturbed cell with no riparian buffer.

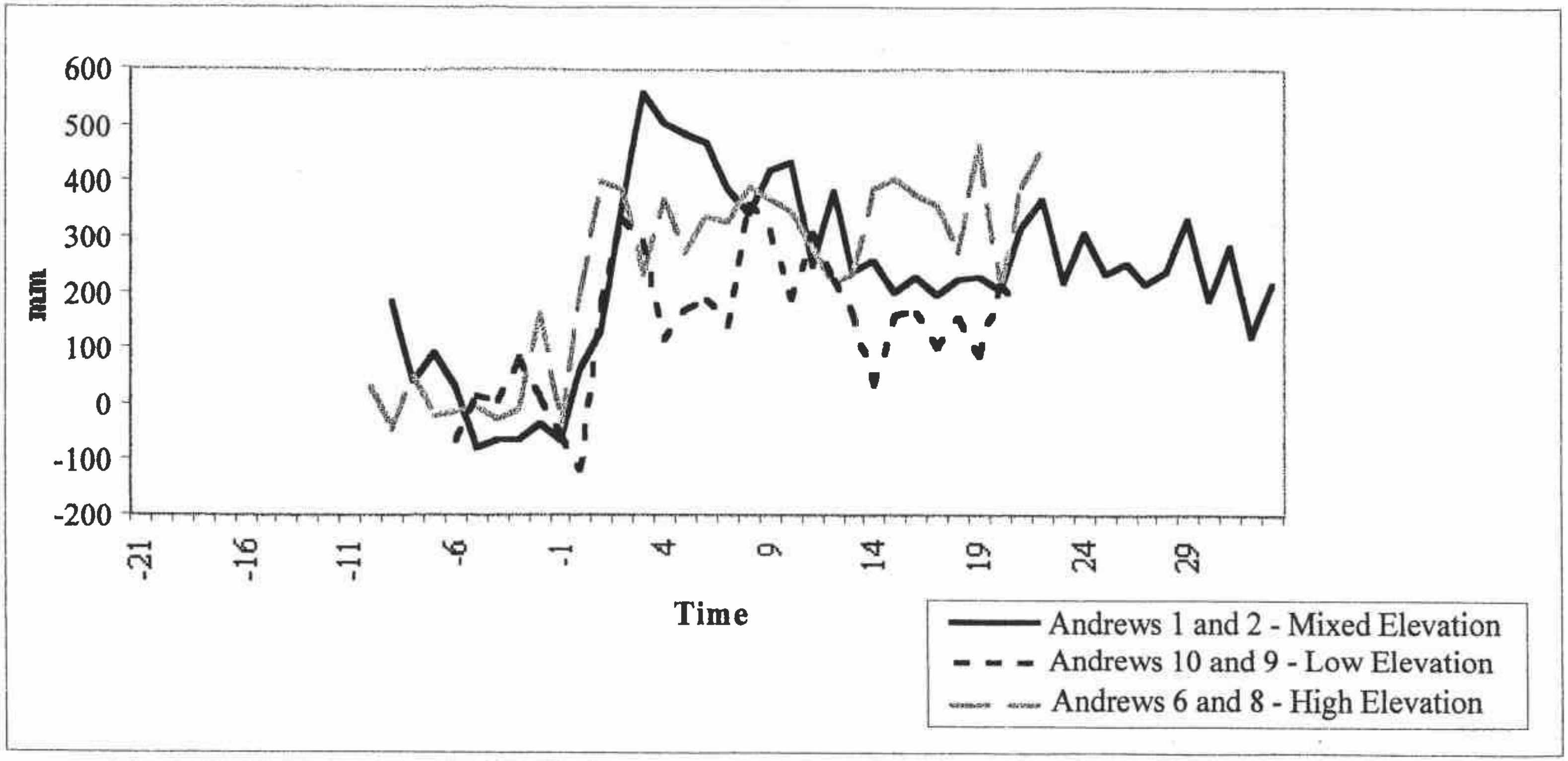


Figure 2.13. Post-harvest annual water yield change in millimeters for three clearcut watersheds, relative to old growth control watersheds (Jones, unpublished data). None of the watersheds has returned to pre-harvest annual yields. Andrews watersheds 1 and 2 have data for 30 years, and if the trend over the last 10 years continues, will return to pre-harvest values in year 52. Trends for the other watersheds were projected using Andrews 1 and 2 as a guide, but there is no evidence to suggest this, especially in Andrews watersheds 10 and 9, where yield has not yet started to decline.

Derivation of Summer Water Yield α

Summer water yield responses were also estimated using stream flow records from paired-basins with and without experimental forest harvest (Jones, 2000; Jones and Post, in prep). For paired basins (Andrews watersheds 1 and 2) spanning elevation from 450 to 1100 m, summer water yield increased after forest removal, but returned to near pre-harvest amounts by five years after harvest, with small changes from years 5 to 30 (Figure 2.14; Jones, unpublished data). Annual data based on a five year moving average, were averaged for the entire 0 to 30 year period, and this number (108 percent; Table 2.13) was applied as α in Equation 5.1 to every cell in the 0 to 30 year age class in each landscape. Other age classes did not contribute to this response, and were applied as 100 percent.

Summer water yield changes have also been documented for two smaller paired watershed studies (Figure 2.14), a pair at an upper elevation range (800-1100 meters, Andrews watersheds 6 and 8) and one at a lower elevation range (400-550 meters, Andrews watersheds 10 and 9; Jones, unpublished data). These data indicate that at low elevations after an initial increase, summer water yield decreases below pre-treatment levels. At high elevations, summer water yield increased and remained elevated for the period of record. Forest harvest occurred in 1974 and 1975 for these two basin pairs, and records were analyzed through 1993, giving post-treatment periods of 16 and 17 years.

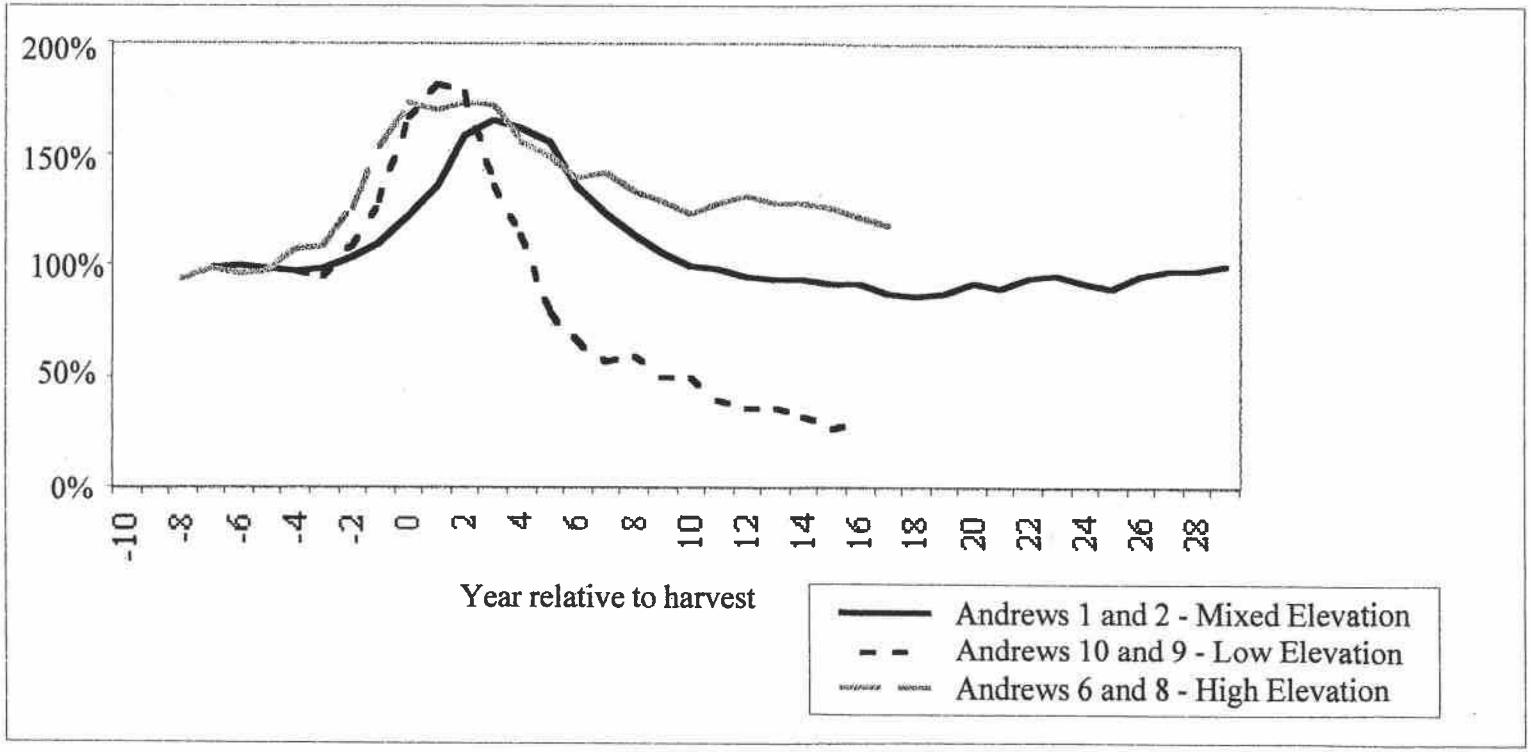


Figure 2.14. Graph of percentage change in post-harvest summer water yield through time in harvested watersheds, indexed to old growth forest control watersheds (Jones, unpublished data). Andrews watersheds 1 and 2, spanning a 450 to 1100 m elevation range, have data available for a 30 year post harvest interval. Andrews watersheds 6 and 8, and Andrews watersheds 10 and 9, had data available for only 16 and 17 years after harvest, respectively. In this analysis, I projected the trends to return to 100% at the same point in time as Andrews watersheds 1 and 2, although there is no evidence to support or contradict this in the data.

For this study, I assumed that summer water yield at these basin pairs would return to pre-treatment levels at approximately year 30, since that is what occurred in the Andrews watersheds 1 and 2 paired basin study where a longer period of record is available. Therefore, in the absence of any data to suggest the character of summer water yield between years 16/17 and year 30, I drew line segments connecting the most recent data point with a 100 percent point at approximately year 30. For Andrews watersheds 6 and 8, the slope of the line from the final 10 years of data was projected, resulting in a return to pre-treatment conditions in year 26. For Andrews watersheds 10 and 9, values were still decreasing until the final year of record, where a slight increase was observed. It was assumed that values would continue increasing at a slow rate for three more years, then at a more rapid rate, to return to normal in approximately 30 years. The projected changes in summer water yield for low and high elevation were then averaged for the 0-30 year age class (Table 2.13). Cells below 700 meters were assigned the low elevation value for α; cells above 700 m the high elevation value.

In the third rule set, distance from the stream network was incorporated, as with annual water yield. However, because of dry summer conditions, a large percent of any increased surface runoff associated with disturbance is likely to be captured by water-stressed vegetation. Therefore, the breakpoints used were modified. Disturbed patches from 200-500 m from the stream were assumed to contribute only 25 percent, while patches more than 500 m were assumed to contribute nothing (Table 2.18).

Table 2.18. Patch arrangement effects on summer water yield after disturbance. Disturbance far from the stream system was assumed to contribute less runoff than nearby disturbance. Disturbance farther than 500 m was assumed to be entirely captured by intervening vegetation.

Distance from stream	Value Computation
< 200 m	100 percent of value
200-500 m	25 percent of elevation value
> 500 m	0 percent of elevation value

Chapter 3 Results

Characteristics of Wildfire-affected, 1995 and Hypothetical Managed Landscapes

Characteristics of Wildfire-affected Landscapes

LADS output: 50 year gridded landscapes

Figures 3.1 through 3.5 display the twenty five selected landscapes from the wildfire simulations. Each figure represents the range of variability within a given simulation run. Visual inspection shows that a substantial amount of spatial variation may occur within a given simulation, particularly in the lower fire frequency simulations where infrequent, large fires may affect a large portion of the landscape. Note that the LADS model is designed to leave unburned islands within disturbed patches, consistent with observations of real fires.

A comparison of the output landscapes with a GIS layer derived from digitization of a 1914 map of burned areas (Elliot, 1914) indicates that the patterns generated by the simulations are consistent with what little documentary evidence exists of historic wildfire patterns on the landscape. The early 1900s were a time of high fire frequency that began around 1850 (Weisberg and Swanson, in press). Consistent with that, the 1914 map is most similar to the frequent fire and empirical simulation landscapes.

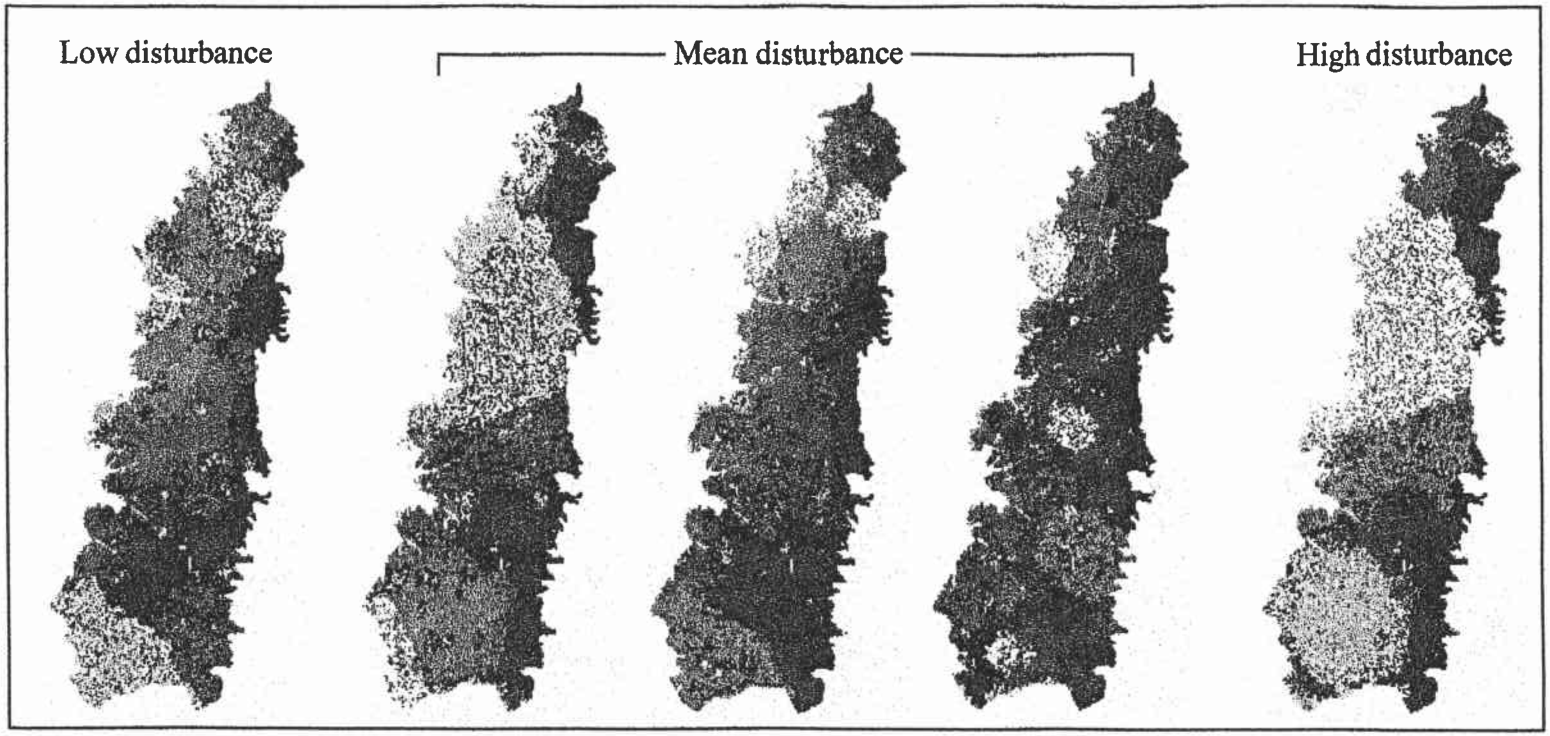
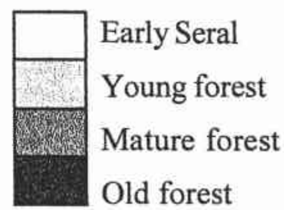


Figure 3.1. Selected landscapes from the very infrequent fire simulation. Landscapes were chosen based on disturbance characteristics, as measured by the amount of early seral vegetation in the landscape. Three average landscapes were selected, one with low disturbance characteristics (5 percentile) and one with high disturbance characteristics (95 percentile). Disturbance increases from left to right in the figure.



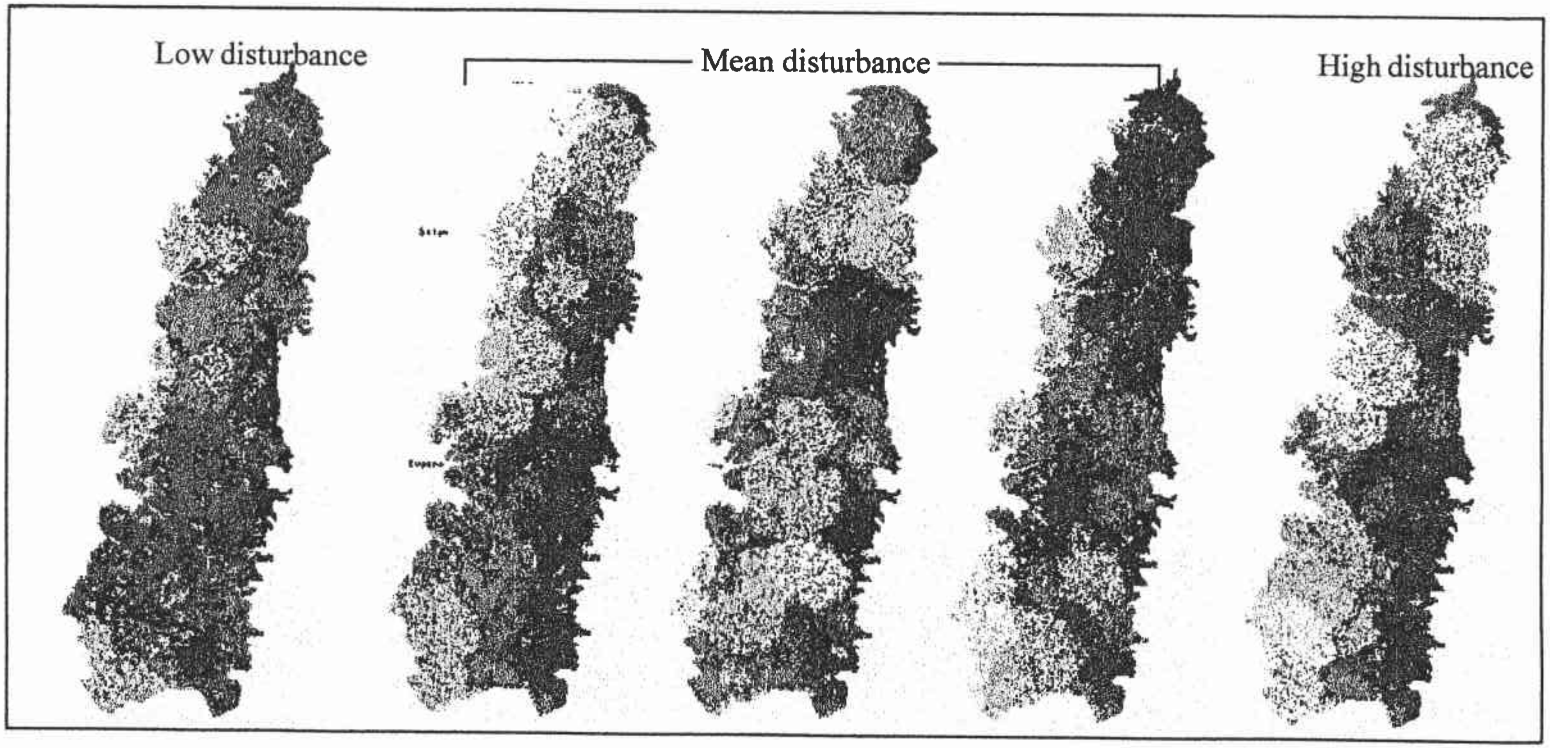
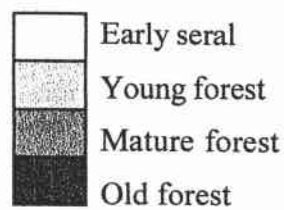


Figure 3.2. Selected landscapes from the infrequent fire simulation. Landscapes were chosen based on disturbance characteristics, as measured by the amount of early seral vegetation in the landscape. Three average landscapes were selected, one with low disturbance characteristics (5 percentile) and one with high disturbance characteristics (95 percentile). Disturbance increases from left to right in the figure.



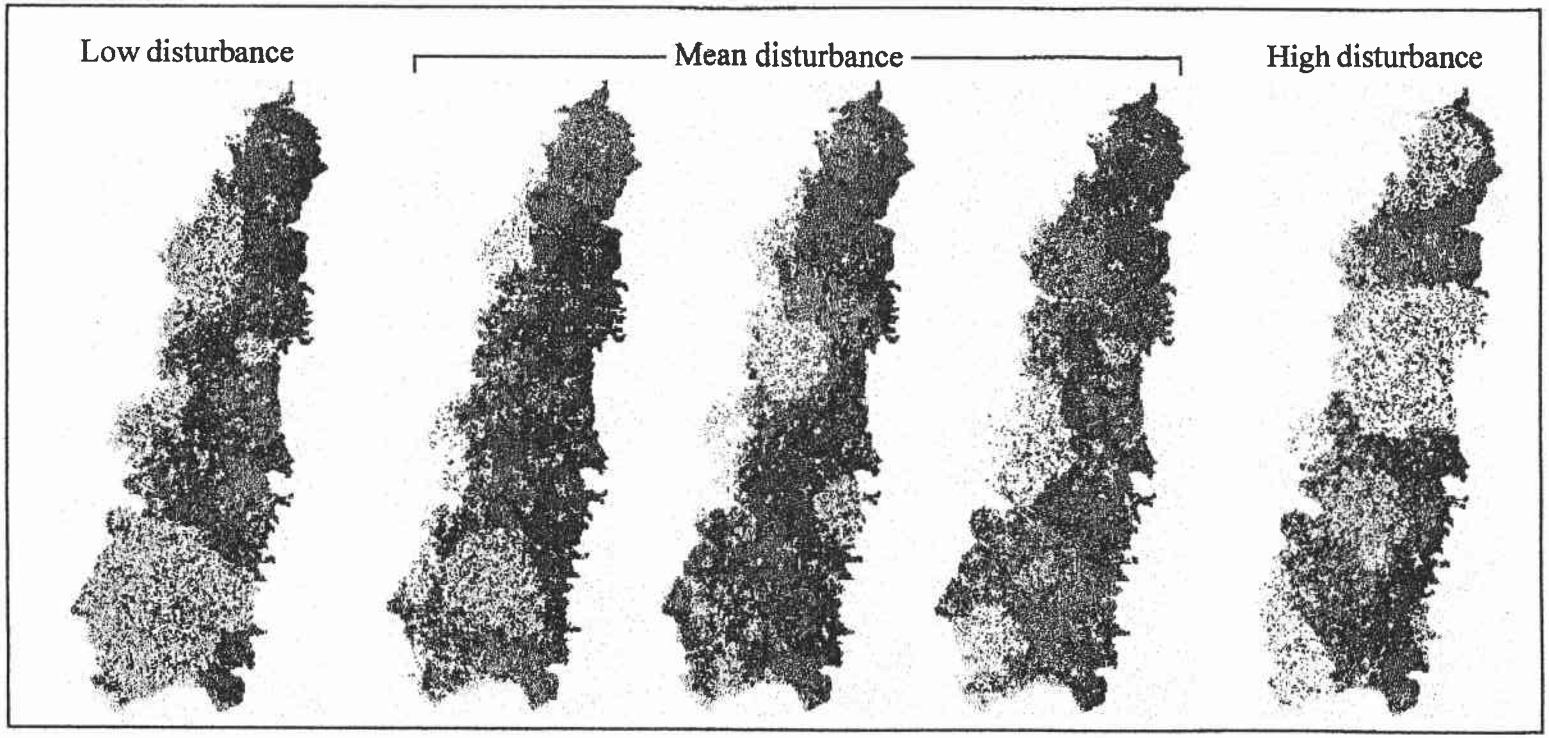
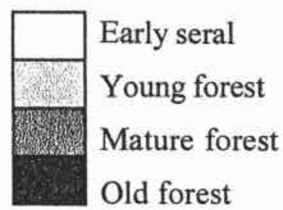
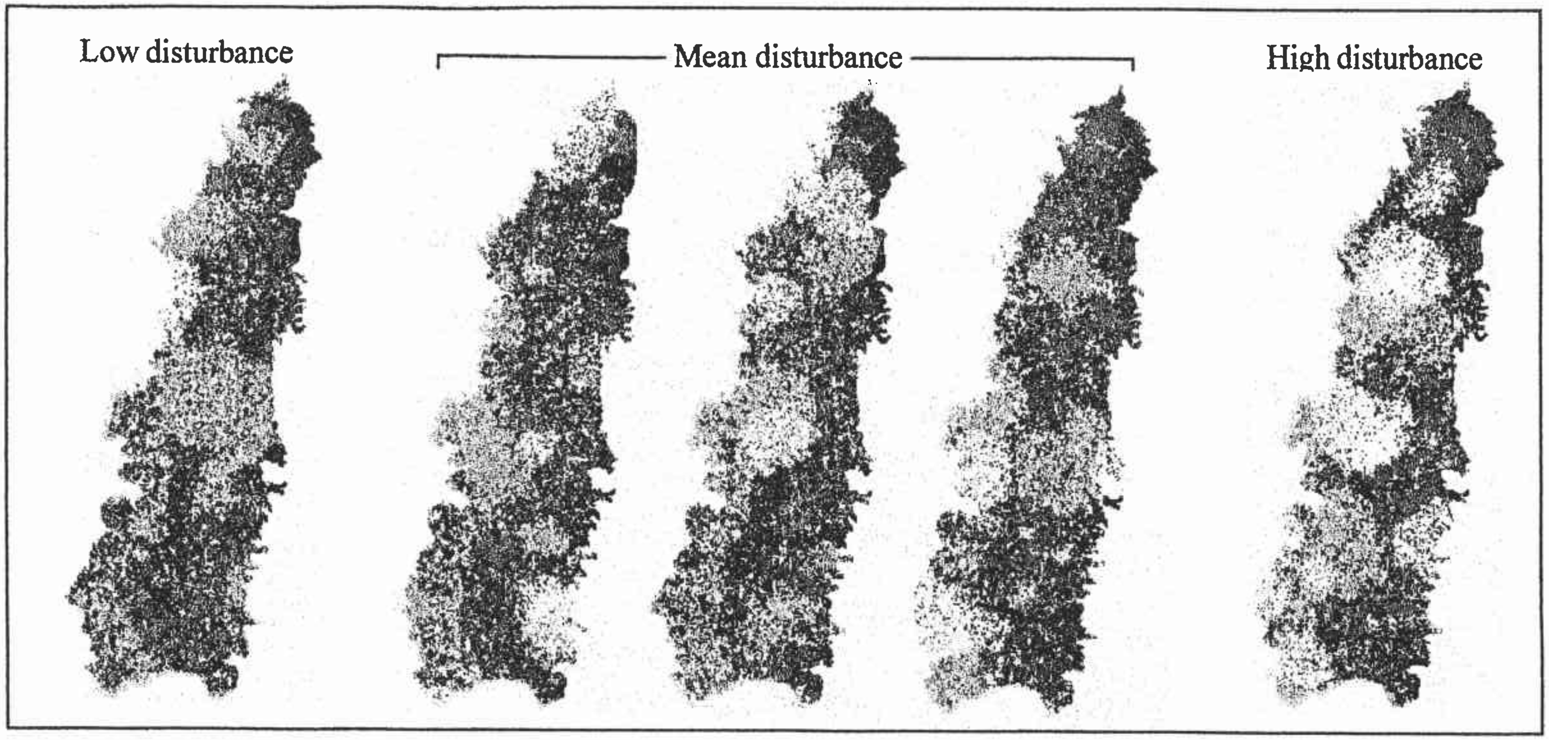


Figure 3.3. Selected landscapes from the moderate frequency fire simulation. Landscapes were chosen based on disturbance characteristics, as measured by the amount of early seral vegetation in the landscape. Three average landscapes were selected, one with low disturbance characteristics (5 percentile) and one with high disturbance characteristics (95 percentile). Disturbance increases from left to right in the figure.





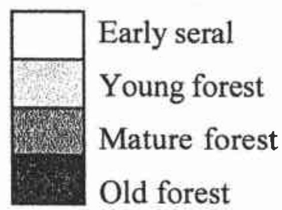


Figure 3.4. Selected landscapes from the frequent fire simulation. Landscapes were chosen based on disturbance characteristics, as measured by the amount of early seral vegetation in the landscape. Three average landscapes were selected, one with low disturbance characteristics (5 percentile) and one with high disturbance characteristics (95 percentile). Disturbance increases from left to right in the figure.

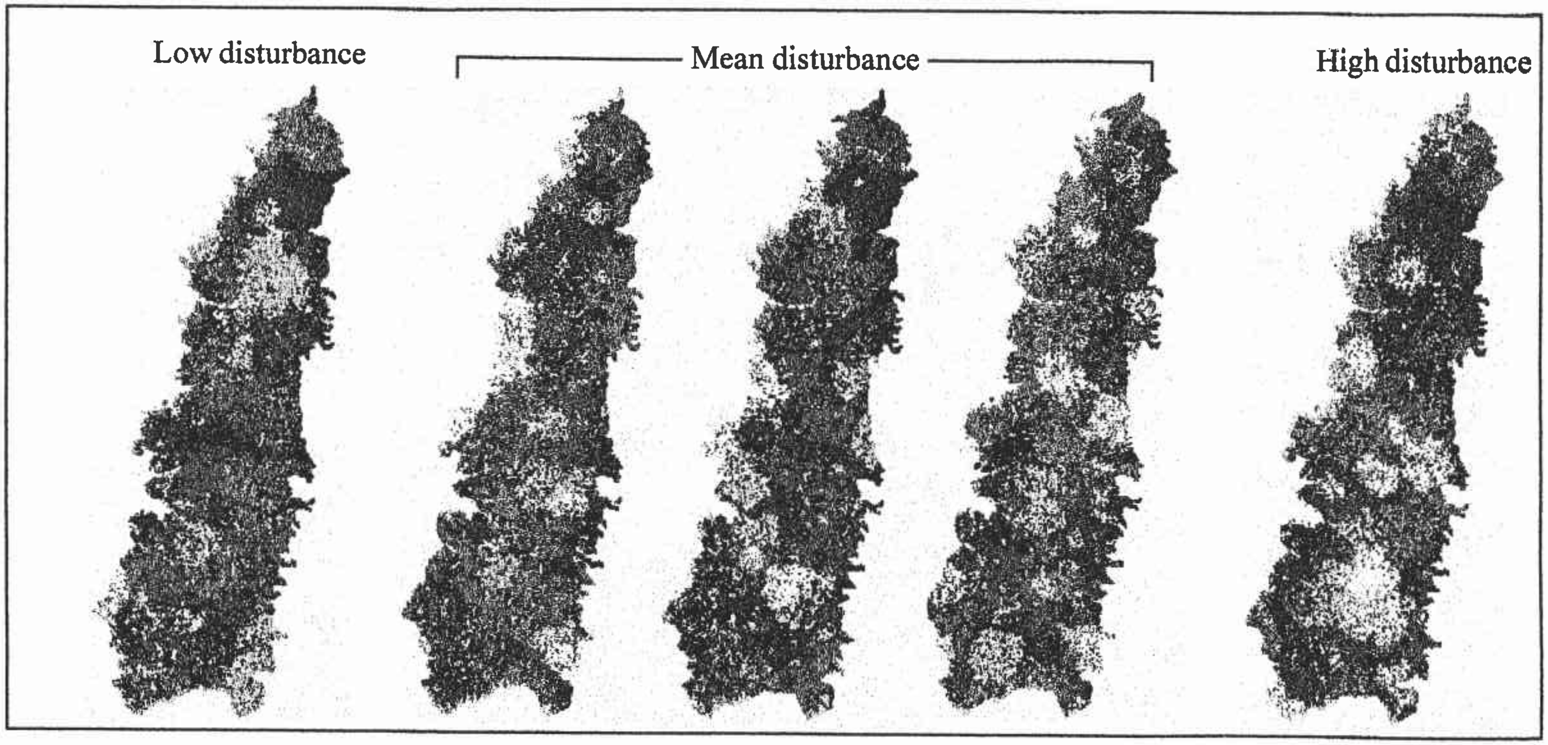


Figure 3.5. Selected landscapes from the empirical climate simulation. Landscapes were chosen based on disturbance characteristics, as measured by the amount of early seral vegetation in the landscape. Three average landscapes were selected, one with low disturbance characteristics (5 percentile) and one with high disturbance characteristics (95 percentile). Disturbance increases from left to right in the figure.

Early seral
Young forest
Mature forest
Old forest

LADS output: analysis of simulation results

Age class amounts for output landscapes from each simulation were graphed as time series (Figures 3.6 to 3.9). Amounts of early seral vegetation show a trend towards increased disturbance (as measured by the amount of early seral vegetation) with increasing fire frequency, ranging from approximately 5 percent to 40 percent (Figure 3.6). Less obvious is increased variability of the very low frequency simulation relative to the frequent fire simulation. This is consistent with the relationship noted from the sensitivity analysis. Low fire frequency produced less disturbed landscapes, but landscapes that were more variable due to the higher mean fire sizes, producing occasional highly disturbed landscape conditions among a background of predominantly undisturbed landscape conditions.

Young forest and mature forest display more overlap between simulation runs, compared with the early seral age class (Figures 3.7 and 3.8). Especially notable is the overlap in the mature forest age class data, in which age class amounts from the five simulation runs are virtually indistinguishable, although the tendency for higher variability with decreased fire frequency may still be observed. Old forest amounts display the least overlap, ranging from a fairly consistent 25 percent in the frequent fire simulations up to highly variable amounts in the very infrequent fire simulations, approaching 80 percent as a maximum (Figure 3.9). Of the four age class amounts, old forest displays the most marked differences in age class mean percent and variability among the five wildfire simulations.

Means and variability for all five wildfire simulations are summarized in histograms of age class amounts (Figure 3.10). Increasing fire frequency produces larger areas of early seral and young forest age classes and smaller areas of old forest. The old forest age class amounts were much more variable in the very infrequent fire simulation, compared with more frequent fire simulations.

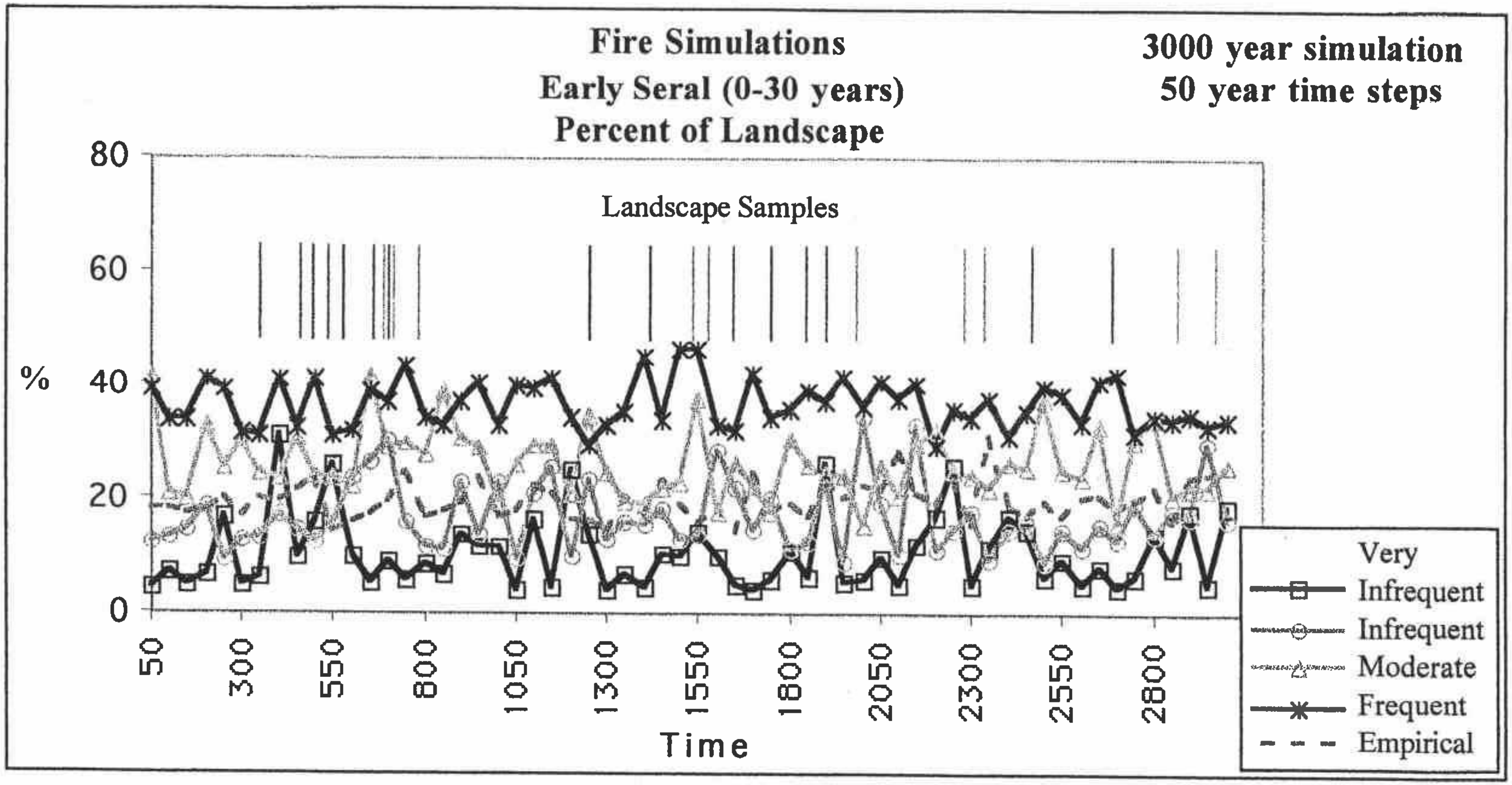


Figure 3.6. Percent of landscape in the early seral (0 - 30 year) age class, for 60 landscapes output from the LADS fire model, in 50 year time steps, for five runs simulating postulated fire parameters under differing climatic conditions. Lines along top represent the point in each simulation run from which a specific landscape was selected for further analysis, color coded to match legend.

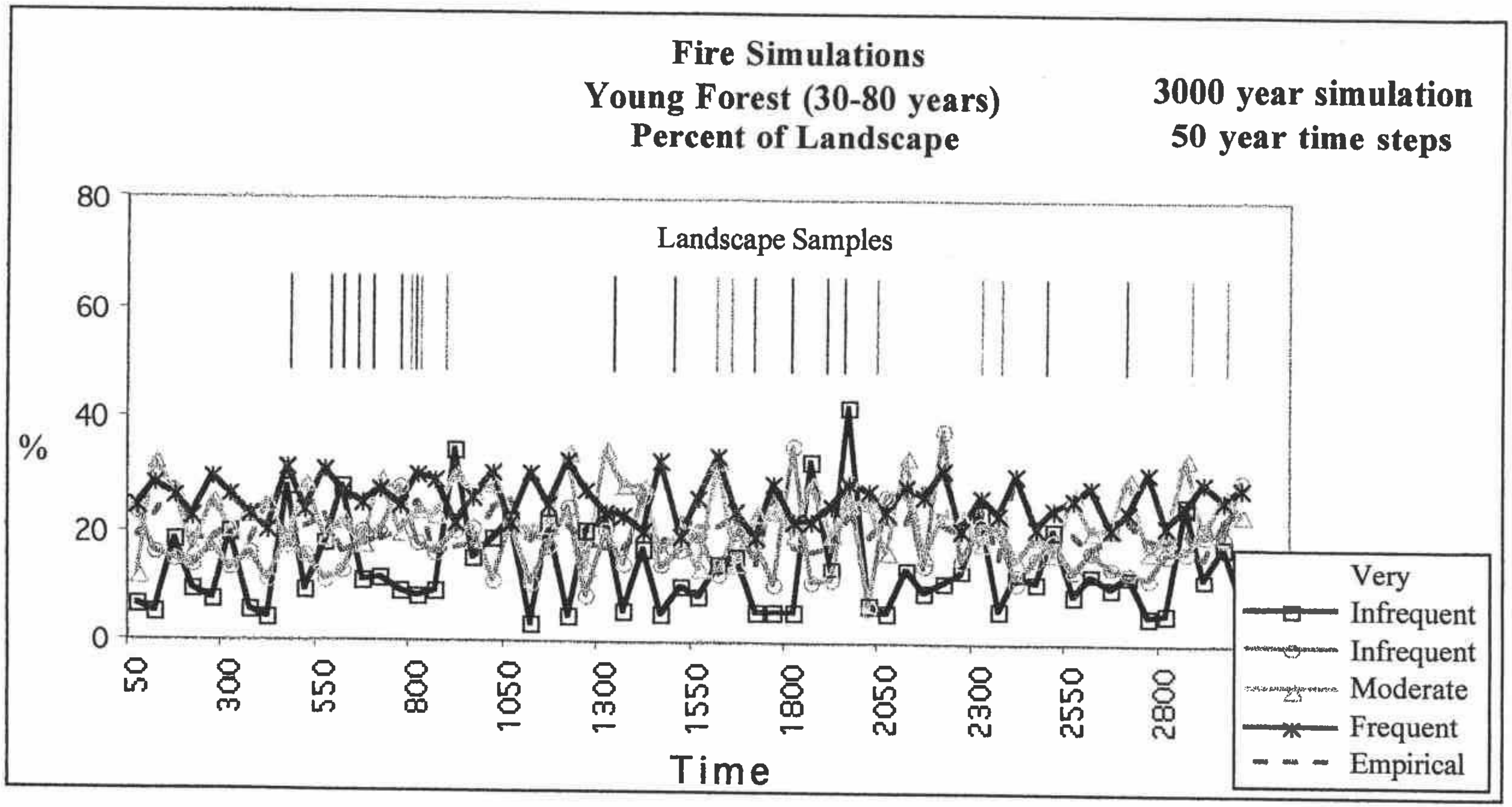


Figure 3.7. Percent of landscape in the young forest (30-80 year) age class, for 60 landscapes output from the LADS fire model, in 50 year time steps, for five runs simulating postulated fire parameters under differing climatic conditions. Lines along top represent the point in each simulation run from which a specific landscape was selected for further analysis, color coded to match legend.

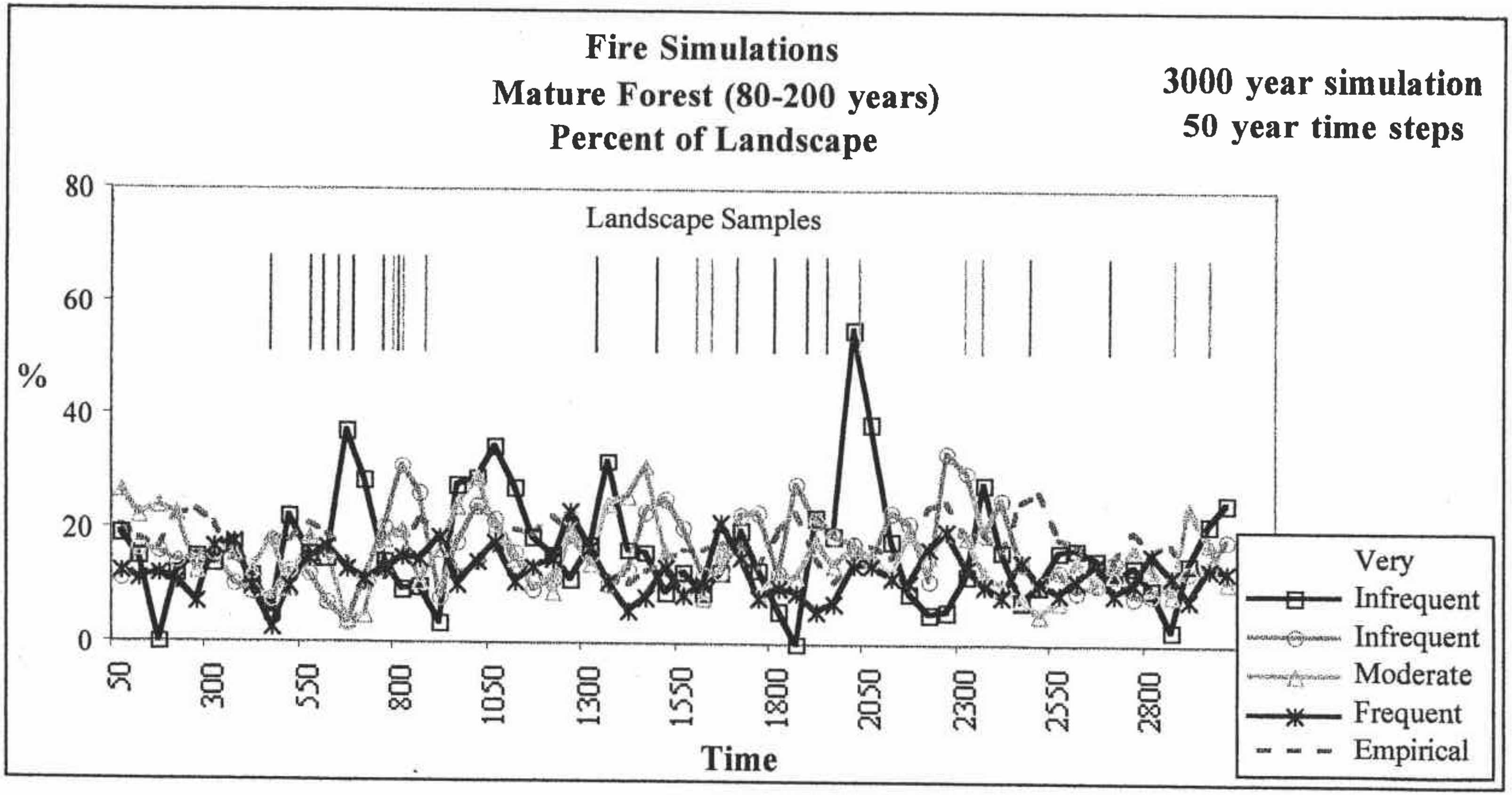


Figure 3.8. Percent of landscape in the mature forest (80-200 year) age class, for 60 landscapes output from the LADS fire model, in 50 year time steps, for five runs simulating postulated fire parameters under differing climatic conditions. Lines along top represent the point in each simulation run from which a specific landscape was selected for further analysis, color coded to match legend.

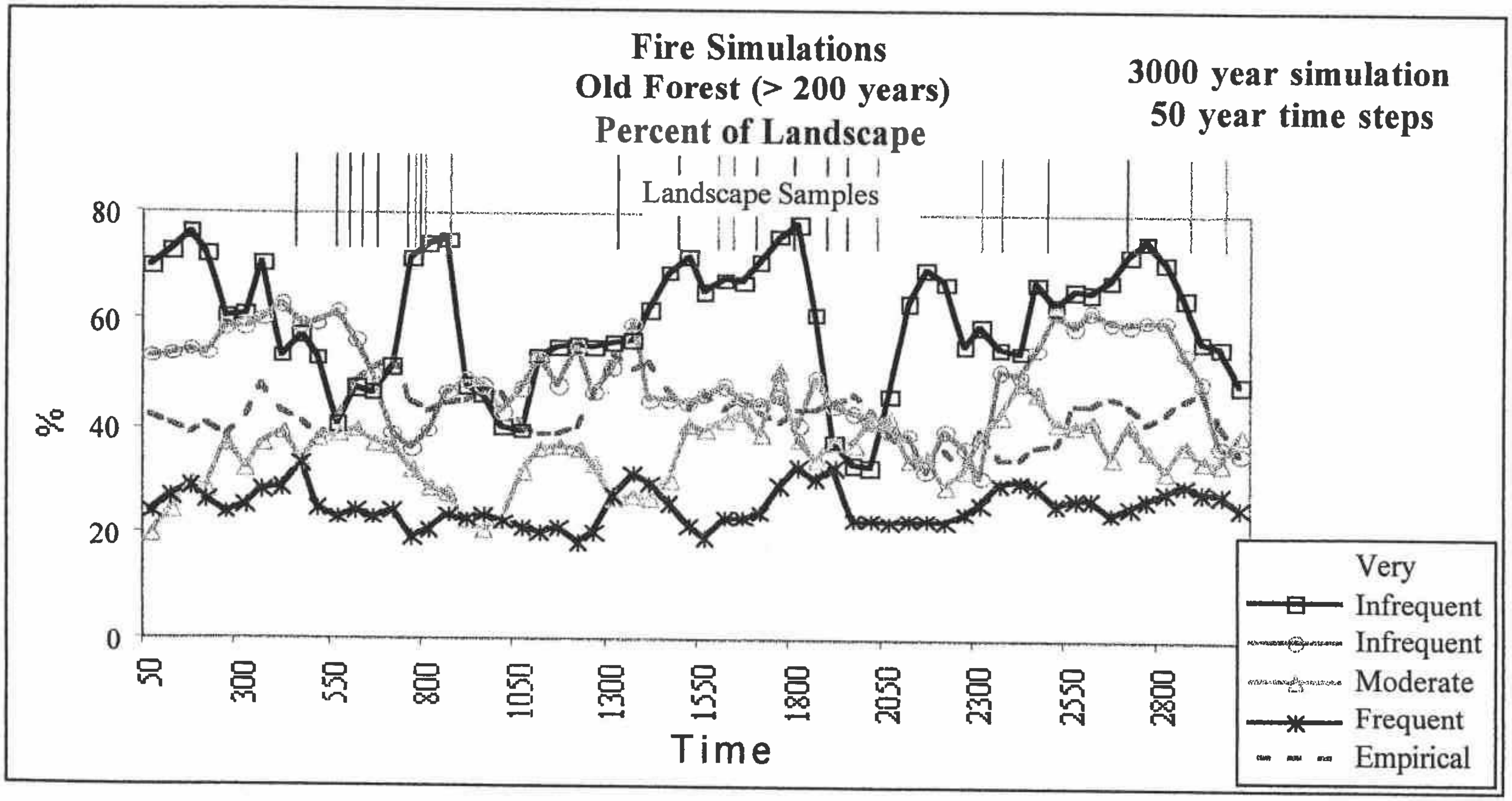


Figure 3.9. Percent of landscape in the old forest (> 200 year) age class, for 60 landscapes output from the LADS fire model, i 50 year time steps, for five runs simulating postulated fire parameters under differing climatic conditions. Lines along top represent the point in each simulation run from which a specific landscape was selected for further analysis, color coded to match legend.

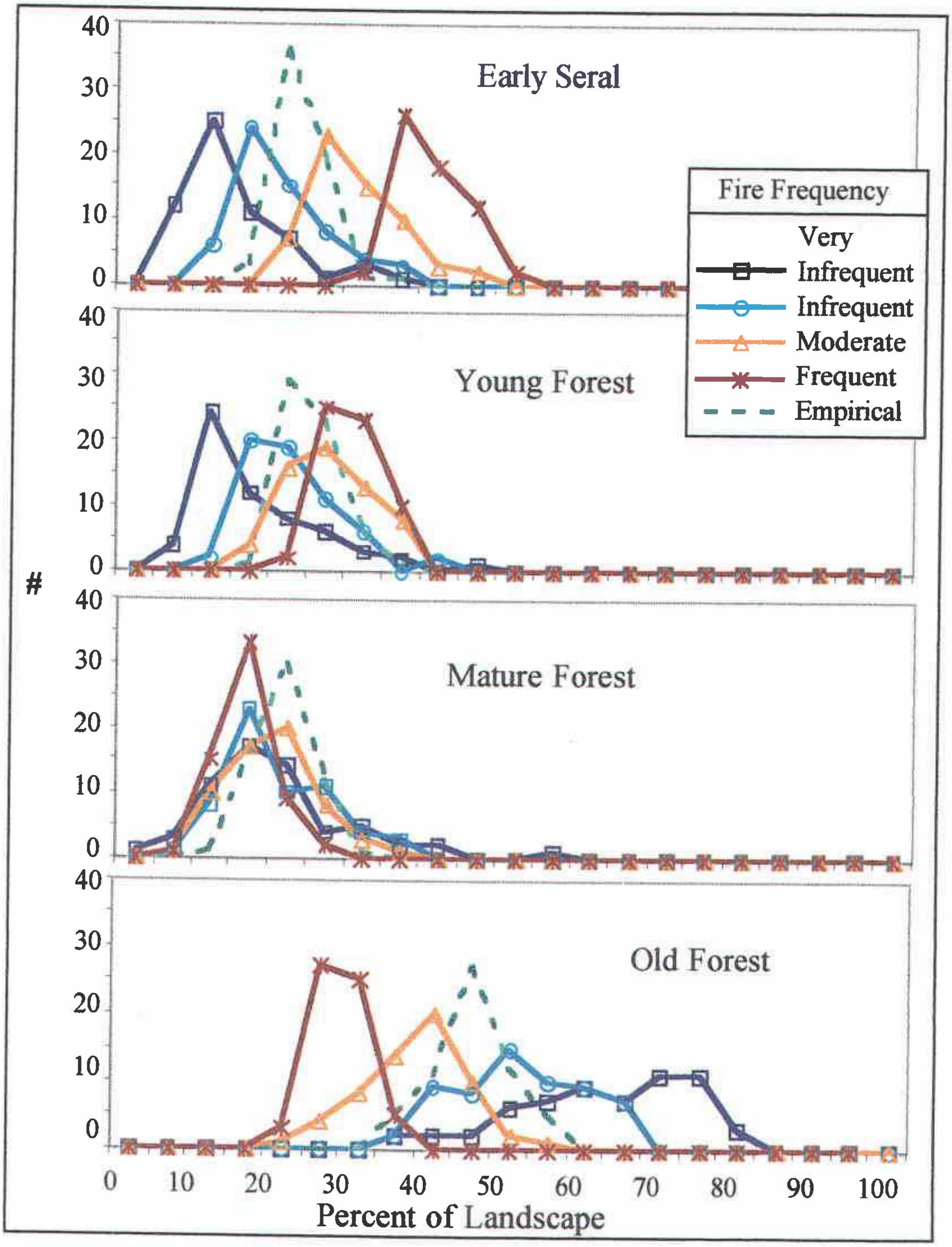


Figure 3.10. Frequency distributions of the landscape percentage of age classes, from five simulation runs representing postulated fire parameters for a range of climatic conditions.

The lack of variability in extent of mature forest is apparent in the histograms, and is somewhat enigmatic. If ages ranging up to 800 years were randomly distributed in equal amounts on the landscapes, mature forest would be expected to make up 15 percent (120 years / 800 years), consistent with simulation results. Early seral vegetation, young and old forest would make up 4 percent, 6 percent and 75 percent, respectively. However, since the likelihood of having burned increases with age and that relationship is incorporated into the model (Wimberly, 2000), old forest makes up a substantially smaller portion of the landscape than would be predicted simply by its proportion of the represented age range (600 of 800 possible years). The probability of burning is also high in early seral vegetation and young forest, therefore these are represented in higher amounts than would be predicted by their relatively small age brackets (30 and 50 years). Since mature forest is the least susceptible to fire, it is also the least responsive to changes in fire characteristics. Additionally, the extent of mature forest on the landscape is greatest in areas of the landscape that have fire frequencies between 80 and 200 years. These areas move around on the landscape with the different simulation parameters, but typically occupy a relatively constant elevation in the mid-elevations. Conversely, when wildfire parameters change, the areas where early seral and old forest age classes are likely to occur expand or shrink. For example, with high fire frequencies the spatial extent of areas with fire frequencies less than 50 years expands, the mature age class migrates higher on the landscape, and the spatial extent of areas with fire frequencies longer than 200 years contracts, resulting in a smaller extent of old forest. Therefore, the extent of both early seral and old forest age classes shows high variability while the mature forest age class remains relatively constant in extent, but changes location.

The trends established by the sensitivity test and observed in the time series are pronounced in the histograms. Decreasing fire frequency from very infrequent, larger sized fires to frequent, smaller fires resulted in an increase in the mean amount of early seral vegetation and decrease in variability. The mean percentage of disturbed, early seral vegetation in the landscape increased from 10.5 percent in the very infrequent fire simulation to 36.5 percent in the frequent fire simulation, with a corresponding decrease in variability (Table 3.1). Values for the percentage of early seral vegetation ranged from less than 4 percent to 31 percent in the lowest frequency simulation, but only from 29 percent to 46 percent in the frequent fire simulation.

Conversely, increasing fire frequency from infrequent to frequent fire resulted in the amount of old forest decreasing from a mean of 59.9 percent in the very infrequent fire simulation to a mean of 25.3 percent in the frequent fire simulation, a change of 34.6 percentage points. The total spread of all old forest observations in the very infrequent fire simulation is an impressive 45.3 percent (32.8 percent to 78.1 percent), more than the observed spread in the other four simulations combined (18.4 percent to 62.8 percent, or 44.4 percent).

Table 3.1. Percent of study area in each of four age classes from 60 simulated landscapes created using the LADS model (Wimberly, 2000). Four runs were conducting by varying input parameters from very infrequent, large, severe fires to frequent, small, less severe fires. The last run used empirical parameters from fire history studies.

		Fire Frequency Simulation Range				Empir-ical
		Very Infre-quent	Infre-quent	Moderate	Frequent	
Early Seral	Mean	10.5	16.8	26.2	36.5	19.6
	St. Error	0.8	0.8	0.8	0.5	0.4
	St. Dev	6.5	6.2	6.0	4.2	3.3
	Min	3.9	8.8	15.7	29.3	14.1
	Max	31.2	34.3	41.5	46.3	31.0
	5^{th} percentile	4.1	9.2	17.7	30.9	14.4
	95^{th} percentile	26.0	30.3	38.6	44.8	24.6
Young Forest	Mean	13.3	17.8	23.0	25.9	20.6
	St. Error	1.1	0.8	0.7	0.5	0.4
	St. Dev	8.4	6.4	5.7	3.7	3.5
	Min	3.1	6.2	11.9	19.2	14.6
	Max	42.3	38.2	34.8	33.7	30.7
	5^{th} percentile	4.3	10.5	13.6	20.3	15.9
	95^{th} percentile	32.6	29.7	33.8	32.6	27.7
Mature Forest	Mean	16.7	16.2	15.6	12.3	17.2
	St. Error	1.3	0.9	0.8	0.5	0.5
	St. Dev	9.8	6.6	6.0	3.9	4.0
	Min	0.2	3.7	4.0	2.7	9.2
	Max	55	33.6	31.2	23	26.7
	5^{th} percentile	3.6	7.7	5.2	6.0	10.6
	95^{th} percentile	37.5	30.2	26.8	19.9	25.0

Table 3.1, continued

Old Forest	Mean	59.9	49.2	35.2	25.3	42.5
	St. Error	1.5	1.1	0.8	0.5	0.6
	St. Dev	11.6	8.5	6.5	3.5	4.9
	Min	32.8	30.7	19.7	18.4	32.0
	Max	78.1	62.8	50.3	33.2	53.8
	5^{th} percentile	37.7	35.2	22.9	19.3	34.1
	95^{th} percentile	76.2	61.8	46.9	32.6	51.9

The empirically-based simulation resulted in landscapes with an average of 19.6 percent early seral vegetation, ranging from 14.1 percent to 31.0 percent. Based on these results, the empirical conditions fell between the infrequent and moderate conditions in the postulated fire frequency range. Because relatively small fire sizes were used in the empirical simulation consistent with reported fire sizes in most of the tree-ring studies, variability in the historic simulation landscapes is small, more typical of that found in the frequent fire simulation.

Twenty five landscapes, five from each wildfire simulation, were selected for stratified analysis by owner/allocation type. The position within each simulation run from which samples were selected is shown on Figures 3.6 to 3.9.

Characteristics of Mixed Landscapes: the 1995 Landscape

The age class map (DISTAGECLASS) resulting from the combination of the harvest disturbance and conifer age maps is shown in Figure 3.11, prior to the final classification of remaining pixels from the vegetation class map. This figure displays the trend from primarily young vegetation in the western, lower elevations to older vegetation in the higher elevations, reflecting the correlation between owner/allocation type and elevation. Lower elevation private industrial lands, which are typically on their 2nd or 3rd rotation since harvesting began more than a century ago with rotations less than 50 years, are predominantly regenerating clear cuts and young conifer plantations. Conversely, mid and upper elevation U.S. Forest Service lands have relatively high proportions of mature and old aged conifer, reflecting their later access for timber harvest (1950s and later; Jones and Grant, 1996), slower harvest rates (Spies et al., 1994), and substantial undisturbed wilderness areas.

Age class amounts from the landscape as a whole are approximately evenly distributed between early seral, mature and old forest, with somewhat lesser amounts of young forest (Figure 3.11). The early seral age class covers half (49.8 percent) of private industrial land, 22.5 percent of U.S. Forest Service non-wilderness lands and less than 3 percent of wilderness acreage. Mature and old forest covers from 68 to 88 percent of U.S. Forest Service and wilderness lands, and only 24 percent on private industrial lands. Bureau of Land Management/private industrial checkerboard lands exhibit intermediate characteristics, consistent with their mixed public/private ownership.

The amounts of mature and old forest are probably overstated for two reasons. First, estimated classification errors are 15 percent. Comparison of the disturbance map with the conifer age map indicated that many of the pixels that are inconsistently classified occur along small streams. It is possible that the Tasseled Cap transformation used in the conifer age classification is identifying sub-pixel streams as increased "wetness", and overstating the age of the forest in that pixel. Additionally, many of the cells identified as old forest are located along private/public owner boundaries and are probably due to misregistration.

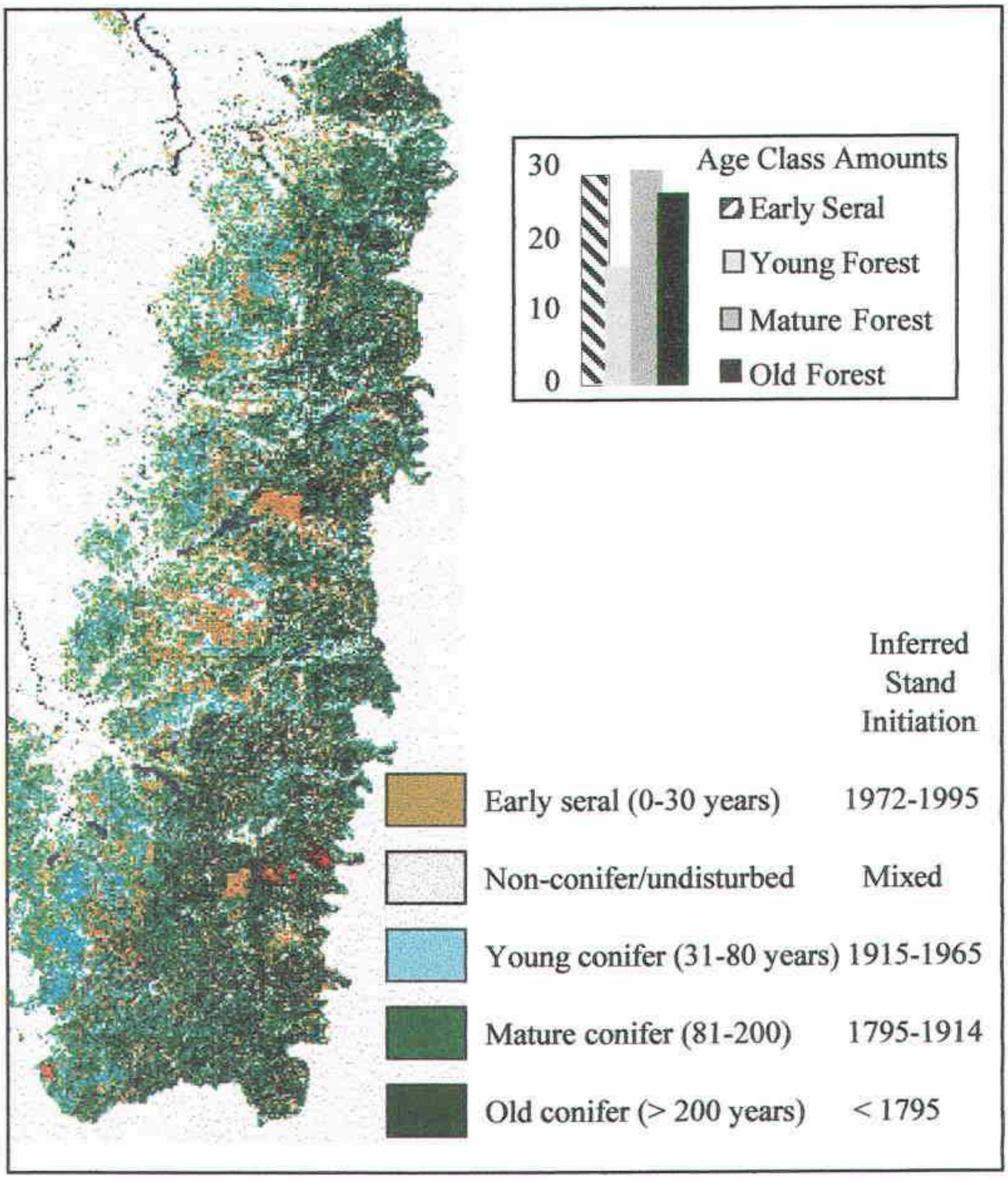


Figure 3.11. Combined disturbance and conifer age maps used to derive estimated time of disturbance and stand initiation dates as of 1995. White areas are non-conifer pixels disturbed prior to 1972. This map was used to create the final age class map. Note the transition from predominantly young classes on the western, low elevation side to predominantly mature and old forest on the eastern, high elevation side of the map, across the boundary between private industrial and Forest Service lands.

Characteristics of Managed Landscapes

The hypothetical managed landscapes (Figure 3.12, 3.13 and 3.14) display substantial differences with each other, and compared to the 1995 landscape, despite the simplified assumptions used to construct them. The riparian-rule managed landscape has more early seral and young forest than the riparian-rule plus reserves landscape, which in turn has more than the riparian-rule plus reserves and mixed-rotation landscape. The riparian-rule and riparian-rule plus reserves landscapes lack mature forest.

Comparison of riparian area under the Oregon Practices Act, Northwest Forest Plan, and Blue River Plan rules

The three management strategies considered in this study include riparian buffer zones along streams of varying widths and under different circumstances (Table 2.9). The Northwest Forest Plan requires buffers of one to two tree heights wide along all streams, fish-bearing or not, whereas the Oregon Forest Practices Act reduces buffer requirements along non-fishbearing streams. The Blue River Plan requires wider buffers applied along fish-bearing streams only.

The three riparian layers were compared separately to assess differences in outcome between the riparian rules (Table 3.2). Varying buffer widths and locations significantly affects the total riparian buffer zone area, which ranged from approximately 147,000 ha (9.4 percent of the landscape) under the Oregon Forest Practices Act to more than 365,000 ha under the Northwest Forest Plan (23.3 percent of the landscape). Because drainage density is higher at low elevations, riparian buffers occupy 11.9 to 28.3 percent of the low elevation area, but only 3.4

to 13.9 percent of the high elevation area. The variation with elevation is least pronounced under the state rules (4.9 to 11.9 percent) and most pronounced under the Northwest Forest Plan rules (13.9 to 28.3 percent).

Table 3.2. Riparian area in three hypothetical managed landscapes, for whole landscapes and stratified by owner and by elevation, reported as area in hectares and as percent of the area in the strata. High elevation > 1200 m, mid elevation 700-1200 m, low elevation < 700 m. WILD = U.S. Forest Service wilderness areas, USFS = U.S. Forest Service non-wilderness areas, PI = private industrial land, CHECK = Bureau of Land Management/private industrial checkerboard acreage.

Strata		Riparian Area – hectares (percent of stratum area)					
		Oregon Forest Practices Act		Northwest Forest Plan		Blue River Plan	
		km^2	%	km^2	%	km^2	%
Elev-ation	High	116	4.9	327	13.9	79	3.4
	Mid	639	8.7	1646	22.3	669	9.1
	Low	688	11.9	1636	28.3	892	15.5
Owner	WILD	81	9.2	202	23.1	89	10.2
	USFS	815	9.4	2014	23.3	929	10.8
	PI	308	9.2	784	23.3	3357	10.5
	CHECK	201	9.0	509	22.7	218	9.8
Whole Landscape		1470	9.4	3657	23.3	1672	10.7

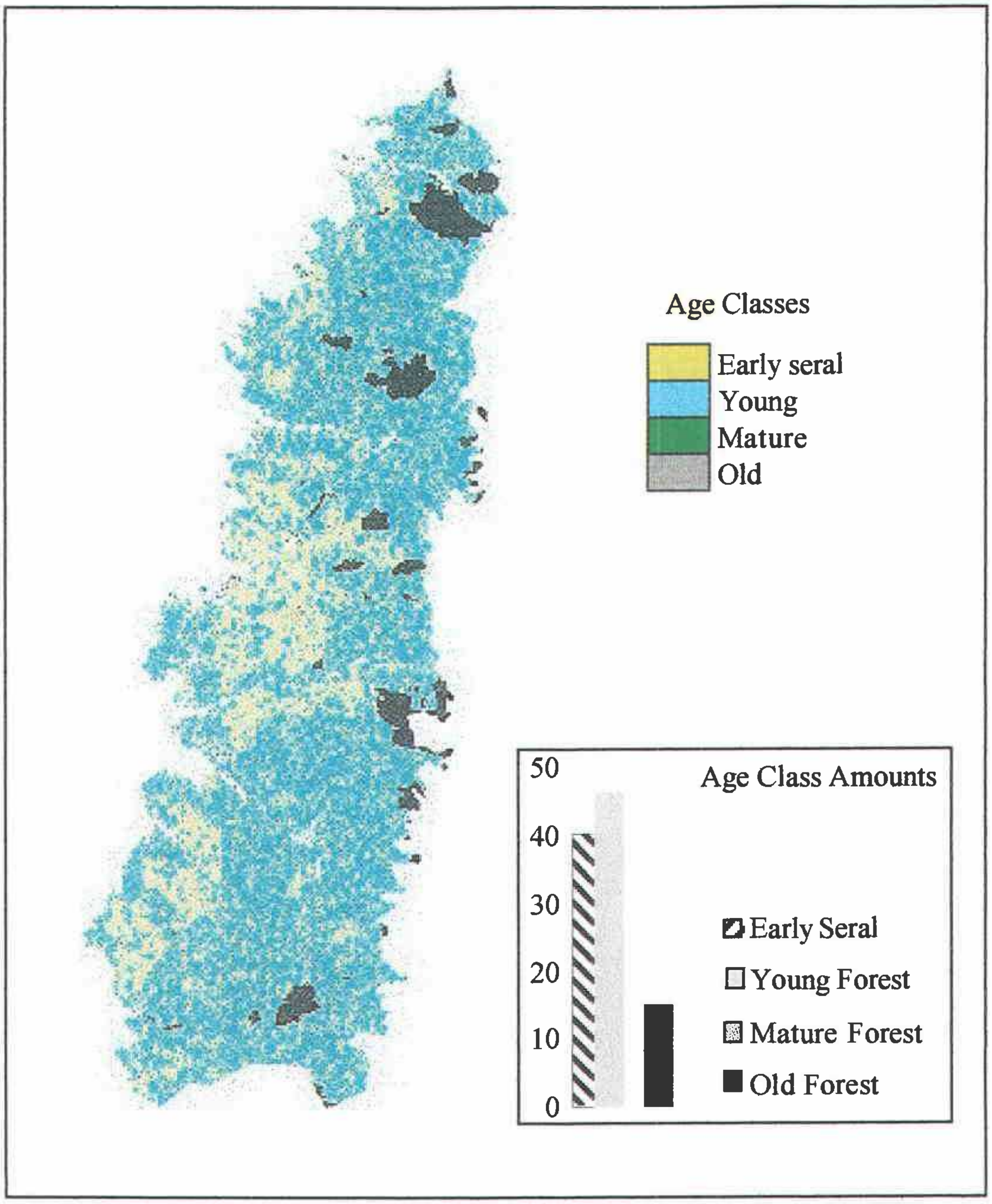


Figure 3.12. The riparian-based managed landscape, with a combination of 40 year rotations and aggregated patches on private industrial land, 80 year rotations and dispersed patches on public lands, and all old forest in wilderness areas. Riparian buffers were modelled in accordance with state law.

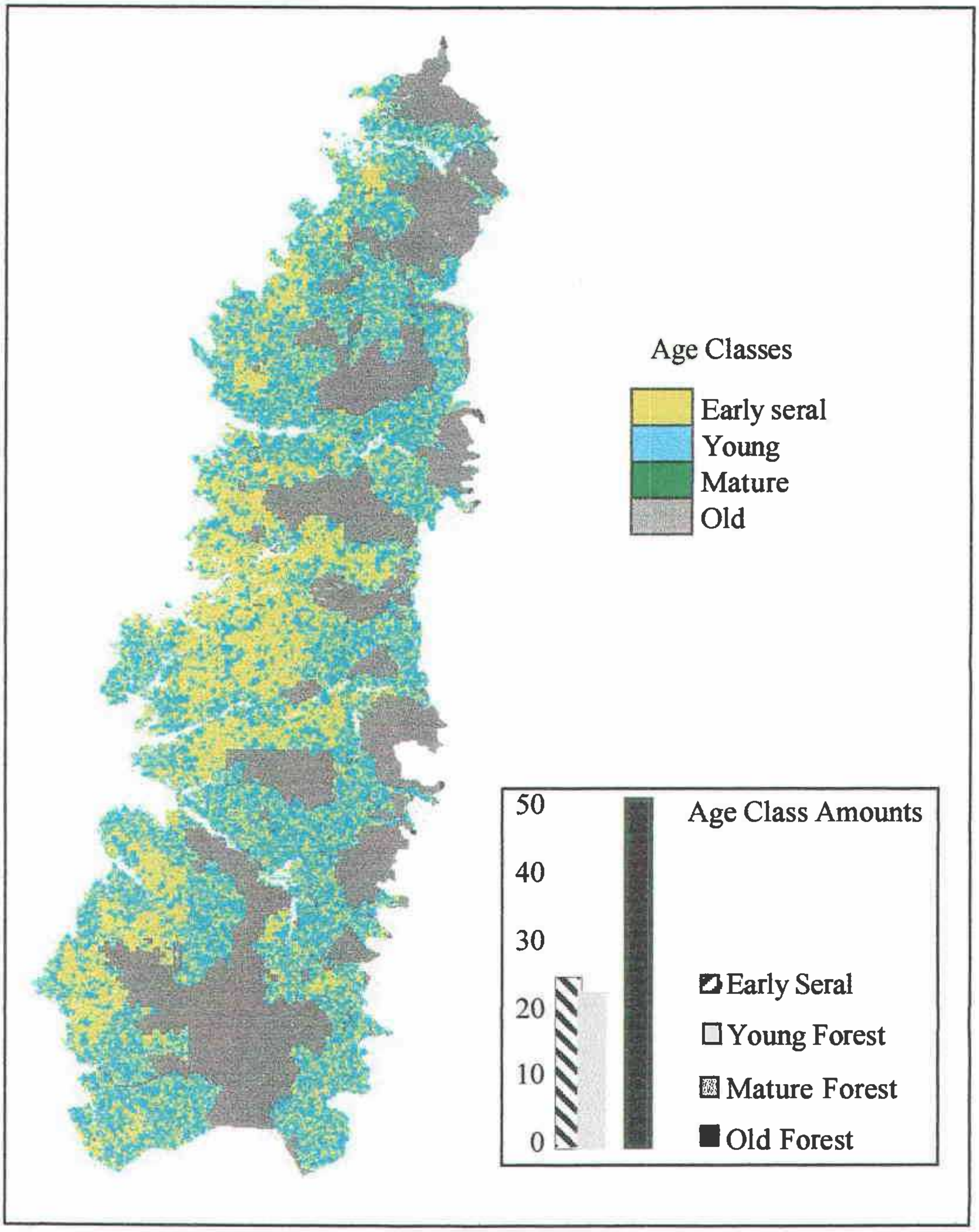


Figure 3.13. The riparian/reserves-based managed landscape, consisting of 40 year rotations and aggregated patches on private lands, 80 year rotations and dispersed patches on public lands, and all old forest in late successional reserves and wilderness areas. Riparian buffers are extensive on public lands in this scenario.

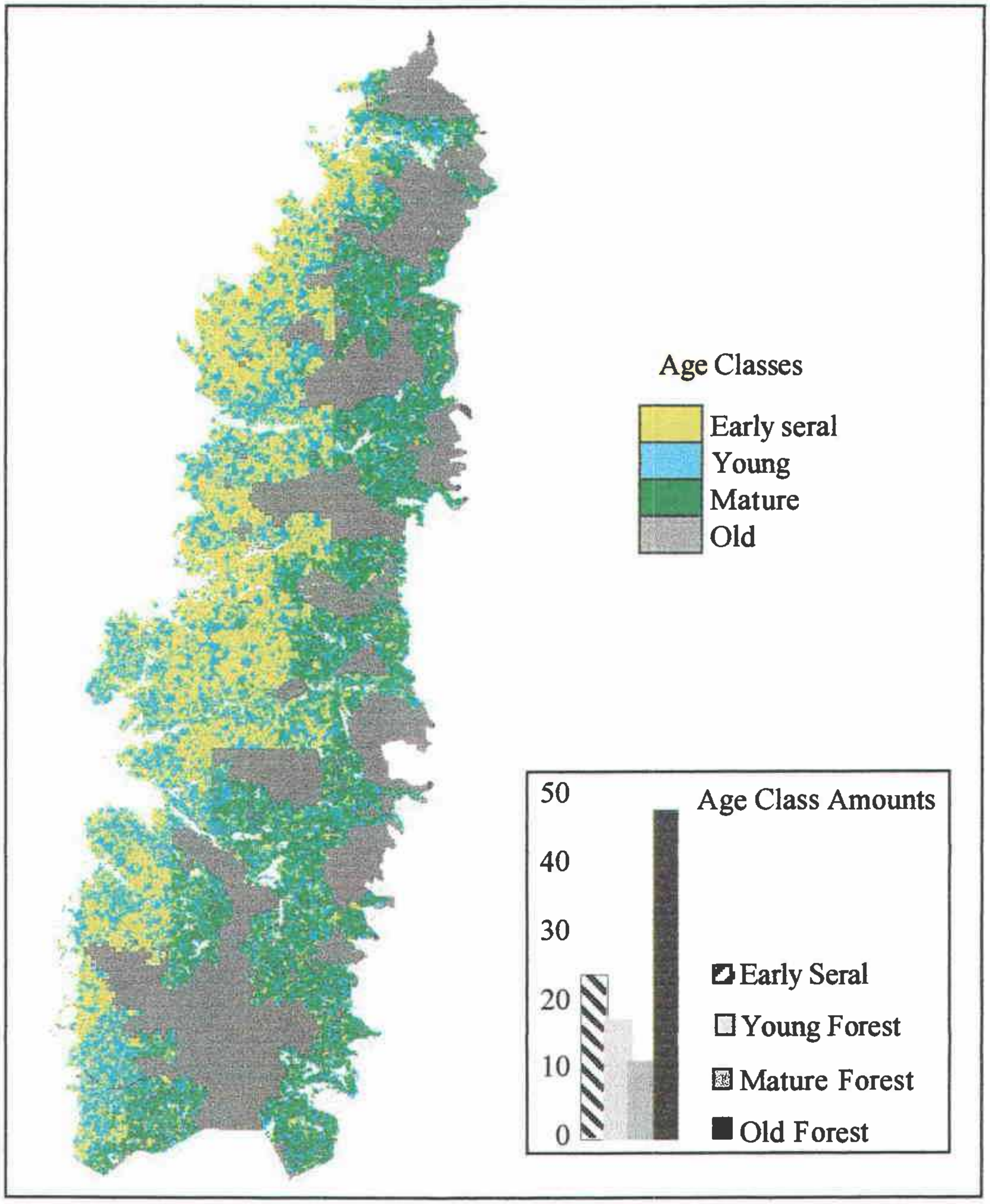


Figure 3.14. The riparian/reserves/rotation-based managed landscape, consisting of 40 year rotations and aggregated patches on private industrial lands, a range of rotations from 100-260 years and a range of patch patterns on public lands, and all old forest in wilderness and late successional reserves. Riparian buffers are only required on fish-bearing streams, and are less extensive on public lands than under state law and the NWFP.

Comparison of the riparian-rule plus reserves and mixed-rotation managed landscape with the Blue River Plan

The approach taken in construction of the riparian-rule plus reserves and mixed-rotation managed landscape was to try to create landscape areas across the U.S. Forest Service non-reserve lands that were roughly equivalent to those in the Blue River Plan (Cissel et al., 1999), in terms of the percentage of area occupied by each landscape area. However, it was not possible to devise a rule set that matched the landscape area percentages at both the larger scale of the full study area and also within the Blue River watershed itself (Table 3.3) because of variation in reserve area across the landscape. A rule set was chosen that allocated 56 percent of the U.S. Forest Service non-reserve area for the full study area to low frequency harvest, compared to 45 percent in the Blue River Plan (Cissel et al., 1999), but that resulted in only 29 percent of the Blue River watershed being designated as low frequency harvest. Twenty five percent of U.S. Forest Service non-reserve area for the full study area was allocated to mid-frequency harvest, compared with 27 percent in the Blue River Plan. The Blue River Plan placed 28 percent of non-reserve area in high frequency harvest, compared with only 19 percent in this study, with 31 percent of the Blue River watershed in high frequency harvest. Table 3.4 summarizes the resulting age class amounts in the riparian-rule plus reserves and mixed-rotation managed landscape, compared with the Blue River Plan results.

Table 3.3. Percentage of matrix area in each of three landscape areas, approximating three fire regimes, at different scales. Blue River watershed matrix percentages (first row of entries) from Cissel et al. (1999) were the target percentages to be spread across the U.S. Forest Service matrix for the study area (last row of entries). Entries in the second row are the resulting percentages in the Blue River watershed in this study. The final landscape area 3 percentage in the U.S. Forest Service matrix was intentionally increased relative to the Blue River Plan to partially compensate for small watershed and special area reserves set aside in the Plan, but not incorporated into this study.

Study	Landscape Area		
	High Frequency	Mid Frequency	Low Frequency
Blue River matrix, from Cissel et al. (1999)	28	27	45
Blue River matrix, this study	31	40	29
USFS matrix	19	25	56

Table 3.4. Percent of study area in each of four age classes in the Blue River watershed non-reserve area, Blue River watershed including reserves, U.S. Forest Service owner/allocation type non-reserve area and U.S. Forest Service owner/allocation type including reserves.

	Blue River Watershed				Larger Study Area	
	Cissel et al., (1999)		This study		This study	
Age Class	Non-reserve	All	Non-reserve	All	USFS Non-reserve	USFS All
Early seral	21	13	19	12	15	6
Young	19	12	29	19	25	10
Mature	32	20	41	28	41	19
Old	28	55	11	41	19	65

Comparison of Structural Elements of Wildfire-affected, 1995 and Managed Landscapes

Comparison of Age Class Types and Amounts

Whole Landscape Comparison

Age class data for the wildfire-affected, 1995 and hypothetical managed landscapes are given in Appendix P. Figure 3.15 displays histograms of age classes from the 25 selected wildfire-affected landscapes, overlain by age class amounts from the 1995 and the three managed landscapes. The 1995 landscape is not similar to a single wildfire simulation run, but rather, varies in similarity with the age class under consideration. In terms of early seral vegetation, the 1995 landscape most resembles the moderate fire frequency simulation, with 28.9 percent compared with a mean of 25.9 percent for the simulation. The 1995 landscape consists of 15.7 percent young forest, most similar to the very infrequent fire simulation (mean 17.2 percent). Mature forest makes up 29.3 percent of the 1995 landscape, above the maximum of 25.5 percent observed in the empirically-based fire simulation, and 10 percent more than the highest values observed in the other simulations. The 1995 landscape consists of 26.1 percent old forest, similar to the mean of the frequent fire simulation (24.2 percent). In no case does the 1995 landscape closely resemble the empirical fire simulation.

The three hypothetical managed landscapes also exhibit variation with respect to the fire landscapes, the 1995 landscape, and each other. The riparian-rule landscape has relatively high amounts of early seral vegetation (39.9 percent) and young forest (45.7 percent) compared with all of the other landscapes (Figure 3.15). Combined, these two age classes account for 85.6 percent of the riparian-rule landscape, much higher than any other landscape, and well above the combined 62 to 68 percent displayed by the frequent fire simulations. The riparian-rule landscape is in the high-end tail of the distribution for early seral vegetation for the wildfire-affected landscapes, and is outside of the distribution for young forest. The riparian-rule plus reserves and riparian-rule plus reserves and mixed-rotation managed landscapes display comparable amounts of early seral vegetation (25.4 and 23.9 percent, respectively), slightly lower than for the 1995 landscape (28.9 percent) and falling in the central portion of the wildfire-distribution of the early seral age class.

The lack of mature forest in the riparian and riparian-rule plus reserves landscapes is a substantial difference between these landscapes, the 1995 landscape and the wildfire-affected landscapes. The riparian-rule plus reserves and mixed-rotation managed landscape has 10.7 percent mature forest, in the range of the distribution shown by the wildfire-affected landscapes, although on the low end (Figure 3.15). The riparian-rule plus reserves and riparian-rule plus reserves and mixed-rotation landscapes have relatively high amounts of old forest relative to the fire landscapes and the 1995 landscape (51.7 and 48.5 percent, respectively), at the high end of the wildfire-affected landscape distribution and comparable to the very infrequent fire simulation. These amounts are consistent with the high end of the range observed in the empirical simulation (37.4 to 52.8 percent). The riparian-rule landscape, with 14.4 percent old forest, has the lowest percentage of any of the 29 landscapes.

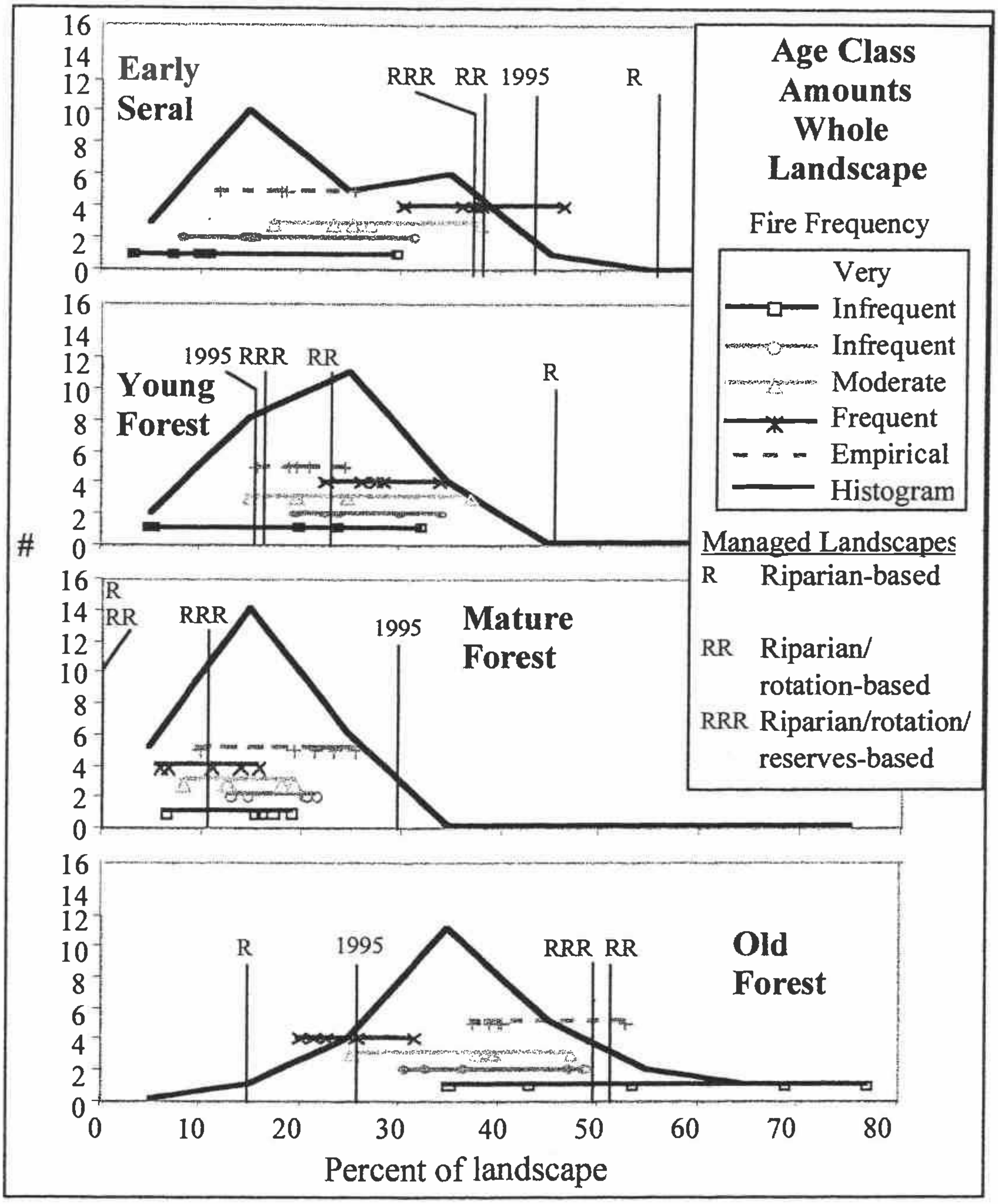


Figure 3.15. Age class amounts for twenty five selected fire landscapes from five fire simulation runs, compared with age class amounts on the 1995 and managed landscapes. Symbols represent the landscape amount for a given fire landscape. Horizontal bars are the range for a given fire simulation run. The solid black line i: the distribution for all 25 fire landscapes. Vertical lines represent the managed an 1995 landscapes.

Comparison By Owner/Allocation Type

The discrepancies between the 1995 landscape and the wildfire simulations may be explained by analysis of age class amounts in different owner/allocation types (Appendix Q). Wilderness lands on the 1995 landscape are comparable to, and in some cases, exceed, the trends observed in the very infrequent fire simulation (Figure 3.16). The amount of early seral vegetation on wilderness lands on the 1995 landscape, 2.8 percent, is at the low end of observations in the very infrequent fire simulation (1.2 to 29.4 percent), and below observations in the empirically based simulation (8.0 to 15.6 percent; Figure 3.16). The amount of young forest in wilderness lands on the 1995 landscape, 8.8 percent, is comparable to the observations from the very infrequent fire simulation (3.0 to 11.5 percent, with one very high simulated episode of 30.3 percent) and less than observations from the empirically-based simulation (11.6 to 24.6 percent). The 1995 amount of wilderness mature forest, 49.0 percent, is higher than any observations on the wildfire-affected landscapes, the maximum of which was 32.0 percent on one of the infrequent fire landscapes. Old forest in wilderness lands on the 1995 landscape, at 39.4 percent, was well within the simulation observations (27.3 to 91.2 percent). Therefore, the 1995 wilderness landscape is on the low end of the range of conditions likely to have occurred in the past for the early seral vegetation and has much higher amounts of mature forest. Compared with the empirically-based wildfire-affected landscapes, 1995 wilderness areas were outside of the observed range of early seral, young and mature forest amounts and at the extreme low end of observed old forest amounts.

The hypothetical managed landscapes in wilderness lands were prescribed as all old forest, with the only exceptions occurring due to edge effects. Therefore, they show even less early seral vegetation than in the 1995 landscape, and decreased amounts of young forest (Figure 3.16). In contrast to the high amounts of mature forest on the 1995 landscape in wilderness lands, the hypothetical managed landscapes show no mature forest. These results were controlled by the prescription of all old forest to wilderness lands. They illustrate that in the absence of disturbance in wilderness areas, the high amounts of mature forest currently in those areas will age into the old forest age class in the coming decades and will result in old forest amounts that exceed anything observed in the wildfire-landscapes.

U.S. Forest Service non-wilderness lands on the 1995 landscape consist of 22.5 percent early seral vegetation, within the range of the moderate fire frequency and empirically based simulations (12.3 to 29.7 percent and 8.3 to 25.9 percent, respectively; Figure 3.17). Young forest makes up 9.3 percent of the 1995 U.S. Forest Service non-wilderness landscape, on the low end of simulation observations, but within the range observed on the very infrequent fire simulation (3.2 to 20.6 percent). Mature forest is 31.4 percent on U.S. Forest Service non-wilderness lands on the 1995 landscape, at the highest end of the simulation range (4.9 to 30.9 percent), nearly matched by only one observation on the empirically based wildfire-affected landscape. Old forest comprises 36.8 percent, within the ranges of the moderate, frequent and empirically based wildfire-affected landscapes (32.8 to 60.8, 26.8 to 42.3 and 35.4 to 55.3 percent, respectively).

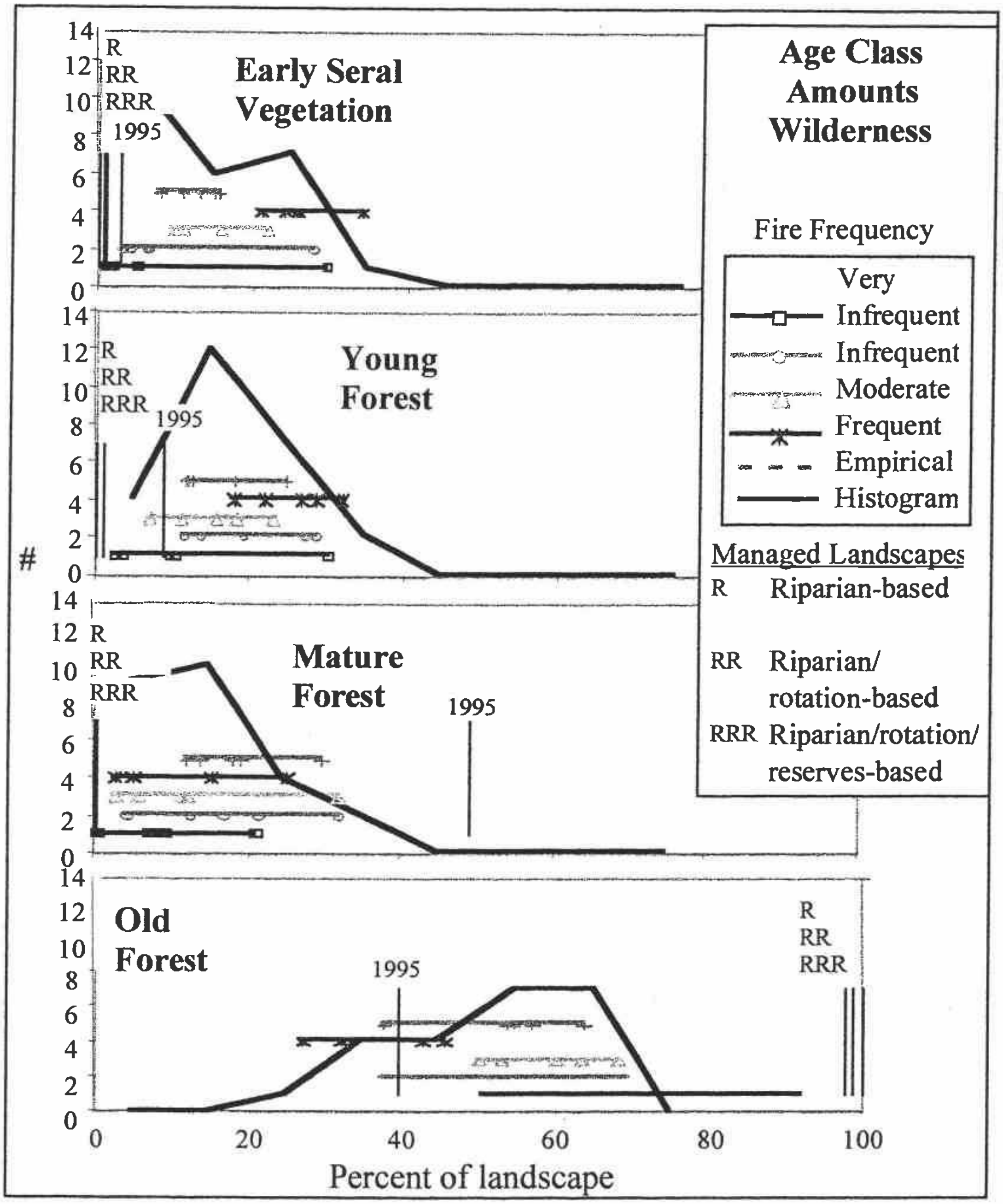


Figure 3.16. Age class amounts for the wilderness owner/allocation type, for twenty five selected fire landscapes from five fire simulation runs, compared with age class amounts on the 1995 and managed landscapes. Symbols represent the landscape amount for a given fire landscape. Horizontal bars are the range for a given fire simulation run. The solid black line is the distribution of all 25 fire landscapes. Vertical lines represent the managed and 1995 landscapes.

On U.S. Forest Service non-wilderness lands on the 1995 landscape, although young and mature forest amounts are somewhat unusual, they are within the range of simulated conditions, and early seral and old forest amounts are well within simulated ranges. Additionally, only young forest amounts are outside of the range of conditions observed in the empirically based wildfire-affected landscapes. Therefore, age class amounts on U.S. Forest Service non-wilderness lands on the 1995, 1995 landscape were within the range of conditions likely to have occurred in both the recent and distant past.

U.S. Forest Service non-wilderness lands on the hypothetical managed landscapes are more revealing than on the other allocation types, since many more criteria were incorporated into landscape construction, particularly for the riparian-rule plus reserves and mixed-rotation managed landscape. Early seral vegetation was much higher on the riparian-rule managed landscape (34.6 percent) than on the 1995 landscape (22.5 percent) while the riparian-rule plus reserves and riparian-rule plus reserves and mixed-rotation managed landscapes exhibited lesser amounts of early seral vegetation (14.3 and 6.1 percent, respectively; Figure 3.17). All three hypothetical managed landscapes showed more young forest on U.S. Forest Service non-wilderness lands compared with the 1995 landscape, ranging from slightly higher on the riparian-rule plus reserves and mixed-rotation landscape (from 9.3 to 10.2 percent) to quite higher (exceeding 40 percentage points, from 9.3 to 53.0 percent) on the riparian-rule managed landscape, far exceeding observations on the wildfire-affected landscapes. The high amount of mature forest on the 1995 landscape in U.S. Forest Service non-wilderness lands (31.4 percent) was lower in the riparian-rule plus reserves/rotation landscape (18.8 percent), but completely lacking on the other two managed landscapes.

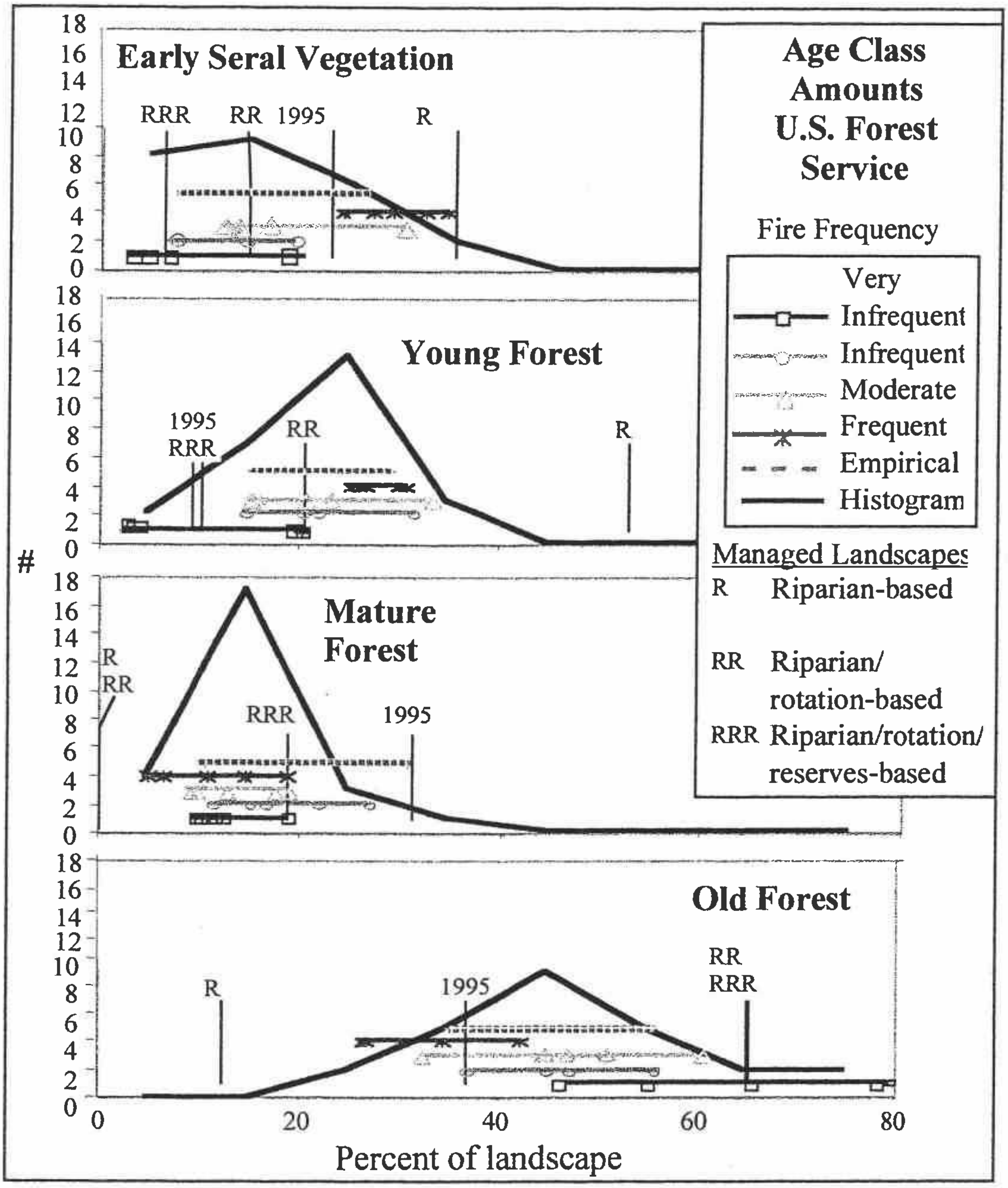


Figure 3.17. Age class amounts for the U.S. Forest Service non-wilderness owner/allocation type, for twenty five selected fire landscapes from five fire simulation runs, compared with age class amounts on the 1995 and managed landscapes. Symbols represent the landscape amount for a given fire landscape. Horizontal bars are the range for a given fire simulation run. The solid black line i the distribution of all 25 fire landscapes. Vertical lines represent the managed and 1995 landscapes.

Old forest amounts were lower by approximately 25 percentage points on the riparian-rule managed landscape compared to the 1995 landscape (from 36.8 to 12.5 percent), placing it outside of the observed range on the wildfire-affected landscapes. Conversely, old forest area was approximately 30 percentage points higher on the riparian-rule plus reserves and riparian-rule plus reserves and mixed-rotation managed landscapes compared to the 1995 landscape (to 65.1 and 64.9 percent, respectively), the high-end of observations from the wildfire-affected landscapes.

Private industrial lands on the 1995 landscape consist of 49.8 percent early seral vegetation, 26.2 percent young forest, 17.6 percent mature forest and 6.3 percent old forest. As noted previously, these amounts may be overstated. Private industrial lands for the 1995 landscape are most comparable to, and in some cases exceed, the trends observed in the frequent fire simulation (Figures 3.18). The amount of early seral vegetation on private industrial lands in 1995 is on the high end of that observed in the frequent fire simulation (38.0 to 58.0 percent), and on the high-end tails of the moderate to infrequent fire simulations (23.8 to 52.9 percent and 9.0 to 52.8 percent, respectively). It exceeds the amount of early seral vegetation in the empirical (maximum 28.2 percent) and very infrequent fire (maximum 45.6 percent) simulations. The amount of young forest in private industrial lands on the 1995 landscape (26.2 percent) is somewhat higher than observed in the empirical simulation (14.9 to 20.7 percent), but comparable to observations in the full fire frequency simulation range (6.1 to 49.2 percent). Mature forest for 1995 private industrial lands (17.6 percent) was well within the overlap of observations in all of the wildfire simulations. The amount of old forest, 6.3 percent, is lower than the range of variability observed in the simulations (10.1 to 74.6 percent). Therefore, based on this comparison, the 1995 private industrial landscape is most comparable to the frequent fire simulation, is outside of the range of variability simulated based on the empirical data in all but the mature age class, and is outside the range of conditions likely to have occurred at any time in the simulated past for the old forest age class, even under the warmest, highest frequency fire conditions.

The hypothetical managed landscapes display early seral vegetation amounts ranging from 58.4 to 68.4 percent on the three landscapes, higher than any observations on the 25 wildfire-affected landscapes (Figure 3.18). Young forest, ranging from 21.4 to 22.3 percent, was somewhat less than on the 1995 landscape (26.2 percent), but well within the range observed on the wildfire-affected landscapes and slightly higher than landscapes from the empirical simulation (14.9 to 20.7 percent). The absence of mature forest on private industrial lands on the hypothetical managed landscapes, as noted above for the whole landscapes, is a major difference. Interestingly, old forest age class amounts are higher on the hypothetical managed landscapes than the 1995 landscape (9.3 to 16.4 percent compared with 6.3 percent), and are within the range observed on some of the wildfire-affected landscapes, although on the low end. However, old forest age class amounts are below observations for the empirical simulation (27.0 to 51.3 percent). Therefore, these results suggest that in the future private industrial lands could potentially become more unlike the historic past than the 1995 landscape in terms of early seral vegetation and mature forest . If riparian buffer requirements result in an increase in the amount of old forest, old forest may increase into the low-end range of the historic past.

Last, Bureau of Land Management/private industrial checkerboard lands are intermediate to trends observed on U.S. Forest Service non-wilderness and private industrial lands (Figures 3.19). Checkerboard lands on the 1995 landscape have 34.3 percent early seral vegetation, 25.3 percent young forest, 27.5 percent mature forest, and 12.9 percent old forest amounts. Interestingly, all of these age class amounts are well within the range observed on the wildfire-affected landscapes.

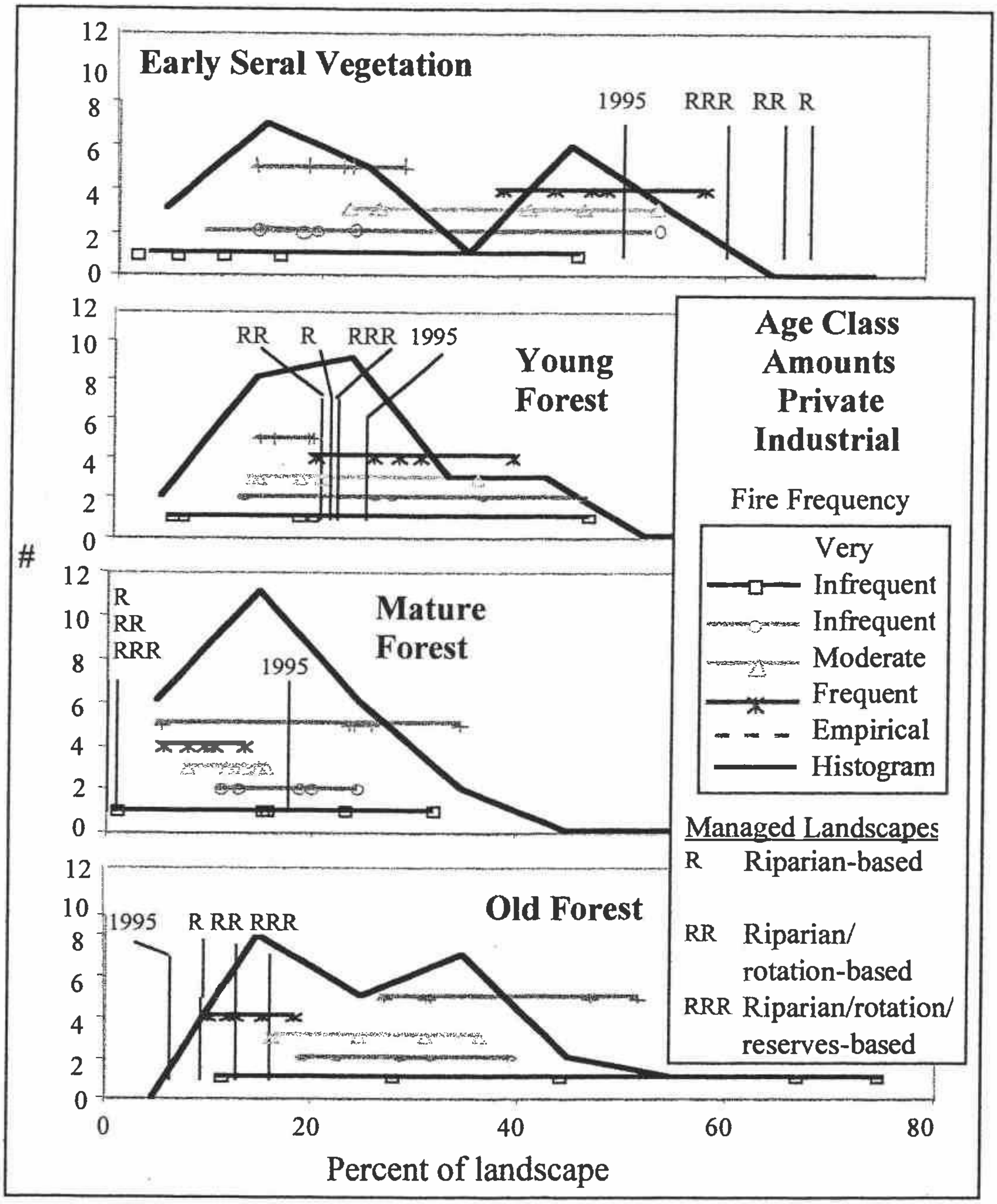


Figure 3.18. Age class amounts for the private industrial owner/allocation type, for twenty five selected fire landscapes from five fire simulation runs, compared with age class amounts on the 1995 and managed landscapes. Symbols represent the landscape amount for a given fire landscape. Horizontal bars are the range for a given fire simulation run. The solid black line is the distribution of all 25 fire landscapes. Vertical lines represent the managed and 1995 landscapes.

Early seral vegetation and mature forest are within the range observed on the empirically based wildfire-affected landscapes (20.6 to 25.6 percent early seral, 8.9 to 30.4 percent mature forest). Although the publicly and privately operated parts of the checkerboard owner/allocation type have very different harvest practices that are likely individually to be comparable to the U.S. Forest Service non-wilderness and private industrial results respectively, the combination of the two results in less variable landscapes that are within the range of the historic past. Little is to be gained by analysis of the hypothetical managed landscapes on checkerboard lands, since it was not possible to prescribe the age classes and riparian buffers on the public and private parts separately since the owner boundaries were dissolved when the areas were merged.

In summary, results from age class analysis of the 1995 landscape at this scale indicate that both the private industrial and wilderness lands are outside of the observed range based on empirical data in three of the four age classes, and outside of the observed range based on all five simulations in one of the four age classes. However, they represent deviations in opposite directions. Private industrial lands have less old forest than in the frequent fire simulations. Wilderness lands have more old forest than in the very infrequent fire simulations. Future conditions are likely to improve the match with the historical range of variability in some age classes and reduce the match in others. U.S. Forest Service non-wilderness lands on the 1995 landscape are comparable to the simulated wildfire conditions. Depending on future management practices, these areas may be lacking in mature forest. Checkerboard lands are also comparable to the simulated wildfire conditions, although at a smaller scale where individual tracts could be analyzed, it is likely that this might not be the case.

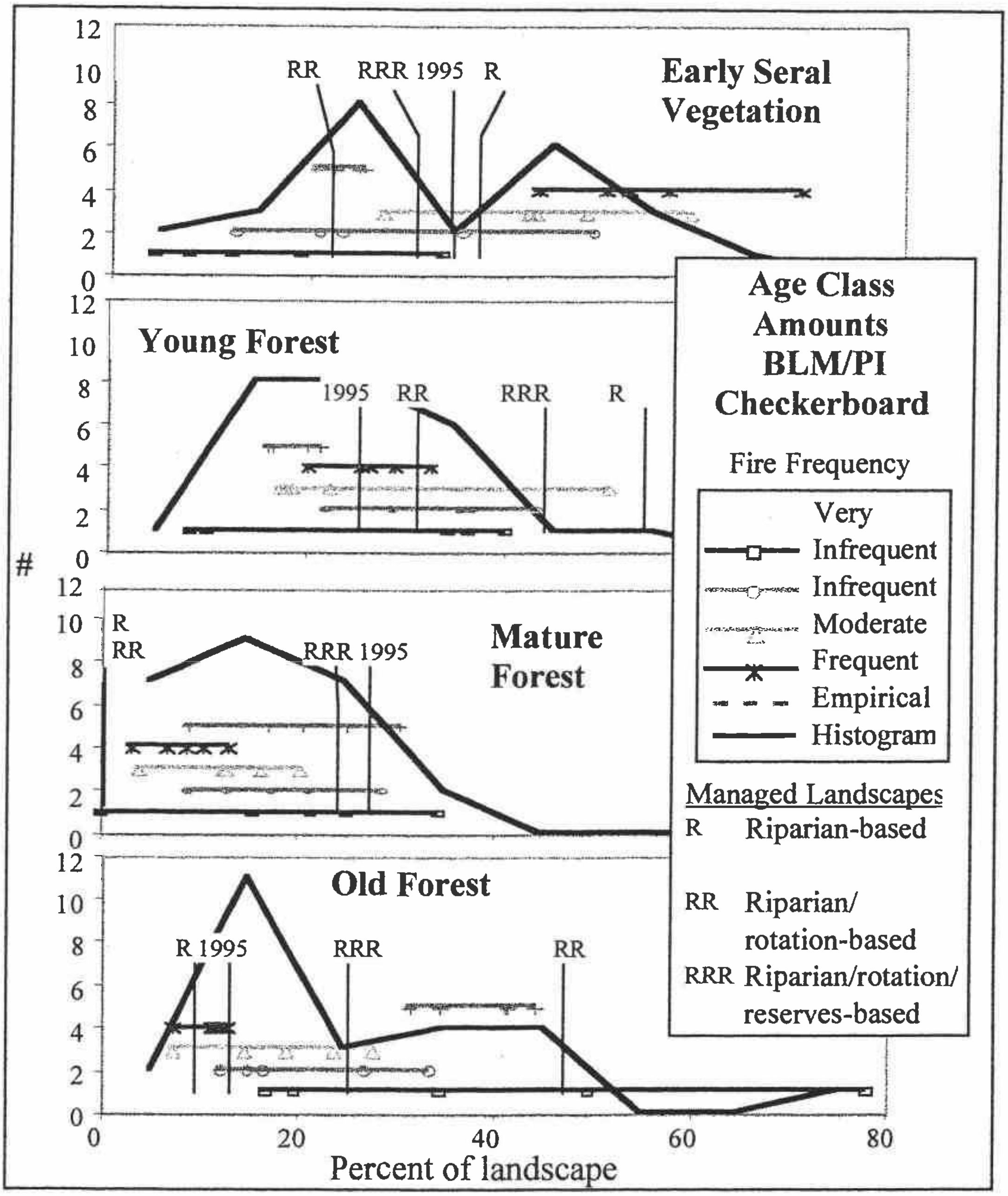


Figure 3.19. Age class amounts for the Bureau of Land Management/private industrial owner/allocation type, for twenty five selected fire landscapes from five fire simulation runs, compared with age class amounts on the 1995 and managed landscapes. Symbols represent the landscape amount for a given fire landscape. Horizontal bars are the range for a given fire simulation run. The solid black line is the distribution of all 25 fire landscapes. Vertical lines represent the managed and 1995 landscapes.

Comparison of Patch Characteristics

Whole Landscape Comparison

Patch characteristics for the wildfire-affected, 1995 and hypothetical managed landscapes are given in Appendix R. In summary, mean patch sizes for all age classes are much smaller on the 1995 landscape than on the wildfire-affected landscapes (Figure 3.20), with many more patches. The largest patch size of each age class is also much higher on the wildfire-affected landscapes. Except for young forest, edge densities are higher on the 1995 landscape. There are very, very few similarities between patch characteristics on the 1995 landscape and wildfire-affected landscapes. The hypothetical managed landscapes show much smaller early seral mean patch sizes than the wildfire-affected landscapes, but larger old forest mean patch sizes (Figure 3.20). The large old forest mean patch sizes are due to the extensive riparian buffers that were modeled as continuous old forest connected with the old forest reserve and wilderness areas, hence, represent the entire old forest area rather than one large block.

Comparison By Owner/Allocation Type

Mean patch size and edge density characteristics by owner/allocation type are listed in Appendices S and T. In summary, none of the mean patch sizes on any of the owner/allocation types for the 1995 landscape were within the ranges observed on the wildfire-affected landscapes; all were far lower. The riparian-rule plus reserves and mixed-rotation managed landscape had larger mean patch sizes

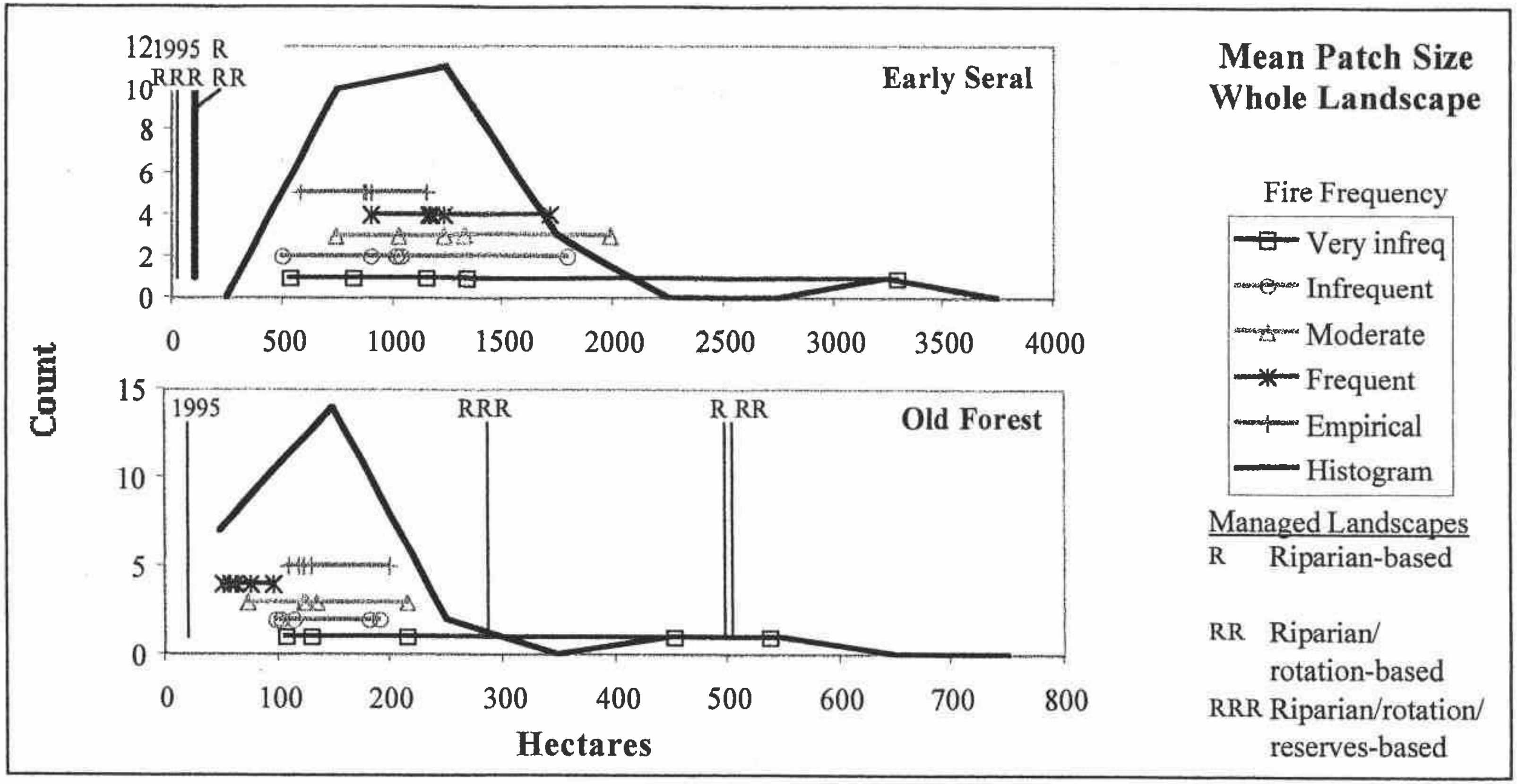


Figure 3.20. Early seral (0-30 years) and old forest (> 200 years) mean patch size for twenty five selected fire landscapes from five fire simulation runs, compared with mean patch size on the 1995 and managed landscapes. Symbols represent the mean patch size for a given fire landscape. Horizontal bars are the range for a given fire simulation run. The solid black line is the distribution of all 25 fire landscapes. Vertical lines represent the managed and 1995 landscapes.

than the 1995 landscape, with mature and old forest mean patch sizes in the wildfire-affected landscape ranges. Edge densities were comparable between the 1995 landscape and the wildfire-affected landscapes for all but the U.S. Forest Service non-wilderness owner/allocation type, which had higher edge densities than observed on the wildfire-affected landscapes. The riparian-rule plus reserves and mixed-rotation managed landscape reduced edge densities on the U.S. Forest Service non-wilderness land into the range of the wildfire-affected landscapes.

Comparison of Patch Arrangement: Patch Proximity Analysis

The 1995, riparian-rule plus reserves and riparian-rule plus reserves and mixed-rotation landscapes show more clustering of early seral vegetation around early seral target pixels than might be expected in a wildfire distribution (Figure 3.21). This is consistent with the mean patch size analysis, which indicated a mean patch size of 27 ha for the 1995 landscape and 876 ha for the empirical wildfire-affected landscapes. The mean patch sizes correspond to circular samples of radii 293 m and 1670 m, respectively. Therefore, aggregation of early seral pixels for the 1995 landscape is greatest close to the target pixel, but rapidly decreases at distances larger than mean patch size, consistent with the graph. Conversely, clustering on the wildfire landscapes should extend for some distance from the target pixel, also shown by the graph. The wildfire-affected landscapes show less contrast (early seral near old forest) than the hypothetical managed landscapes, with the riparian-rule plus reserves landscape showing the most contrast, with many early seral patches adjacent to old forest.

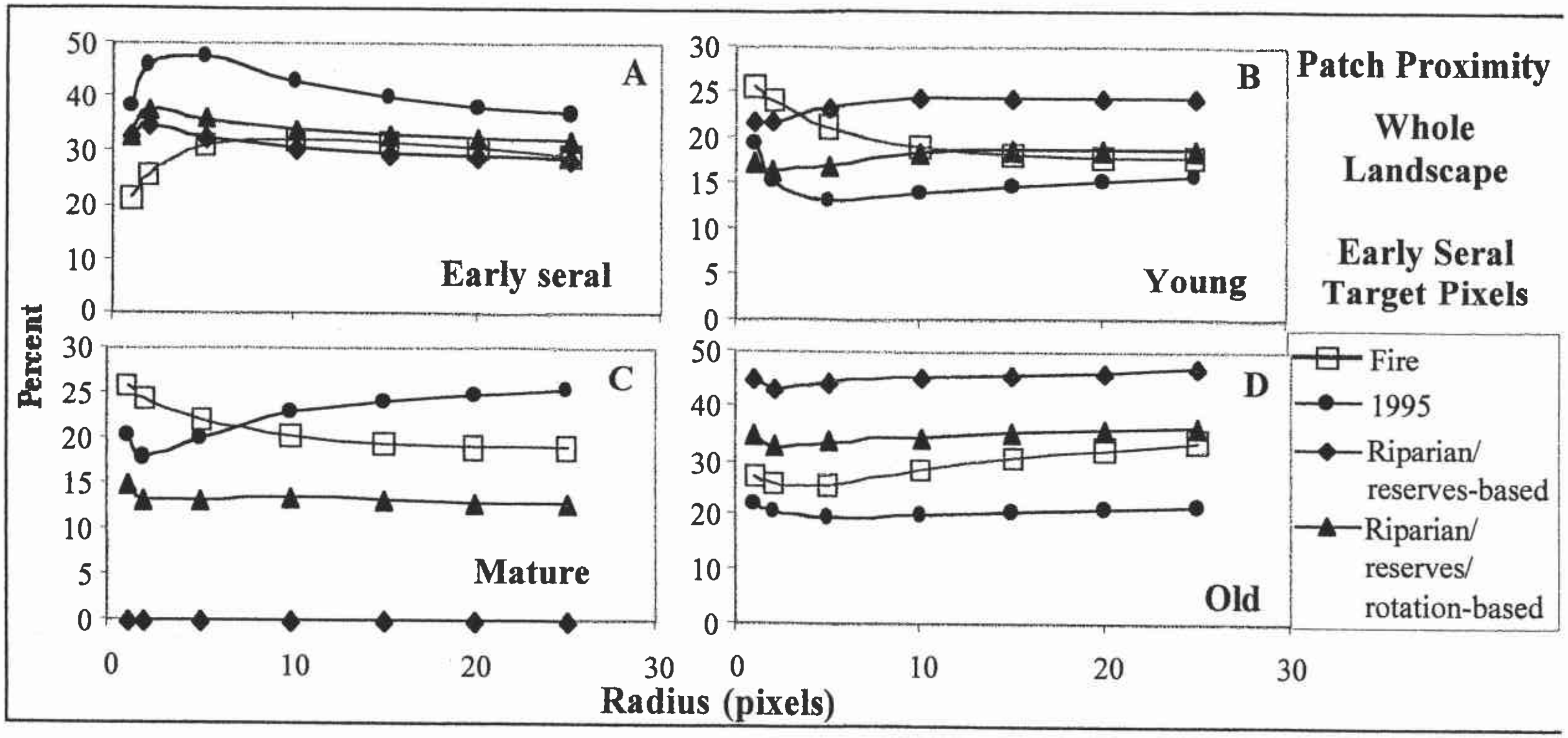


Figure 3.21. Patch proximity analysis for four landscapes. Analysis was conducted for each paired age class combination. For each pixel of the target age class, counts of the number of pixels of the four age classes surrounding that target pixel were made, at seven distance classes: 1, 2, 5, 10, 15, 20 and 25 pixel radii. Results are indicative of the change in the percent of given age classes within the sample with distance. The statistical significance of differences between landscapes cannot be ascertained from these data due to the lack of multiple samples. A) Early seral to early seral B) Early seral to young forest C) Early seral to mature forest and D) Early seral to old forest.

Comparison of Disturbed Patch Arrangement Relative to the Stream Network

Because of the cut offs used, identified streams are likely to be 2nd order or higher. Small, 1st order streams cannot be identified at this scale. However, pixels that are far from a 2nd order stream are also more likely to be far from a 1st order stream, so that while the absolute distances used are not accurate, comparisons between different distance classes are valid in a relative sense.

All pixels in the study area are within 3000 m of an identified stream segment. Only a very small proportion are in the 2000 to 3000 m distance class, and most of these occur in the higher elevations where drainage density is very low because of the highly porous volcanic substrate. The majority of early seral pixels occur within 1000 m of the stream network and consistently decrease in area with distance from the stream.

Stratified by elevation there is a shift from most early seral pixels occurring close to identified stream segments in low elevations to increased numbers occurring farther from the stream network at high elevations where drainage densities are lower (Figure 3.22). In low elevations, the majority of disturbed pixels were within 1000 m of identified streams, and the majority of these were within 500 m. In high elevations, the majority of disturbed pixels were in the 1000 to 2000 m distance class.

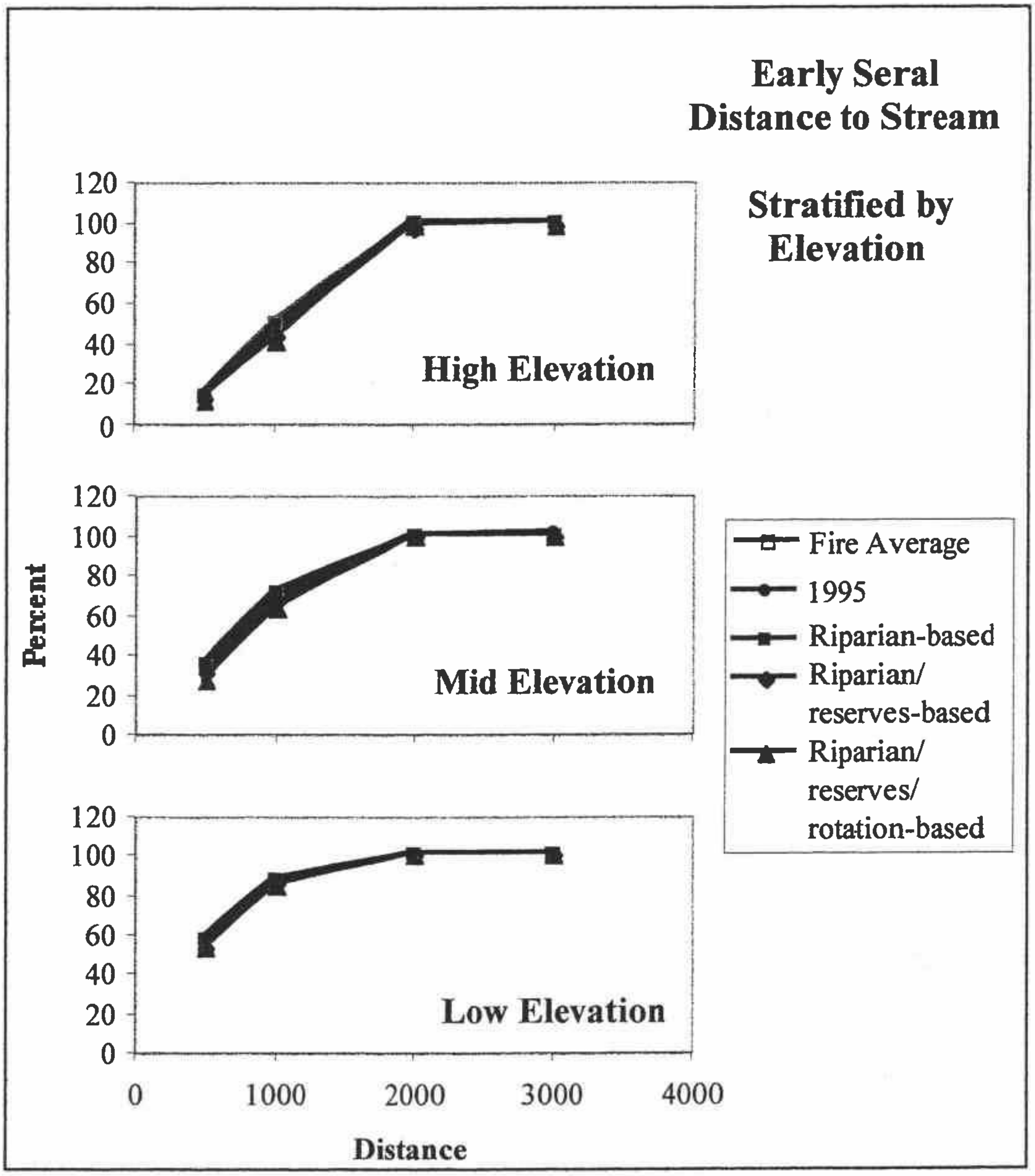


Figure 3.22. Cumulative frequency diagrams of the number of early seral pixels within five distance classes of the stream network, stratified by elevation. The distance classes used were: 0-500, 500-1000, 1000-2000 and 2000-3000 meters. The stream network was delineated, buffer zones created around the stream network at the given distance classes, and the number of early seral pixels within each buffer zone counted. Data from twenty five fire landscapes were averaged.

Comparison of Ecosystem Properties of Wildfire-affected, 1995 and Managed Landscapes

Carbon Storage

Converted Wood Boles During Disturbance

Total wood bole volume converted to other carbon-storage types on the wildfire-affected landscapes ranged from 117 to 1006 MM g, or 301 to 2567 m^3/ha (Figure 3.23). Wood conversion from the 1995 and all 3 hypothetical managed landscapes fell well within this range (Figure 3.23). The 1995 and managed landscapes are within the range of observations on the wildfire-affected landscapes for all owner/allocation types (Figure 3.23), although the wilderness lands were at the extreme low end of observations. On U.S. Forest Service non-wilderness lands, the 1995 landscape is most comparable to the empirical to frequent fire landscapes.

The data exhibit a non-linear relationship between the amount of early seral vegetation on the landscape and the total volume of wood removed from the landscape due to changes in the amount of wood removed per hectare with increasing amounts of disturbance. As high disturbance rates are maintained on a landscape, the age class of the wood removed gets progressively younger. For private industrial lands the average volume of removed wood per hectare is quite low for the 1995 and hypothetical managed landscapes compared to the wildfire-affected landscapes, because private industrial landscapes were presumed to always remove young forest.

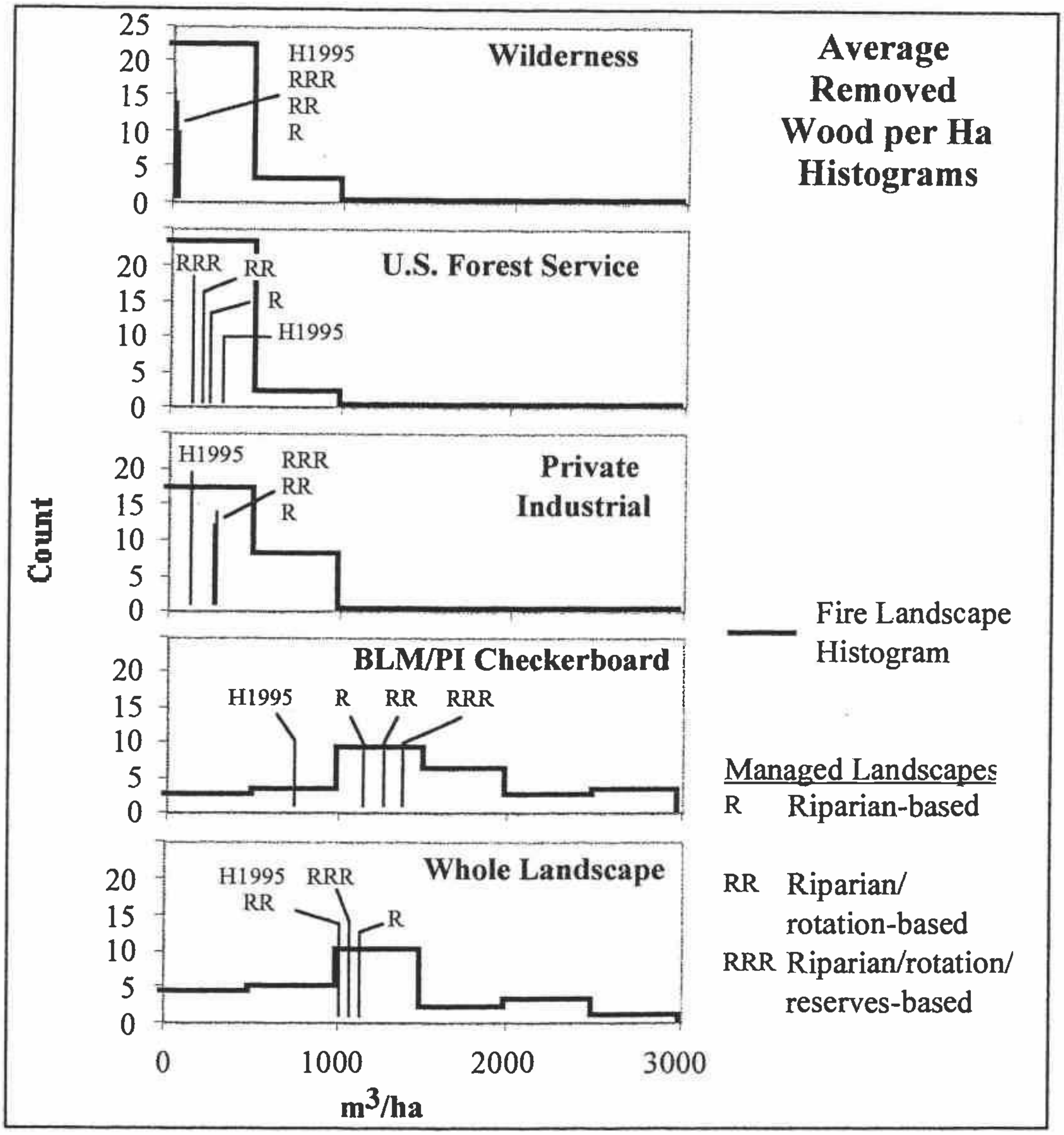


Figure 3.23. Histograms of removed wood per hectare from twenty five fire landscapes (Figures 3.1 to 3.5), compared with removed wood from the managed and 1995 landscapes. Values are estimated from the age class of the removed wood and average growth rates. Fire landscape values were based on the age class of the previous fire landscape in the simulation. Harvest landscape values were based on prescribed rotations for owner/allocation types, assuming 40 year rotations for private industrial lands and 80 year rotations for public lands. The annual growth increment was based on a map of site productivity class by Isaac (*ca.* 1945) and estimates of average growth rates for each site class, ranging from 0.7 to 15.75 m^3/ha per year (Ohmann, personal communication).

Standing Wood

Standing wood bole volume ranged from 1270 to 3140 m^3/ha for the wildfire-affected landscapes as a whole (Figure 3.24). The riparian-rule plus reserves and riparian-rule plus reserves and mixed-rotation landscapes were well within that range, with 2097 and 2144 m^3/ha carbon, respectively. The 1995 and riparian-rule managed landscapes were near the low end or outside of that range, with 1522 and 880 m^3/ha carbon, respectively. Stratified by owner/allocation type, the volume of standing wood boles on Bureau of Land Management/private industrial checkerboard and wilderness lands on the 1995 and hypothetical managed landscapes was within the ranges displayed by the wildfire-affected landscapes on those lands. Wildfire-affected landscapes on private industrial lands showed between 917 and 3249 m^3/ha standing wood bole volume. The 1995 and managed landscapes on private industrial lands showed volumes between 678 and 1007 m^3/ha, on the low end of, and lower than, the range of the wildfire-affected landscapes. The U.S. Forest Service non-wilderness lands displayed volumes from 1379 to 3174 m^3/ha. The 1995, riparian-rule plus reserves and riparian-rule plus reserves and mixed-rotation landscapes were well within that range, at 1863, 2510 and 2742 m^3/ha carbon, respectively. The riparian-rule managed landscape, with 825 m^3/ha, was well below the range shown by the wildfire-affected landscapes. On wilderness lands, the 1995 and hypothetical managed landscapes were within the range of observations from the wildfire-affected landscapes.

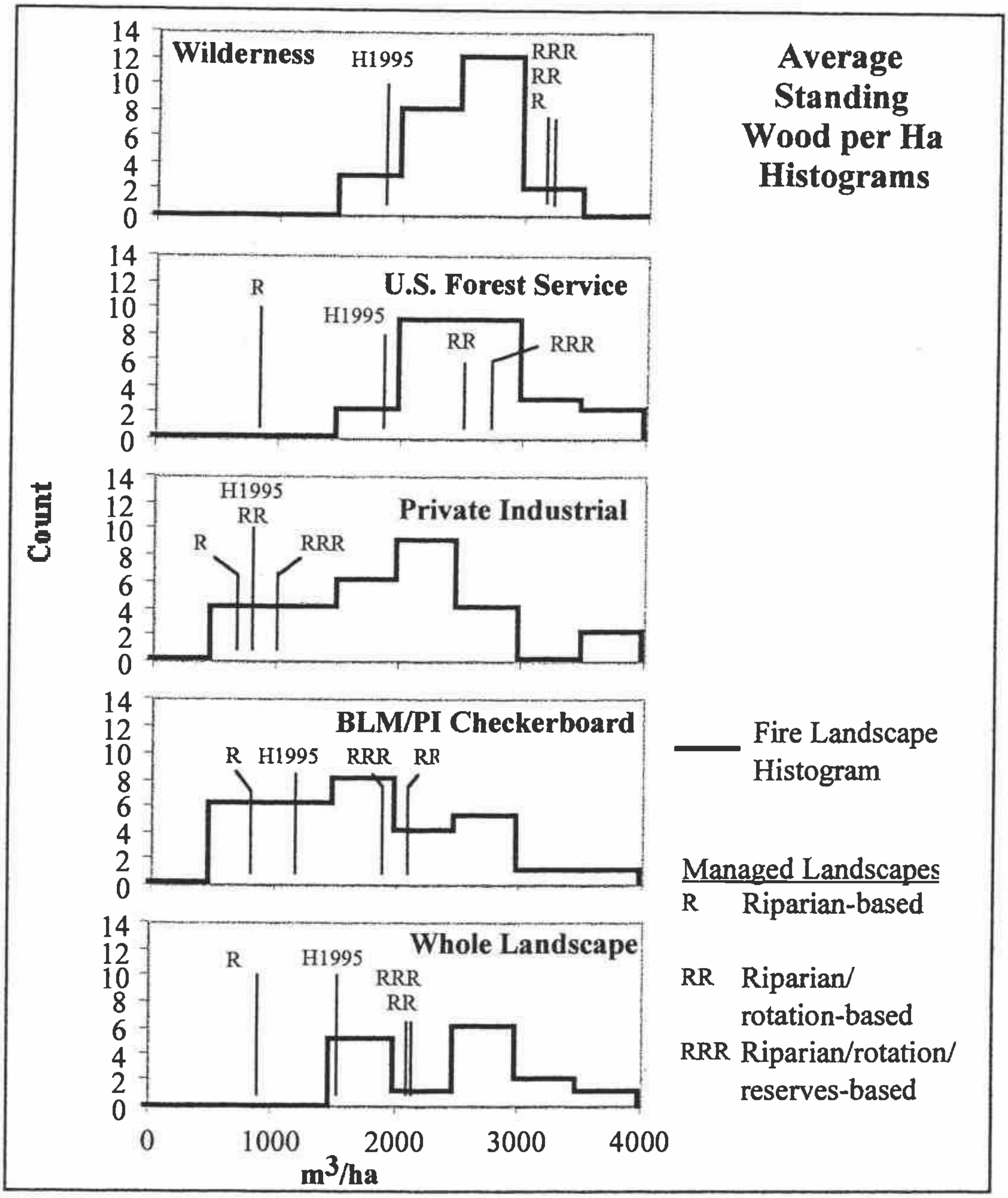


Figure 3.24. Histograms of standing wood per hectare from twenty five fire landscapes (Figures 3.1 to 3.5), compared with removed wood from the managed and 1995 landscapes. Values are estimated based on age class and average growth rates. The annual growth increment was based on a map of site productivity class by Isaac (*ca.* 1945) and estimates of average growth rates for each site class, ranging from 0.7 to 15.75 m3/ha per year (Ohmann, personal communication).

Total Ecosystem Carbon

Total ecosystem carbon (TEC), which includes below ground and detrital carbon in addition to standing wood boles, ranged from an average of 629 to 776 Mg carbon/ha from the wildfire-affected landscapes (Figure 3.25). The 1995 and managed landscapes were all within that range for the whole landscape, with the exception of the riparian-rule managed landscape, which had only 576 Mg C/ha. Stratified by owner/allocation type, the 1995 and managed landscapes were all within the range of values shown by the wildfire-affected landscapes on those lands, except for the riparian-rule managed landscape on U.S. Forest Service non-wilderness lands (Figure 3.41). However, the values on private industrial lands were on the low end, while the values on wilderness lands were on the high end of observed ranges on wildfire-affected landscapes.

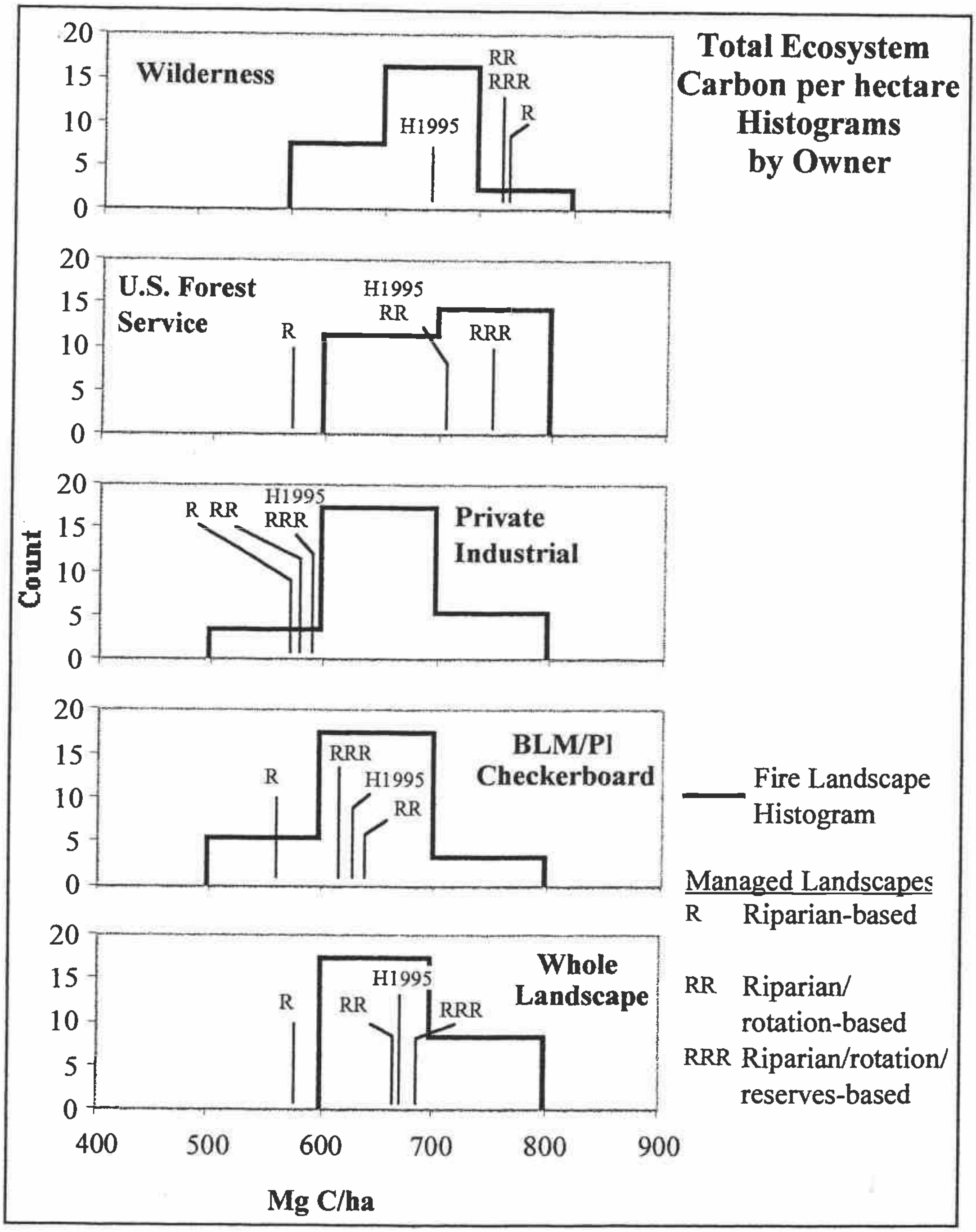


Figure 3.25. Histograms of total ecosystem carbon from twenty five fire landscapes (Figures 3.1 to 3.5), compared with total ecosystem carbon from the MANAGED and 1995 landscapes. Values are for each age class are averaged fror a secondary succession model (Harmon, 2001) combined with empirical data (Smithwick et al., in press).

Biodiversity: Potential vertebrate species richness

For the whole landscape, all four of the 1995 and hypothetical managed landscapes are within the range shown by the wildfire-affected landscapes for birds, mammals and reptiles (Figures 3.26 to 3.29). However, the riparian-rule managed landscape is at the extreme low end of observations for amphibians (Figure 3.26), and at the extreme high end of observations for reptiles (Figure 3.29). On Bureau of Land Management/private industrial checkerboard none of the four 1995 and managed landscapes was outside of the ranges shown by the wildfire-affected landscapes. On private industrial lands, the 1995 landscape was within observed ranges on wildfire-affected landscapes, but the managed landscapes were not, for all but reptile counts on the riparian-rule plus reserves and mixed-rotation managed landscape. U.S. Forest Service non-wilderness lands were outside of the observed range only for amphibian counts on the riparian-rule managed landscape. All of the potential vertebrate counts on wilderness lands were within the observed range, although amphibian counts were on the extreme high end.

Water Yield After Disturbance

Annual water yield

The wildfire-affected landscapes showed annual water yield increases ranging from 1.7 to 33.8 mm (Figure 3.30). The histogram was negatively skewed,

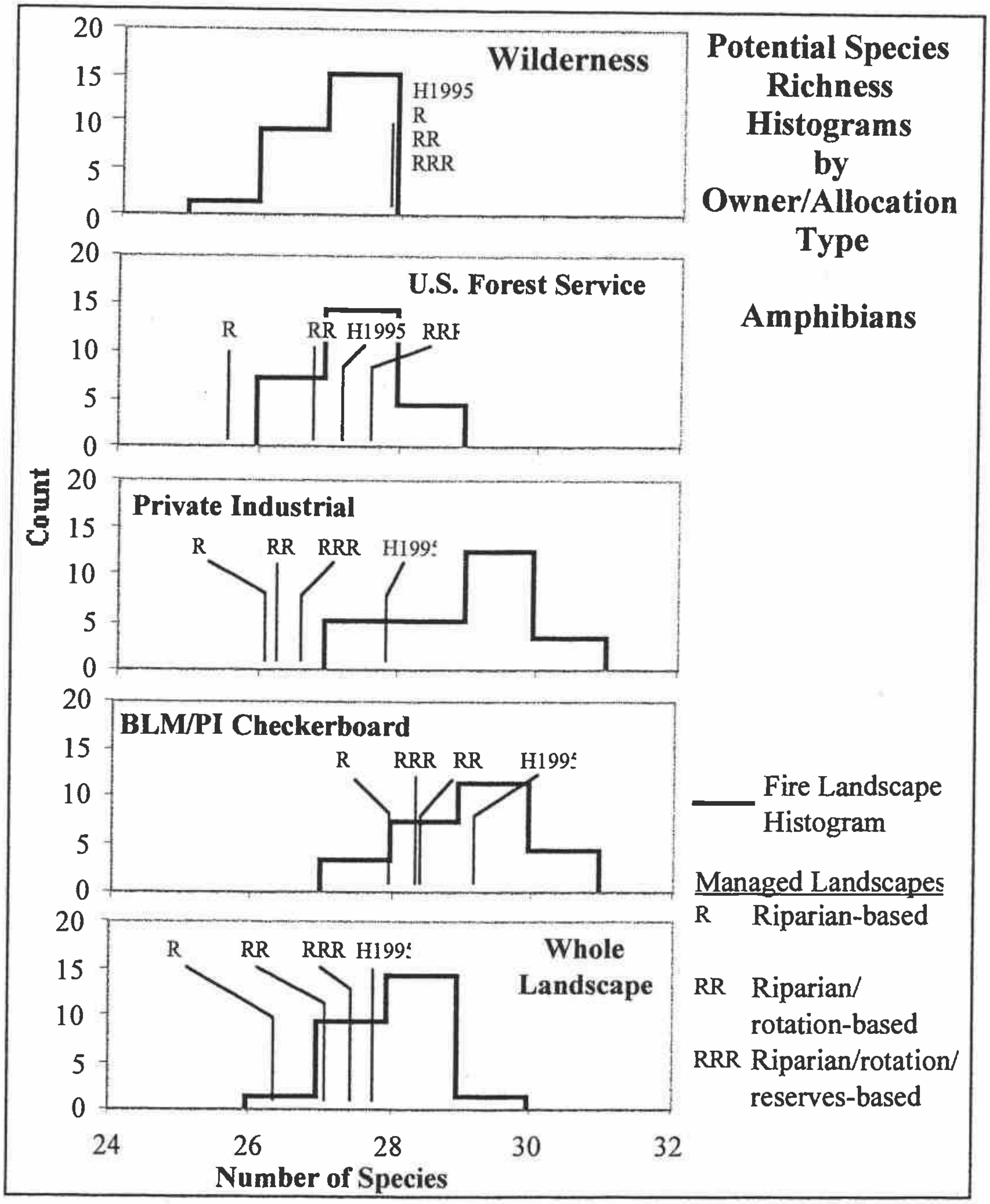


Figure 3.26. Histograms of potential species richness from twenty five fire landscapes (Figures 3.1 to 3.5), compared with potential species richness from the managed and 1995 landscapes, for amphibians. Species counts based on the age class and elevation rule set, compiled from Johnson and O'Neill (2001).

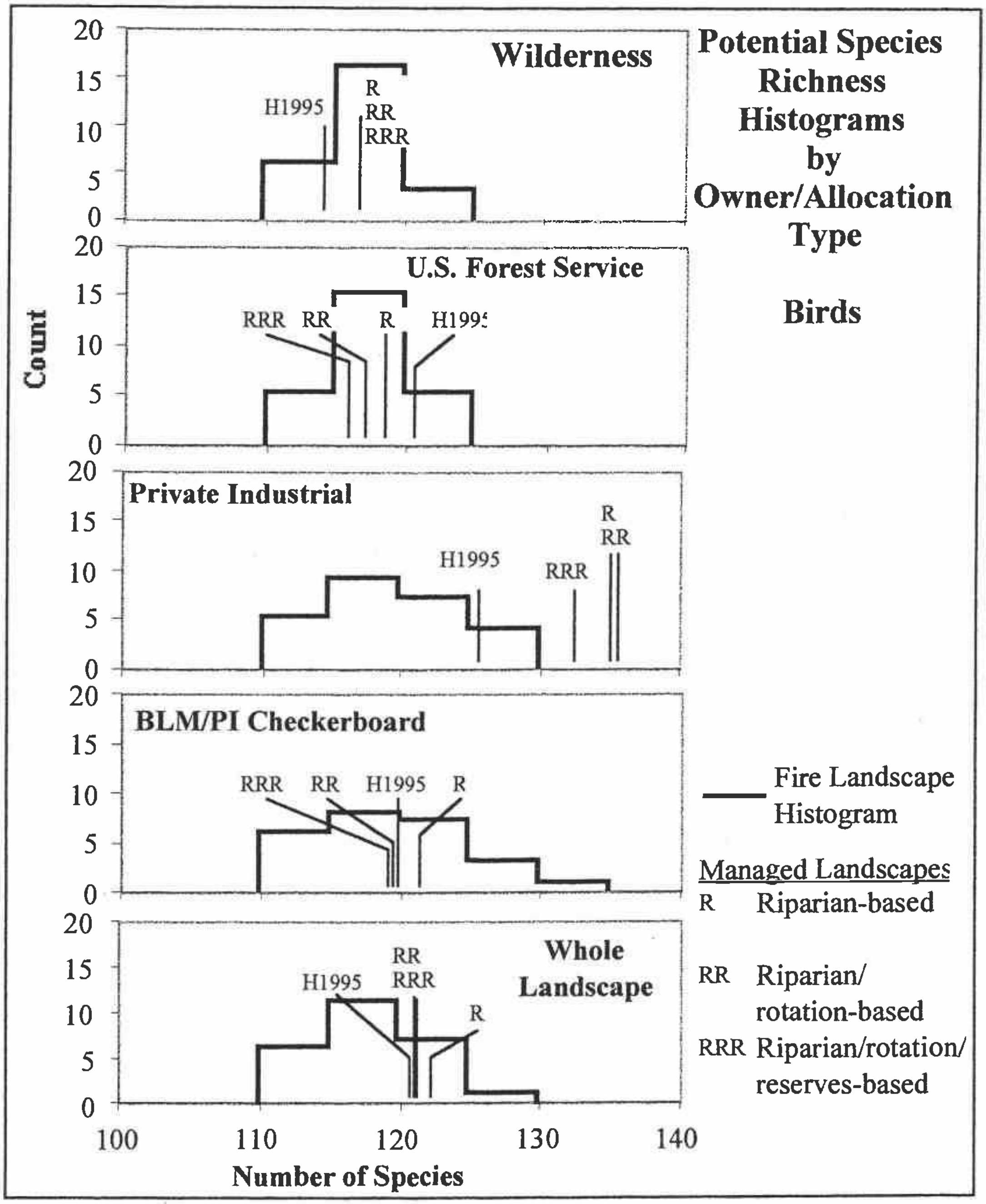


Figure 3.27. Histograms of potential species richness from twenty five fire landscapes (Figure 3.1 to 3.5), compared with potential species richness from the managed and 1995 landscapes, for birds. Species counts based on the age class and elevation rule set, compiled from Johnson and O'Neill (2001).

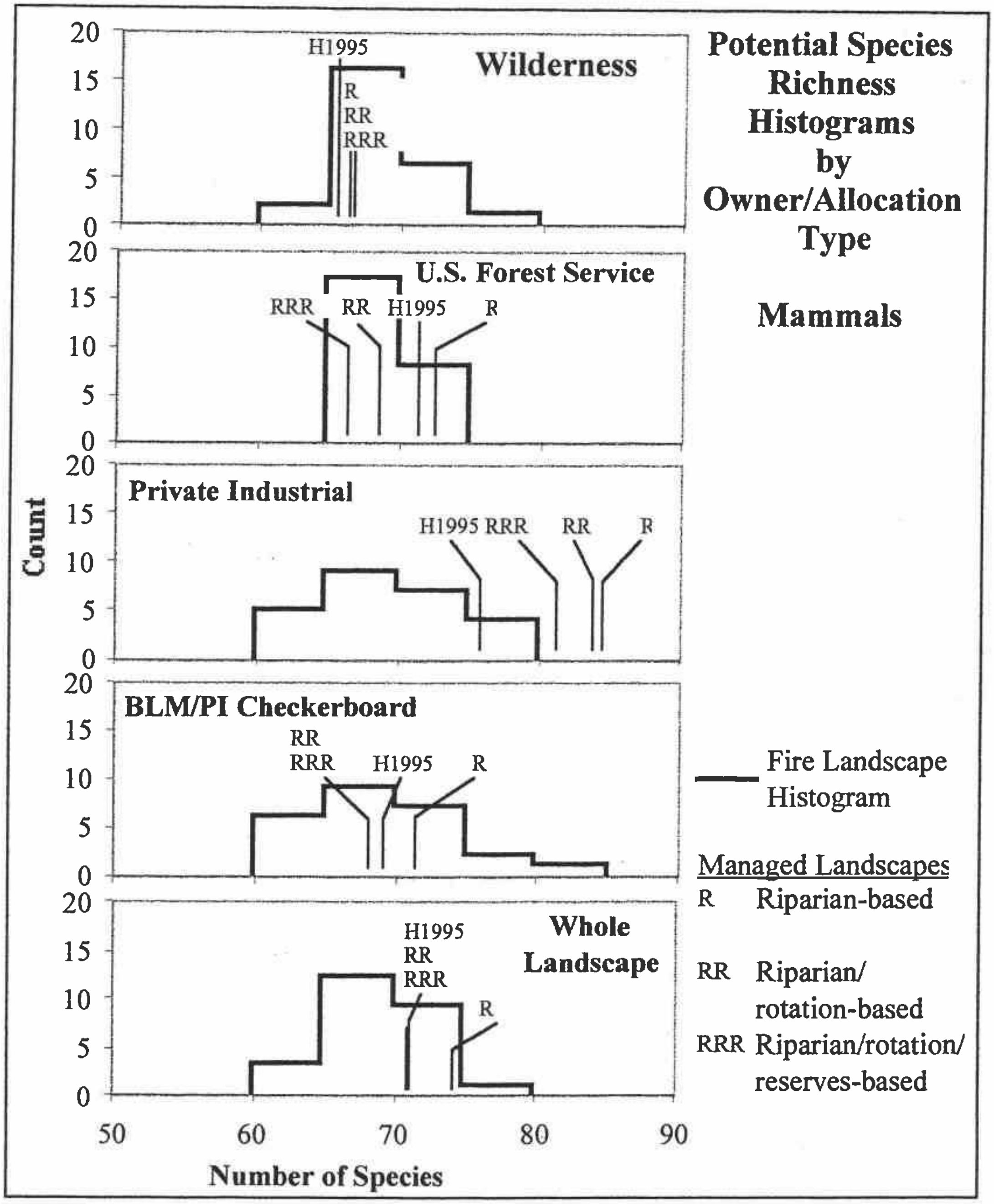


Figure 3.28. Histograms of potential species richness from twenty five fire landscapes (Figures 3.1 to 3.5), compared with potential species richness from the managed and 1995 landscapes, for mammals. Species counts based on the age class and elevation rule set, compiled from Johnson and O'Neill (2001).

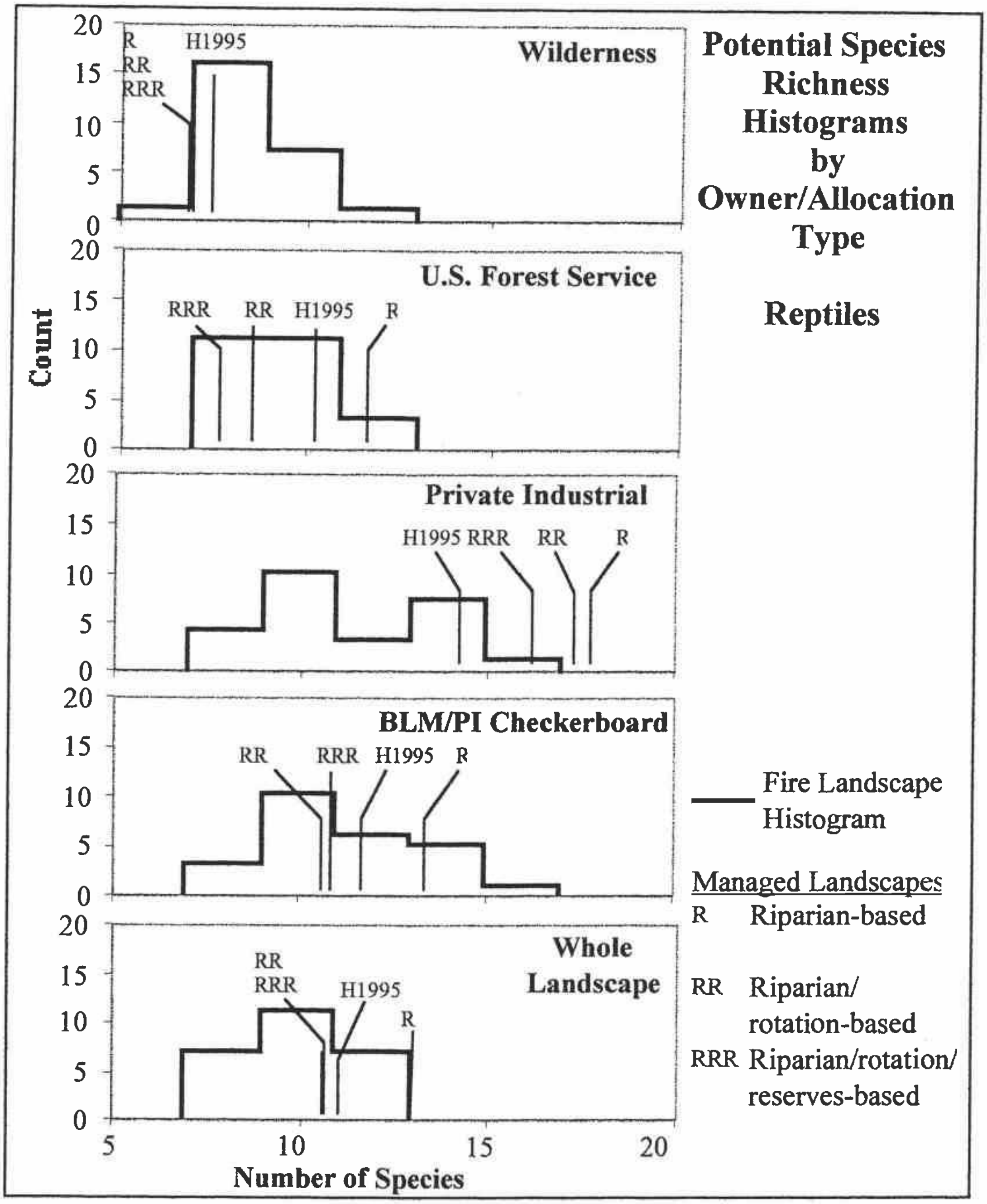


Figure 3.29. Histograms of potential species richness from twenty five fire landscapes (Figures 3.1 to 3.5), compared with potential species richness from the managed and 1995 landscapes, for reptiles. Species counts based on the age class and elevation rule set, compiled from Johnson and O'Neill (2001).

with most landscapes exhibiting increases less than 15 mm. The 1995, riparian-rule plus reserves and riparian-rule plus reserves and mixed-rotation landscapes displayed increases of 26.8 mm, 21.6 mm and 25.8 mm, respectively, within the range of the wildfire-affected landscapes but on the high end. The riparian-rule managed landscape was higher than the range of values exhibited by the wildfire-affected landscapes, with 37.0 mm.

By owner/allocation type, the observed range on the wildfire-affected landscapes was slightly higher, just over 40 mm on private industrial lands. These graphs indicate that the 1995 landscape was within the range of the wildfire-affected landscapes for all owner/allocation types. The riparian-rule managed landscape was outside of the observed historic range for the U.S. Forest Service non-wilderness owner/allocation type, while both the riparian-rule and riparian-rule plus reserves and mixed-rotation based landscapes exceeded that range on private industrial lands.

Summer water yield

The wildfire-affected landscapes displayed a range of summer water yield change from 91.5 to 99.6 percent of pre-disturbance yield, for the third rule set (Figure 3.31). For the whole landscape, all four of the 1995 and hypothetical managed landscapes were well within that range. More variation was observed among the owner/allocation types. The broadest range of values was found on wilderness lands, showing from 88.5 to 102.4 percent of original yield. By owner/allocation type, the 1995 and managed landscapes were all within the range observed on the wildfire-affected landscape, with the exception of the 1995 landscape on U.S. Forest Service lands, which was higher than the observed range.

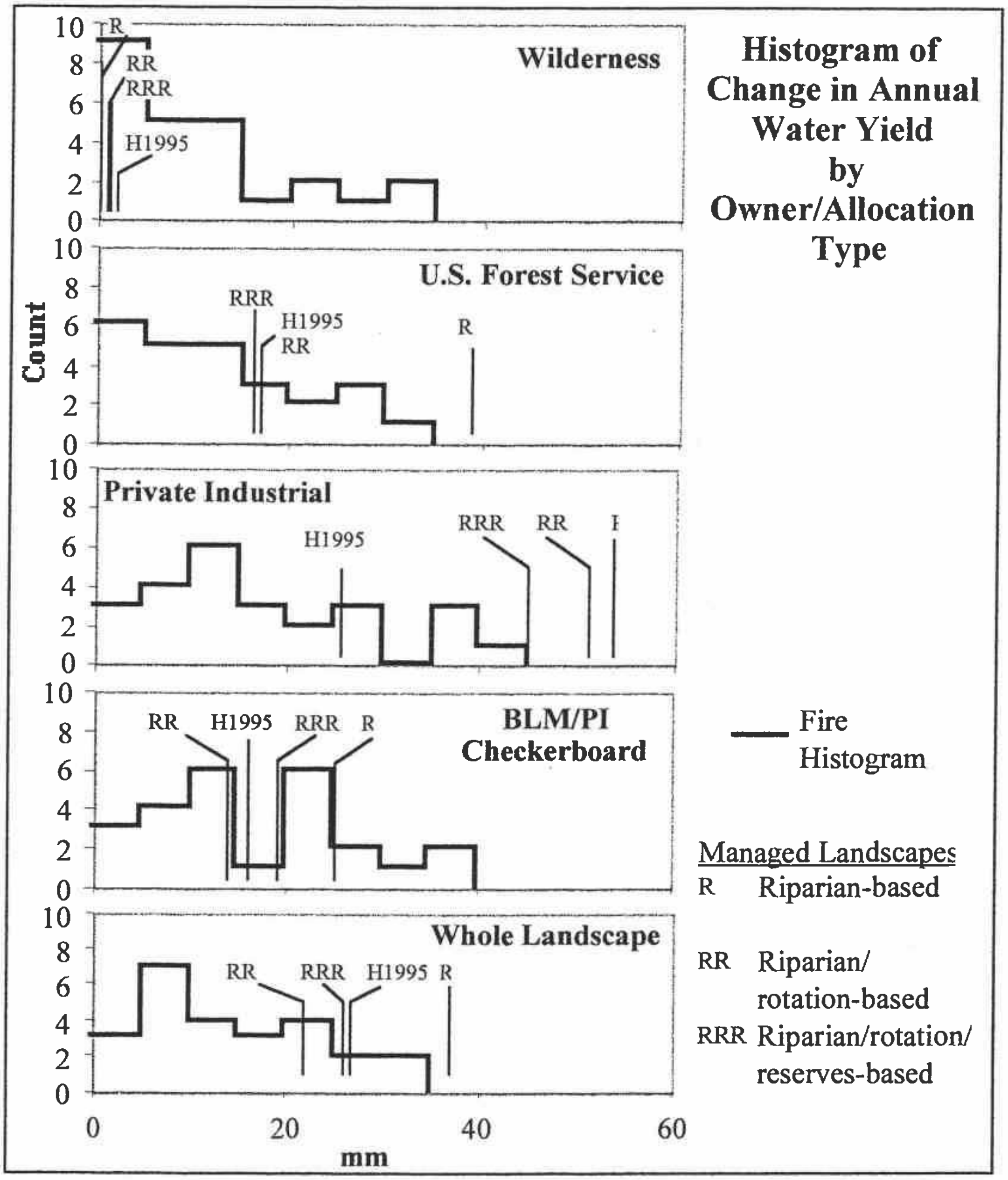


Figure 3.30. Histogram of average change in annual water yield after disturbance from twenty five fire landscapes (Figures 3.1 to 3.5) compared with average change from the managed and 1995 landscapes, by owner/allocation type. Values were calculated based on parameters estimated from Jones (unpublished data). Average change in yield was constrained by the distance of the disturbance from the nearest stream, where disturbance more than 1000 m from the stream network was assumed to have no effect on stream flow.

Summer water yield response is strongly correlated with the amount of disturbance, when only age class types and amounts are considered. As more complex spatial interactions are incorporated, that correlation is much less pronounced. In the first rule set, using parameters from a mixed elevation watershed, average summer water yield increased linearly from 100 percent in the all-old, undisturbed landscape to 105 percent in the 40-year rotation single-pattern landscape with 76 percent disturbance. Incorporating elevation trends by using parameters from the low and high elevation watersheds showed little effect on the maximum increase in summer yield (104 percent), but resulted in a wide dispersion of data, including many landscapes that exhibited a net decrease in summer water yield. The lowest value was 96.0 percent for one of the infrequent fire landscapes. All of the single pattern landscapes showed a net increase in summer water yield, while most of the wildfire-affected landscapes showed net decreases. Additionally, for wildfire-affected landscapes of a given fire frequency simulation, increasing disturbance had a tendency to result in decreasing water yield, resulting in a negatively sloped trend within data from each given fire simulation. When distance from the stream was incorporated every landscape, including the single pattern landscapes, resulted in a decrease in water yield, as low as 91.5 percent in a very infrequent fire landscape. The within-simulation trend of decreasing yield with increasing disturbance is more pronounced.

The owner/allocation stratifications indicate that when the mixed elevation value was applied, all owner/allocation types showed increases in summer water yield. When the high and low elevation parameters were applied, the higher elevation wilderness and U.S. Forest Service lands showed increases while the lower elevation private industrial and Bureau of Land Management/private industrial checkerboard lands showed decreases in summer water yield, as low as 90 percent on private industrial lands. When distance from the stream assessment was incorporated, all owner types showed lower summer water yields relative to the second rule set. In the case of the wilderness allocation type, most landscapes hovered around 100 percent, with a low of 95 percent in one landscape, and with most between 97 and 103 percent. While the majority of U.S. Forest Service lands also were between 97 and 103 percent, there were more landscapes with low yields; three below 95 percent. Private industrial and Bureau of Land Management/private industrial checkerboard lands all displayed summer water yields between 91 and 98 percent. As in the case of the whole landscape, owner/allocation types also display a trend from a fairly linear relationship when the mixed elevation data were used, to higher dispersion in the other two cases, and display within-fire simulation trends of decreasing summer water yield with increasing disturbance.

The hypothetical managed landscapes are very comparable to the wildfire-affected landscapes as a whole, except for the riparian-rule managed landscape, which is again most similar to the single pattern landscape trend. When only elevation is taken into account, the riparian-rule plus reserves and mixed-rotation managed landscape shows a slight decrease in water yield (98 percent), riparian-rule plus reserves based landscape shows no change, and the 1995 landscape shows a slight increase (Figure 3.64). When distance from the stream is incorporated, all three landscapes show slight decreases in summer water yield, between 97 and 99 percent. When these landscapes are compared on U.S Forest Service lands, all of the landscapes show increases in summer water yield, with the highest increase in the 1995 landscape (103 percent). The other three landscapes display a trend from 101+ percent in the riparian-rule, to 101- percent in the riparian-rule plus reserves, to nearly 100 percent in the riparian-rule plus reserves and mixed-rotation landscapes.

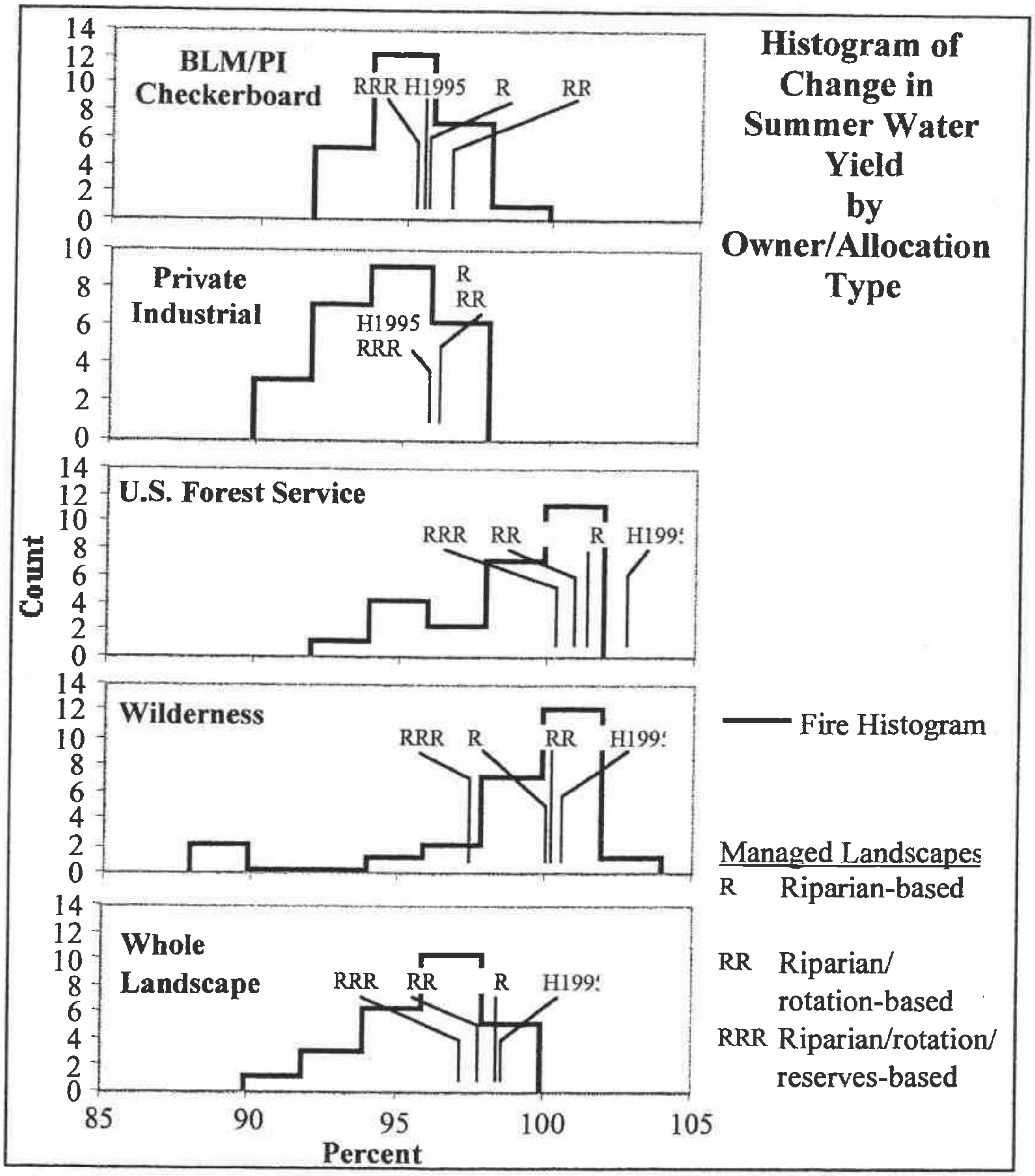


Figure 3.31. Histogram of average change in summer water yield after disturbanc as a percent of pre-disturbance values, from twenty five fire landscapes (Figures 3.1to 3.5) compared with the average change from the managed and 1995 landscapes, by owner/allocation type. Values were calculated based on parameters estimated from Jones (unpublished data). Average change in yield wa constrained by the distance of the disturbance from the nearest stream, where disturbance more than 500 m from the stream network was assumed to have no effect on stream flow.

Chapter 4 Discussion

Age Class Assignments

A number of sources of error contribute to uncertainty in assignment of pixels to age classes. The most reliable data are from the disturbance map, since it makes the least number of assumptions in the analysis, deals with relatively recent disturbance data (1972 to 1995), and has a relatively short temporal resolution (4 to 6 years). Unfortunately, longer-term data do not exist at the same temporal resolution as the disturbance map. Conifer age yields disturbance information back more than 800 years b.p., but because of the large, 102 year standard error these data have coarse temporal resolution. The vegetation class map does not explicitly yield pixel age; it must be inferred using assumptions from vegetation successional theory. The wildfire history studies have a temporal resolution of approximately 25 years (Weisberg and Swanson, 2001), but cover only a small fraction of the western Cascades study area (Weisberg and Swanson, in press). Wildfire-affected landscapes can be simulated at any resolution desired, but the results are only as reliable as the input parameters and the assumptions of the model.

Further complicating age class assignments are semantic problems. The theoretical successional path in this area is open, semi-open, broadleaf, mixed broadleaf/conifer, to conifer (Franklin and Hemstrom, 1981). One specific problem that surfaced in the age class analysis was discrepancies in the usage of "semi-open" as a structural class, and the implied age class. As used in the theoretical successional path, the semi-open class implies a successional stage between the open stage and young forest, typically 20 to 30 years after disturbance (Franklin et al., 2002). In this case, it could be placed into its own age class. However, a semi-open state can also exist due to thinning of the forest, whether by fire or by harvest, in which case it may consist of an overstory that is of any age, and an understory reflecting recent disturbance. This is the usage of the LADS fire model, for which open and semi-open age classes represent the same period of time, immediately post-disturbance, and differ only in the severity of disturbance. Both of these usages are restricted to consideration of a single stand. In remotely sensed data, where individual pixels may consist of a combination of open and forested conditions for multiple stands, the semi-open term can be even more ambiguous. A semi-open pixel may represent either of the above two conditions, or, it may capture more than one stand, one of which is open and has recently been disturbed and the other(s) not. The only inference that may be made from a semi-open classification from remotely sensed imagery is that a portion of the pixel has been recently disturbed, and the disturbed portion could be anywhere from 0 to roughly 30 years old. For these reasons, this study did not attempt to distinguish between the age of open and semi-open vegetation classes, but, rather, lumped them into an early seral age class.

Another age class concern becomes obvious when one considers the successional pathway of semi-open pixels that have resulted from forest thinning. A semi-open pixel implies something about the age of the disturbed portion of the pixel; it implies nothing about the age of the undisturbed portion. As the disturbed portion ages into closed canopy forest, if the disturbed portion predominates, it is then classed as young forest with an older overstory. If the overstory is a significant portion of the area, typically it is then classed according to the age of the oldest trees, rather than the age of the disturbed portion. Therefore, a given area may proceed from the semi-open class into the mature or old forest classes, skipping intervening classes. These multiple usages of the semi-open term are the source of much confusion and better terminology is needed to more accurately convey what is known about canopy age and structure.

Age class problems also exist with the mixed broadleaf/conifer class used in the remotely sensed imagery. According to common usage in the Pacific Northwest, this implies a stand age of 20 to 40 years, as the stand is transitioning to pure conifer forest. However, the large percentage of mixed broadleaf/conifer pixels in the wilderness (approximately 20 percent), which has not been disturbed to any large degree in a century, would argue that this is not an appropriate inference. It is probable that a mixture of broadleaf conditions occurs naturally along with conifers of a range of ages (Heinselman, 1981; Holling, 1995). Since age class could not be assigned for these mixed stands, a number of pixels were left unassigned.

The inability to incorporate semi-open and mixed pixels probably altered the results of some of the analyses. Almost certainly the mixture of structural types present in most forests (including gaps of various sizes) has an enormous impact on species richness. Where possible, these characteristics were incorporated. While the semi-open class of the fire model was not reported as a separate age class, that information was retained from the simulations and incorporated into the carbon, biodiversity, water calculations by assuming a 50 percent mix and interpolating early seral and forest values.

The decision to model a few, relatively broad, irregularly spaced age classes (0-30, 31-80, 81-200, >200 years) rather than a larger number of evenly spaced bins was based on two factors. First, while high resolution data can be coarsened, it is not possible to improve the resolution of coarse data. Therefore, while the post-1972 disturbance data could be placed into narrow bins, older vegetation on the 1995 landscape could not. To accurately compare wildfire and harvest landscapes at the 25 year resolution of the fire history studies, long term, high temporal resolution data are needed. Reducing the standard error of conifer age estimates through improved techniques would resolve this problem in part.

Second, the broad age classes are in common usage, are linked with structural conditions that have ecological significance and could be linked with a variety of empirical studies (Franklin et al., 2002). For example, the vertebrate species plant associations used in the response analysis are described based on forest structural changes rather than age. Since major structural changes that occur at approximately 30, 80 and 200 years (Franklin et al., in press), a linkage between vertebrate structural associations and the age classes used in this analysis could be made. Finer resolution of ages would not have enabled a more precise linkage.

However, while the selected age classes lessened problems in some respects, they incorporated new problems in others. Comparisons of unequally sized age bins inhibit the analysis of probability distributions of ages. It masks potentially interesting temporal patterns by adding a length-of-bin effect. This study attempted to capture both age class and structurally-related patterns, neither of which is adequately defined, and attempted to link them to properties that also are only defined in limited spatial and temporal circumstances. For instance, water yield studies describe the summed response of entire small (10-100 ha) watersheds over less than 20 years post-harvest, but the goal of the study was to assign that effect in a spatially-explicit manner over 500+ years of forest growth. This mismatch between spatial and temporal scales, both in resolution and extent, created a difficult study scenario and limited the conclusions that could be drawn.

As with any scientific study, the scale of the question should match the scale of the data provided to answer that question. The broad scale goals of simulating wildfire landscapes and comparing patterns of wildfire and harvest landscapes had clear precedent prior to the study; the goal of quantifying the effect of those broad scale patterns on ecosystem properties did not have clear precedent. The empirical data available to try to quantify the effect of pattern on ecosystem properties are fine scale, in space, time, extent and/or resolution. Therefore, there was a mismatch between the scale of the output of the first part of the study and the data available for the last part of the study. Additionally, there was a mismatch between data types. The landscape representations used age classes. Many, if not most, empirical studies use forest structural information rather than age. A study in which forest structural classes are delineated, rather than age classes, might be more appropriate for an analysis of the effects of forest pattern on ecosystem properties.

Comparison of the Empirical Fire Data with Modeled Parameters

Five of the seven fire history field studies (Figure 2.2) are located along an east-west transect through the central portion of the study area, and two are located at the extreme ends of the study area. Although considerable variability occurs, two trends may be observed: decreasing fire frequency from low elevation to high elevation, and decreasing fire frequency from south to north. These trends are consistent with relatively cooler, moister climates at high elevations and more northerly locations. Consistent with theory, decreasing fire frequency in the empirical data is correlated with increasing fire size and severity.

The Bull Run study at the far north end of the study area exemplifies this trend (Agee and Krusemark, 2001), with a single, large, stand-replacing fire that occurred approximately 350 years ago, and which burned the entire study area (26,000 ha). No subsequent fires of such extent have occurred. Therefore, the natural fire rotation for that area has a lower limit of 350 years, and the upper limit is unknown, with a fire size that probably exceeds 26,000 ha. The results most similar to Bull Run in the study area have been found along the Cascade crest (Kertis, 2001), where unpublished data indicate somewhat more frequent fire than Bull Run (200-300 years), but with mostly stand-replacing fires. High severity burning in upper elevation stands results in part from the high-susceptibility of thin-barked true fir trees. To the north, a natural fire rotation of 465 years was calculated for the Mount Rainier area (Hemstrom and Franklin, 1982). The upper limit of fire frequency used in the north regime for the very infrequent fire simulation was 1000 years, with a lower limit for the frequent fire simulation of 100 years. This is a broad range, but since no additional studies offer supporting/conflicting evidence, these values seem reasonable for brackets of hypothetical variability in the north regime.

The range of fire frequency at the other extreme, for warmer and drier spatial locations, was more difficult to delineate. Two studies seem to reflect these conditions: Coburg Hills and Little River (Figure 2.2). Coburg Hill represents the lowest elevation site, in the Cascade foothills (Weisberg, 1997b). It displays the highest fire frequency characteristics, 54 years, and relatively small, low severity fires, consistent with expectations. However, at the far south end of the study area at an approximately comparable elevation, the Little River study reported mixed results (Van Norman, 1998). Fires were much less frequent (136 years) than reported at Coburg Hills and comparable to those found at higher elevation study sites, but fires were very small, and for the most part, could not be correlated between sample sites. The small fire size is consistent with expectations for a site at this southerly location, but the less frequent fire is not.

One possible explanation is the Little River area may have consisted predominantly of low severity surface fires that leave scant evidence and hence are not incorporated into the natural fire rotation calculation. For sites that consist primarily of moderate to high severity burns, calculated rotations are not greatly affected by the exclusion of low severity fires. The higher the percentage of surface burns typical of an area, the more the results may err in the direction of longer fire rotations. Because of the discrepancy between the reported fire frequency and other fire characteristics at the Little River site, it was placed at the boundary between the west and middle fire regimes, but that boundary was modified slightly to suggest a trend towards warmer and drier conditions.

In the central portion of the study area, three studies reported mixed fire regime characteristics, including a range from low severity to stand-replacing events. A range of fire frequencies were reported (78 to 250 years), that also show spatial and temporal variability with each study area. The variability observed in the central portion of the study area may also be typical elsewhere; the lack of multiple studies in other parts of the study area precludes any assessment of local fire regime variability in those areas. However, it is possible that the observed variability in the central portion of the study area may be due to the high topographic variability in the central Cascades, which are much more steeply dissected than either the high or low elevations, and may interact more strongly with changing fire patterns. If high fire variability is associated with topographic variability in the western Cascades, one would expect fire characteristics to be less variable at high and low elevations than in the middle elevations. This hypothesis could only be tested with additional wildfire history studies. Strong topographic association of fire characteristics, while not unique to wildfire in the Cascades, is not necessarily observed in every mountain wildfire system (Baker and Kipfmueller, 2001), and was not observed in the single fire history study conducted in the highly dissected, but lower relief Coast Range to the west (Impara, 1997).

The range of simulated parameters, for the most part, is likely to encompass the full range that might potentially have occurred over the past few millennia. Although it is possible that the range of simulated parameters is broader than actually existed in the past, it is unlikely that the range is too narrow. It is possible that under the warmest conditions, lower elevation areas could have small, moderate severity fires every 10 years, and that at the highest elevations, in cold climates, stand-replacing fires could occur every 1000 years. However, it is not realistic to assume that those conditions would have been maintained for the lengths of time that were simulated. In any event climate varied at multiple scales, such as ENSO and the intercentury scale identified by Weisberg and Swanson (in press), and fire may have tracked this variability to varying degrees. These transient effects were not incorporated into any of the simulations. Climate appears to undergo major fluctuations in 70 year cycles in this area (Greenland, 1994), therefore extremely cool conditions are likely to be maintained for only a few decades, too short an interval to allow most of the early seral and young forest to age into mature and old forest. And in the case of warm climates, fuels would have rapidly been consumed, possibly lowering the fire frequency. Therefore, while a few decades of warm weather may be adequate to allow extensive burning of the lower elevations, the subsequent lack of fuel would force a reduction in fire frequency. Weisberg and Swanson (in press) believed that a regional transition to less frequent fire around 1650 A.D. preceded the transition to cooler climate, possibly due to fire inhibition by fuel consumption. Therefore, both internal (fuel consumption) and external (fluctuating climate) processes limit the length of time the landscape might remain in a high frequency fire regime. The interaction with fuel consumption at high fire frequencies is not simulated with the LADS model, which does not operate at the scale necessary to track fuels.

The effect of these issues on the wildfire simulation results is that the sustained conditions needed to achieve some of the more extreme wildfire-affected landscapes are not likely to have occurred. Landscapes with little or no early seral vegetation and young forest, as modeled with the very infrequent fire simulation, are unlikely due to climate fluctuation. Landscape with very high amounts of early seral vegetation, as modeled with the frequent fire simulations, may have occurred on occasion, but the concomitant reduction in fuels would mandate that they were immediately followed by a longer period of little fire, allowing the forest landscape to age. Therefore, the effect of the modeled parameters on the simulated landscapes is broader than likely in reality. This implies that the modeled range of wildfire-affected landscapes may represent possible extremes, but the tails of the distribution probably occurred very infrequently, if at all. They represent the most liberal view possible of the extremes that natural wildfire disturbance may have produced on the landscape.

Comparison Between Landscapes

Simulated wildfire disturbance for the past 500 years produced landscapes with mean area of early seral vegetation of approximately 20 percent, young forest of 21 percent, mature forest of 17 percent and old forest of 42 percent. Using fire size characteristics inferred from empirical studies produced low variability in the extent of each age class in the empirically-based simulation: 5th and 95th percentile ranges were 14 to 25 percent for early seral vegetation, 16 to 28 percent for young forest, 11 to 25 percent for mature forest, and 34 to 52 percent for old forest. Mean patch sizes were 876 ha, 227 ha, 164 ha and 121 ha, for early seral, young, mature and old forest, respectively.

Simulated fire frequency variability over the past few millennia produced a much broader range of landscape characteristics than observed in the past 500 years. Considering all the fire frequency scenarios, the study area may have had from 10 to 37 percent early seral vegetation, 13 to 26 percent young forest, 12 to 17 percent mature forest and 25 to 60 percent old forest, depending on climate. 5th and 95th percentile ranges were 4 to 45 percent for early seral vegetation, 4 to 34 percent for young forest, 4 to 38 percent for mature forest and 19 to 76 percent for old forest. Mean patch size in the simulation ranged from 1051 to 1427 ha for early seral vegetation, 110 to 593 ha for young forest, 62 to 628 ha for mature forest and 71 to 328 ha for old forest, larger than reported in the wildfire history studies for the area (Teensma, 1987; Morrison and Swanson, 1990; Van Norman, 1998; Weisberg,1998; Agee and Krusemark, 2001) which covered study sites with area less than potential fires.

The 1995 landscape is outside the range of variability of simulated wildfire-affected landscapes from the past 500 years, with 29 percent early seral vegetation, 16 percent young forest, 29 percent mature forest and 26 percent old forest. It has roughly 4 percent more early seral and mature forest than the 95th percentile amounts found in the wildfire-affected landscapes, young forest that is equal to the

5th percentile on the wildfire-affected landscapes, and old forest that is 8 percent lower than the 5th percentile on the wildfire-affected landscapes. If fire sizes were larger on average for the past 500 years than the parameters used for the simulation, variability would increase, and the 1995 landscape would probably be in the range of past landscape variability shown by the 5th and 95th percentile landscapes. Therefore, the 1995 landscape may be equivalent to landscapes that occurred very rarely in the past 500 years, in terms of age class amounts. Patch sizes in the 1995 landscape are smaller than those from the wildfire simulations, particularly for the younger age classes, averaging 27 ha for early seral vegetation, 109 ha for young forest, 107 ha for mature forest and 96 ha for old forest. If fire sizes were increased in the simulation, patch sizes would increase as well, and this discrepancy would be larger. The 1995 landscape is within the range of mean age class amounts shown by longer-term wildfire-affected landscapes for early seral vegetation, young forest and old forest, and well within the 5th and 95th percentile range. Mature forest on the 1995 landscape is roughly 15 percent higher than the range of mean amounts, but is within the 95th percentile range. Patch sizes on the 1995 landscape, particularly for the younger age classes, are very much smaller than the range of average patch sizes that likely occurred over the past few millennia. Therefore, in terms of age class amounts, the 1995 landscape is within the range of variability that is likely to have occurred over the past few millennia, but patch sizes are much smaller than was probably typical of the past.

Wildfire-affected landscapes show a gradient of decreasing frequency of disturbance with elevation. That trend is also shown by the 1995 landscape, due to the correlation between owner/allocation type and elevation. Increased disturbance occurs in response to short-rotation forest cutting on private industrial lands at low elevations, decreased disturbance occurs in response to fire suppression in wilderness areas at high elevations, and intermediate disturbance occurs in U.S. Forest Service non-wilderness lands in intermediate elevations. Harvest disturbance in different owner/allocation types are compared with wildfire disturbance in those same areas. Because disturbance varies spatially in both wildfire-affected and the 1995 landscapes, structural differences should be assessed at the smaller scale of owner/allocation types, which correspond with different climate zones across the W-E environmental gradient.

Low elevation private industrial lands on the 1995 landscape are outside of the simulated range of variability for wildfire-affected landscapes of the equivalent low elevation area for the past 500 years, and at the extreme ends of the range of variability observed for the longer term, particularly for early seral vegetation and old forest. Early seral vegetation in private industrial lands comprise 50 percent of the 1995 landscape, compared with 14 to 28 percent (mean 21 percent) over the past 500 years for 25 representative wildfire-affected landscapes that include the 5th and 95th percentiles from the whole-landscape full simulations. For the past few millennia, early seral vegetation in private industrial lands may have ranged from 3 to 58 percent. Early seral vegetation amounts equal to or exceeding the amount observed in the 1995 landscape occurred on only 2 of the 25 wildfire-affected landscapes, and both of those were 95th percentile landscapes from the full simulation. The five selected landscapes from the frequent fire simulation showed a range of early seral vegetation from 38 to 58 percent. Therefore, the amounts of early seral vegetation observed in the 1995 landscape in private industrial lands are outside of the range of the past 500 years, and at the extreme high end of the range for the past few millennia, and would have only occurred during periods of relatively high fire frequency that were not likely to have been maintained for more than a few decades.

Only 6 percent of private industrial lands in the 1995 landscape were old forest, based on remote sensing analysis, well below the range exhibited in these lands by the 25 selected wildfire-affected landscapes for the past 500 years (27 to 51 percent) and also below the range for the longer term (10 to 75 percent). Given known registration and classification errors, the actual percentage of old forest on private lands is probably less. Thus, private industrial forest lands in the study area apparently had less old forest in 1995 than at any time in the past few millennia.

On private industrial lands harvests using 40-year rotations could lead to landscapes with even more early seral vegetation (58 to 68 percent) than was present in 1995. Consistent application of riparian buffers required by state law, and recommended by federal policy, would increase the amount of old forest to between 9 and 16 percent, an amount that is at the extreme low end of the wildfire simulated range for the past few millennia.

Wilderness lands currently consist of 3 percent early seral vegetation, 9 percent young forest, 49 percent mature forest and 39 percent old forest. These amounts are outside of the estimated range for the past 500 years on wilderness lands (from 25 wildfire-affected landscapes) for early seral (8 to 16 percent), young (12 to 25 percent) and mature (12 to 30 percent) forest, and at the low end of the range for old forest (38 to 64 percent). They are inside the range exhibited for the past few millennia for early seral (1 to 34 percent), young (3 to 32 percent), and old (27 to 91 percent) forest, but outside of the range for mature forest (1 to 25 percent). In some cases it appears that wilderness lands were designated along boundaries that excluded old forest, presumably leaving it available for future cutting, and that included mature forest established after wildfire in the 1800s and early 1900s.

Much of the high amount of mature forest is a legacy from extensive wildfires in the late19 th and early 20th centuries, roughly 80 to 140 years old. Some of these fires may have been ignited by early European travelers and sheepherders (Burke 1979). Within a century, that group will age into the old forest category. At that time, assuming continued suppression of disturbance, the wilderness landscape would consist almost exclusively of old forest, outside of the wildfire simulated range for all age classes in both the past 500 years and past few millennia.

U.S. Forest Service non-wilderness lands in the 1995 landscape were comprised of 23 percent early seral vegetation, 9 percent young forest, 31 percent mature forest and 37 percent old forest. These amounts are within the range of variability from the past 500 years for early seral vegetation (8 to 26 percent) and old forest (35 to 55 percent), but less than that of young forest (15 to 29 percent) and more than that for mature forest (11 to 31 percent). Young forest amounts are within the longer-term range exhibited by all 25 wildfire-affected landscapes (3 to 33 percent).

Although the U.S. Forest Service non-wilderness lands more closely approximated historic landscapes than other owner/allocation types, this is in part due to the later application of harvesting and its slower pace compared with the private industrial owner/allocation type, the mixture of wildfire and harvest disturbance in public non-wilderness lands, and the variability in management policy with time. Variability in disturbance through space and through time is, in and of itself, typical of natural disturbance, therefore variability in harvest policy produces landscapes more typical of natural disturbance. Federal timber management policies in the mid-20th century, had they continued, would have resulted in landscapes that were just as far outside of the historic range of variability as the private industrial lands, differing primarily in a larger percentage of young forest relative to early seral vegetation. Both the riparian-rule plus reserves and riparian-rule plus reserves and mixed-rotation landscapes are within the range of variability of the wildfire simulations, except for the lack of mature forest in the riparian-rule plus reserves landscape. They more closely resemble landscapes produced by simulations using low frequency fire regime characteristics than those using high frequency characteristics. The Northwest Forest Plan, if implemented over the long term, will result in early seral and young forest amounts that are well within the range of the past 500 years, but higher amounts of old forest and lower amounts of mature forest than produced by the wildfire simulations. The riparian-rule plus reserves and mixed-rotation approach retains the high amounts of old forest as in the riparian-rule plus reserves approach, increases the amount of mature forest, but reduces early seral vegetation and young forest to amounts below the range of wildfire simulations over the past 500 years.

Landscapes in the private industrial and wilderness owner/allocation types, while possibly having similarities to landscapes occurring in the past, were almost certainly exceedingly rare, and would not have been maintained for long. Landscapes such as these likely only occurred during either very high frequency fire times (some parallels with private industrial) or very low frequency fire times (some parallels with wilderness with fire suppression). Fire regimes with these characteristics would be related to the extremes of climatic cycles (warm and cold excursions, respectively). U.S. Forest Service non-wilderness lands are between these two extremes. Continued distributed patch clearcutting would have resulted in landscapes more similar to those simulated using moderate to frequent fire regimes, but current and proposed practices (Northwest Forest Plan and Blue River Plan) would produce landscapes similar to those simulated using moderate to infrequent fire regimes. If the climate of the region warms, the landscape patterns generated by current and proposed practices may diverge further from those implied by the wildfire simulations.

Ecosystem Properties

Published studies of ecosystem property implications at this scale have not previously been attempted. many assumptions must be made in order to extrapolate pattern effects across large scales where empirical data do not exist. In particular, interactions with broader scale gradients (e.g. climate, stream network development, slope) are poorly understood. Fine-scale interactions, such as those explored in the patch proximity analysis of species diversity, and the proximity to stream analysis for summer water yield, are very difficult to capture at the broader scale. Because empirical studies of these relationships have only been conducted at the smaller scale, findings may or may not be applicable in other landscape contexts, and where variation is likely to occur empirical data that quantify that variability do not exist. For example, arbitrary assumptions were made regarding how the effect of disturbance on water yield varies as disturbance occurs farther from the stream, and how patch size requirements vary with mobility of a species.

In some cases, it is reasonably easy to qualitatively predict what the interaction must be, but exceedingly difficult to quantify the interaction. For example, it is conceptually simple to understand that a species will only inhabit forest if all of the species' habitat requirements are met within its mobility range, and that homogenous forest is less likely to support a wide diversity of species than heterogeneous forest. However, specifying the precise habitat requirements for each species is difficult at any particular place on the landscape, much less quantifying how those requirements might change across environmental gradients. The range of effects of pattern on ecosystem properties across broader areas is uncertain, requiring many assumptions that limit the conclusions that may be drawn.

It is likely that the fine temporal resolution of, for instance, the water yield data could be linked with a process model characterizing the early development of structural complexity of open and semi-open pixels far more effectively than happened with the top-down approach of this study. On the other hand, a top-down approach to quantify the effect of pattern on species richness will likely be needed, but will require better structural characterization of the landscape and far more empirical data regarding those effects. To date, we know a great deal about a few, mostly endangered species, but these provide information about exceptions to the rule, not the norm for most species. Because studies in the Pacific Northwest have focused on the spotted owl, we know what that species requires in terms of patch sizes, but little about the requirements of the other hundreds of bird species in the area.

Given the limitations of this analysis, there were some interesting findings. Although the spatial distribution of age classes had a large effect on all of the measured ecosystem properties, the response was large for both wildfire-affected and harvest landscapes. Therefore, all of the responses for the 1995 and managed landscapes were within the range of the wildfire-affected response. Nevertheless, not all ecosystems that have potentially occurred in the past are equally desirable. Because of the non-linear response of some of the properties to the amount and spatial distribution of age classes, relatively small changes in the location of harvest could be used to bring about substantive changes in specific ecosystem properties. Although not shown, a comparison was made of the magnitude of ecosystem response for randomly distributed age classes and the simulated distribution of age classes, and those results were compared with and without spatial parameters included (e.g. patch proximity, distance to the stream). Response was more pronounced to the spatial parameters than to the range of age classes incorporated by the simulated landscapes.

The findings suggest that it is unlikely that any timber management approach would truly push the system beyond anything that has occurred at some point in the past, and that ecosystem properties are less sensitive to changing disturbance patterns than might have been expected. The volume of wood boles converted to other mass types (e.g. released to the atmosphere, on-site debris) ranged from 0 to 3000 m3/ha in the for the wildfire landscapes. The sensitivity of other ecosystem properties to that wide range depended on the property. Standing wood bole volume was very sensitive to the amount of removed wood, ranging from 1500 to 4000 m3/ha, with a potential reduction of 63 percent of maximum. However, total ecosystem carbon was less sensitive, ranging from 600 to 800 Mg C/ha, potentially a 25 percent reduction of maximum. Total ecosystem carbon is less sensitive because the majority of ecosystem carbon occurs below ground and as surface debris and is not affected by wood bole disturbance. Total vertebrate species richness ranged from 203 to 253 species, a reduction of 20 percent of maximum. Annual water yield ranged from 0 to 35 mm, a 100 percent potential reduction. Summer water yield changed from 90 to 100 percent, only a 10 percent reduction from the maximum value. Therefore, a 100 percent increase in wood bole conversion in wildfire landscapes would be associated with the following, in decreasing order of sensitivity: increased annual water yield, decreased standing wood bole volume, decreased total ecosystem carbon, increased total vertebrate species richness, and decreased summer water yield.

Comparison with Other Studies

The results of this study are dependent on wildfire and disturbance reconstructions (Teensma, 1987; Morrison and Swanson, 1990; Weisberg, 1997a, 1997b, 1998; Van Norman, 1998; Sinton et al., 2000; Agee and Krusemark, 2001;). No published studies resemble this study; but similar work has been conducted as part of the CLAMS study (Wimberly and Spies, submitted; Wimberly et al., 2000) and some of the ideas are being tested as part of the Blue River AMA (Cissel et al., 1999). Results can also be compared to a few independent studies investigating patterns by owner/allocation type in portions of the same area (Spies et al., 1994) and elsewhere (Turner et al., 1996; Crow et al., 1999).

The wildfire simulation modeling for this study area (Oregon Cascades) produced results that are quite similar to those from the Oregon Coast Range using the same model (Wimberly et al., 2000). They found a wider range of variability in the amount of old-growth forest, but also found that the current landscape is outside that range. Three factors influence comparisons between this study and their study. First, the Coast Range simulations encompassed an area roughly 43 percent larger than this study area. The larger area would be expected to result in less variable results (Turner et al., 1990; Wimberly et al, 2000). Second, the Coast Range simulation used larger fire sizes, which would have resulted in more variability. Third, rather than simulating a range of conceivable extremes, they attempted to simulate conditions as close to reality as possible by incorporating temporal change in parameters, based on information on historic wildfire from one fire history study (Impara, 1997) and information on long term (9000 year) fire frequency change from one study of charcoal in lake sediments (Long et al., 1998). Therefore each of their simulation runs made assumptions about fire frequency change with time, rather than modeling steady state parameters through time.

This study attempted to incorporate greater spatial complexity and topographic influences that may have a greater impact on wildfire processes in the Cascades than in the Coast Range. For example, parts of the Cascades have greater local relief and more complex topography than Coast Range terrain. These differences do not appear to have been captured by the LADS model in this study. Simulated landscapes were stratified by slope and aspect, and it was found that north-facing slopes burned just as extensively as high, dry south-facing slopes and ridges. Development of a more mechanistic model capable of running efficiently at broad scales would undoubtedly improve the results.

Discrepancies between age class amounts on the riparian-rule plus reserves/rotation-based landscape and the Blue River Plan (Cissel et al., 1999) were due to 1) different sized reserve areas, and 2) subjectivity in the selection of landscape areas in the Blue River Plan. The subjective criteria used in the Blue River Plan could be incorporated by land managers, using the riparian-rule plus reserves/rotation-based landscape as a starting point.

Spies et al. (1994) studied disturbance trajectories for a 2589 km^2 area in the central portion of this study area from 1972 to 1988. The amounts of forest cover they found on public lands are roughly consistent with this study. However, this study found 50.2 percent young, mature and old forest on private industrial land, compared with 27.6 percent in their study. The large difference between the findings of the two studies on private industrial lands reflects the different study areas. The private industrial lands included in the study area by Spies et al. were dominated by a large area that has been harvested since 1972. Much of the private industrial land in the larger study area is in the young forest category, probably harvested just prior to 1972.

Several subsequent studies have attempted to delineate the effect of ownership on land cover change. Turner et al. (1996) studied a watershed in the Southern Appalachians and two watersheds on the Olympic Peninsula, and Crow et al. (1999) studied an area in Wisconsin. In both studies ownership (public and private) and environmental variables were considered; Turner et al. (1996) also considered locational variables. In both cases, ownership and environment were found to be significant. Turner et al. (1996) found inconclusive results regarding effects of locational variables on rate of forest cover change.

From a broader perspective, studies relating changing landscape patterns due to human influences, and the effects of those changes on biophysical processes, are at the forefront of research in landscape ecology. Turner et al. (2001) identify six research frontiers in landscape ecology, three of which are relevant to this study:

1. Understanding the relationship between spatial heterogeneity and ecosystem processes,
2. Relating landscape metrics to ecological processes, and
3. Causes and consequences of land-use change.

As Turner et al. (2001) point out, there have been many studies addressing better ways to measure spatial patterning of the landscape, but process studies focusing on the effect of pattern are expensive and difficult. This study attempted to extrapolate knowledge of ecosystem properties from a limited number of local studies to a broader scale at which some fundamental landscape patterns occur.

Spatial Scaling Effects

The conclusions that are made regarding forest structural differences between wildfire-affected and other landscapes depend on the scale of observation. At the scale of the entire study area, the whole landscape is generally within the range of variability likely to have occurred in the past few millennia, and not far from the range of variability of the past 500 years. At a smaller scale, owner/allocation types vary substantially from each other, and from simulated wildfire landscapes. Since the private industrial and wilderness owner/allocation types deviate from wildfire landscapes in opposing ways, those deviations balance each other out at the larger scale.

Many findings in this study are the result of the spatial extent and resolution of the study. The large study extent combined with the large sizes of wildfires in the simulations had the effect of producing a very wide range of variability in landscape pattern simulations. Thus, riparian-rule plus reserves and riparian-rule plus reserves and mixed-rotation management scenarios, which differ in important ways at the scale of patches and watersheds (Cissel et al., 1999), do not appear to differ greatly when placed in this broader context. So, they are similar to one another in the sense that they both depart in similar directions from the simulated range of variability for wildfire-affected landscapes, but within the context of the narrower range of choices available to managers today they still have important differences (e.g. maximizing interior habitat through relatively small changes in patch sizes).

The resolution of the wildfire model output (4 ha) is relatively coarse compared to the scale at which many ecosystem interactions occur. For instance, the effect of riparian buffers on many ecosystem properties may be profound over a few 10s of meters (Gregory et al. 1991), yet special methods had to be developed in this study to incorporate those at a broader scale. Empirical studies are frequently conducted at relatively fine spatial resolutions, and understanding how these interactions scale is an area of current research focus (Levin, 1992). Arbitrary decisions about stream size cutoffs should eventually be replaced by continuous mathematical models that express how interactions vary with the size of the stream and proximity to the stream. Broader scale studies that attempt to synthesize the full range of ecosystem effects will be difficult, and subject to many assumptions, until scaling effects are better understood.

Stationarity Effects and Temporal Scale Effects

Many of the findings from the study are the result of the assumption of stationarity of landscape-creating processes. Wildfire scenarios were sampled from a single distribution for the entire simulation, which assumes that climate is not varying over the simulation period. Management scenarios used a single set of rules to create only one (or a limited set of) landscapes. However, climate history and management rules are transient, applying for only limited periods of time, and they have interacting effects. These real, "composite" landscapes were represented only by the 1995 landscape in this study. This assumption has several implications: 1) none of the wildfire-affected or management-rule simulated landscapes is realistic, 2) landscapes or portions thereof that fall outside the simulated range of variability of wildfire-affected landscapes are probably even more unusual than this analysis would imply, and 3) the apparent effects of differing landscape patterns on wood removal, carbon storage, species richness and water yield in this study are limited by the simplistic assumptions.

The temporal scale and resolution of this study (four age classes spanning 500 years of forest succession, simulated over 3000 years) probably missed some very important pattern and ecosystem property changes. Studies of summer water yield changes after forest removal show big changes within the first 5-10 years and some changes in direction of effect that were averaged in this study which grouped all effects less than 30 years together. Processes involving biodiversity and carbon also have important shifts at this finer time resolution. Since existing studies predominantly focus on the old vs. early seral distinction many important process and pattern changes are missed by this analysis. The degree to which these transient responses of pattern or ecosystem property might control the longer-term dynamics of the system was not considered in this study, but this study provides a point of departure for examining such effects.

Process Sensitivity to Pattern, or Form and Function

This study attempted to explore the implications of pattern for three key ecosystem functions: biodiversity, carbon and water, at a scale not typically attempted in landscape modeling and analysis. The study made necessarily simplistic assumptions constrained in part by data availability and in part by the scope of the study, which limit the generalizability of specific findings, while underscoring the importance of future work to explore pattern effects on ecosystem properties at this scale. Although from a structural standpoint age class amounts are additive (the whole landscape is the sum of the parts), their effect on ecosystem properties depends on where the age class occurs in the landscape relative to environmental gradients and network processes. Spatial interactions between patch types, environmental gradients and network processes produced distinct trends in disturbance and ecosystem properties that must be incorporated into process analyses (Turner et al., 2001). Spatial interactions are a rich area for future research efforts, especially through field studies from which the models may be parameterized.

Findings suggest that shifting most of the older forest to higher-elevation, less productive sites may have a substantial effect on carbon storage that may only be estimated by better understanding of the complex relationship between landscape position, interactions with stream, microclimatic and soil processes, and productivity (Cohen et al., 1996; Harmon et al., 1996; Ohmann and Spies, 1998; Smithwick et al., in press). The strong response of species richness to patch proximity observed in this study is consistent with empirical studies of patch effects on species (Gutzwiller and Anderson, 1992; Hansen et al., 1993). Given the strong response in both wildfire-affected and harvest landscapes, it is unclear how multiple patch pattern constraints might interact over longer time periods to produce different responses in managed landscapes than in natural landscapes. Consideration of temporal variability in patch characteristics is likely to be important in assessing long-term effects on biodiversity. Lastly, the effects of harvest on water yield, and in particular the relationship between the location of harvest in the landscape and the direction and strength of response, may have substantial implications for regional water availability (Jones and Grant, 1996, 2000; Jones and Post, in press).

Certainly, both desirable and undesirable effects for society will result no matter what harvest disturbance rate is maintained. Difficult decisions will have to be made; it is highly desirable that they be informed decisions. Much work remains before we will be able to predict what the consequences of a given harvest policy will be for the full range of ecosystem properties. There is not likely to be a single landscape configuration that will meet all of our social and environmental objectives. Either our objectives must change, or we must find new ways to alter the effects, or we will need to develop far more complex landscape management plans with temporal variability, that attempt to balance objectives over longer time scales by trading off different objectives at different times and areas. At present we tradeoff across space with the varied owner/allocation land use patterns.

Chapter 5 Conclusions

Based on simulation modeling, private industrial and public wilderness lands in the western Cascades of Oregon appear to be outside of the historical range of landscape variability of the past 500 years, and probably of the past few millennia, for relative extent of land-cover age classes. Low elevation private industrial lands have more extensive area of early seral vegetation (< 30 years) than wildfire-affected landscapes at comparable elevations, even under the most high frequency fire regimes envisioned. Wilderness lands have less extensive area of early seral vegetation than wildfire-affected landscapes at comparable elevations, even under the most low frequency fire regimes examined. Anticipated future trends in management by these owner/allocation types are likely to increase the deviation from historical, natural conditions. Fire suppression in wilderness lands will permit the forests to simply grow older while intensive plantation forestry may result in even shorter rotations on industrial lands.

U.S. Forest Service non-wilderness lands are generally within the range of age class variability of natural landscapes of the past 500 years, and certainly within the range of the past few millennia. Future trends on these lands depends on policy decisions, but both the current Northwest Forest Plan and proposed historical range of variability scenarios should yield landscapes that are within the range of the past landscape conditions. An exception would be the lack of mature forest age class in the Northwest Forest Plan.

Bureau of Land Management/private industrial checkerboard lands show age classes intermediate to U.S. Forest Service non-wilderness and private industrial lands.

None of the current or hypothetical managed landscapes are similar to wildfire-affected landscapes in terms of patch characteristics. The largest harvest patches in hypothetical landscapes in this study are still much smaller than past wildfire disturbance. Future old forests will be concentrated in certain areas of the landscape, rather than spread throughout the landscape as in the past. The creation of extensive riparian buffers to act as corridors between those old forests, juxtaposed against harvest plantations, is unlike any patch development in the past. These riparian patches of old forest will be long and narrow, so they will provide little, if any, interior forest habitat.

Because age classes on private industrial and wilderness lands deviate from natural landscapes in opposite senses, the study area as a whole may be within the range of age class variability of the past few millennia, but not for the past 500 years. The consequences of reducing disturbance in high elevations and increasing it in low elevations are currently unknown. As a first approximation, carbon storage and rate of removal may be within past ranges. Although species richness on private industrial lands was outside of the range of the past for nearly every taxon and landscape combination considered, this study showed species richness for the landscape as a whole to have changed little from the past. Water yield on private industrial lands was outside of the range of the past, but when included with the larger land base of the whole area water yield was within the range of the past.

This study incorporated only a few, simplistic parameters to assess the effect of broad scale landscape patterns on ecological properties. Focused studies indicate that carbon storage, biodiversity and hydrologic processes are far more complex than modeled. Even though the selected parameters were tailored to respond to noted differences between wildfire and harvest-affected landscapes, only minor differences in ecosystem properties were detected. It is possible that adding all relevant details into the analysis would not impact the results further. This suggests that several of the management systems examined do not differ very significantly from the wildfire disturbance regime in the terms of the simulation experiments. Furthermore, the simulated ecosystem properties may not be very sensitive to differences in landscape structures produced by the disturbance scenarios modeled in this study. However, while ecosystem properties may be within the range of the historic past, not all landscape states from the past would be acceptable today because of the fluctuations those patterns cause on hydrologic, biotic processes, and other factors of significance to humans. Other ecosystem properties not examined in this study may react more profoundly to differences in landscape structure. Acceptable management choices are likely to result in more subtle consequences that are difficult to predict with current knowledge and modeling capability. More sophisticated models that incorporate spatial variability in processes at a variety of scales are needed. Those models will require much better parameterization.

Integrated modeling efforts must make choices between the scale of analysis and the level of detail that may be investigated. Coarser scale studies necessarily incorporate less detail, and so are not appropriate for some questions of interest. Yet other questions may only be addressed through broad scale analyses. In this study, an important question arose regarding how given forest patterns may interact differently in different geographic settings with changes in associated features such as stream network development and mesoclimate. Few empirical data are available to attempt to answer questions of this nature, because ecological studies are typically conducted at much smaller scales. Future studies need to be carefully designed to match the questions of interest with the scale of the study and to provide appropriate empirical data with which to parameterize the model.

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Appendices

Appendix A: Description of AML scripts

The following Arc Macro Language scripts are included with this dissertation on a compact disc:

Forest Structure:

vegamount.aml: extracts age class amounts
apack.aml: launches APACK 2.0 (Mladenoff et al., 1995) to calculate patch metrics on each landscape and owner/allocation type
ripleysk.aml: calculates patch proximity measures

Ecosystem Response:

tec.aml: calculates total ecosystem carbon based on age class
wood.aml: calculates wood removal and standing wood based on age class and site class

bio.aml: calculates species richness response to age class and elevation parameters
biok.aml: calculates species richness response to patch proximity

waterann.aml: calculates change in annual water yield from age class and elevation parameters
watersum.aml: calculates change in summer water yield from age class and elevation parameters
waterdist.aml: calculates annual and summer water yield changes incorporating distance of disturbance from the nearest stream

Stratifications:

Scripts to perform stratifications were all similar, changing only the file names and the precise stratifications to be performed. Scripts were named according to the following pattern:

XXXstrata.aml, where XXX is veg, rip, wood, tec, bio, biok, or water, depending on the layers to be stratified.

Appendix B: Data Sources and Base Layers

Digital layers were retrieved from several public sources (Table B.1). All data were imported into ArcInfo 7.2 on Windows NT for analysis. The data were re-projected to UTM coordinates, if needed. The study area was delineated from ORECO, a GIS layer of Oregon ecoregions. The western Cascades polygon was reselected and isolated into a separate coverage, then simplified. The southern boundary was delineated by intersecting the eco polygon with the North Umpqua River arc from the streams layer. The resultant polygon, STUDYAREA, was used to limit the extent of all other layers with the CLIP or GRIDCLIP functions.

Table B.1. Sources of digital data.

Source	Data Type
Forest Science Databank, a partnership between Oregon State University and the U.S. Forest Service Pacific Northwest Research Station	LARS88CONAGE: Conifer Age derived from 1988 TM (Cohen et al.; 2001; 1995a; 1995b) LARS88VEGMAP: Vegetation Class derived from 1988 TM (Cohen et al.; 2001; 1995a; 1995b) LARS95DISTURB: Disturbance derived from change analysis of 1772-1995 TM (Cohen et al., 1998) WORDEM: digital elevation model OWNER_ATT: Land Owner FEDRES1: Wilderness Reserves ORECO: Ecological Group Cultural Data: Cities, Counties Major and Minor Watersheds, Streams
Oregon Department of Forestry	1914 Vegetation (Elliot, 1914)
Regional Ecosystem Office	Northwest Forest Plan land use types
Fire dendrochronological studies	Compiled by Lyn Berkeley (University of Oregon) from Forest Service Databanks.

Appendix C: Owner/allocation Type Layer (Figure C.1)

The land owner (OWN_ATT) layer and a layer of federal timber reserves (FEDRES1) were retrieved from the U.S. Forest Service databank (Appendix B). The owner layer, compiled in 1994, included individual owner names and owner classes from the 1990-91 ACI ownership database. The original layer classified land owners into major classes: U.S. Forest Service (USFS), Bureau of Land Management (BLM), state of Oregon (STATE), private industrial (PI), private non-industrial (PNI), miscellaneous (MISC), and NODATA. It was unioned with FEDRES1, to obtain the wilderness areas (WILD), and with HRUS, to obtain the H.J. Andrews Experimental Forest boundary (HJA). The PI owners were reclassified to distinguish between large private industrial firms, and small ones, which were lumped together into an OTHER class.

Checkerboard areas (CHECK) were identified by reselecting PI polygons less than 1000 ha in size, and creating a region to combine these with BLM acreage. A small number of polygons larger than 1000 ha were manually added to the region, where they were contiguous.

Polygons of the four primary classes, CHECK, PI, USFS, and WILD were rasterized into 200 meter resolution grids, to create masks for grid analysis (MASKBLMCHECK, MASKPI, MASKUSFS, MASKRES). Cells in the mask were assigned 1 if they were in that class, 0 if they were in the study area boundary but not in that class, and NODATA outside of the study area. The masks were combined to create a single grid of the four major class types, ZONEOWNER.

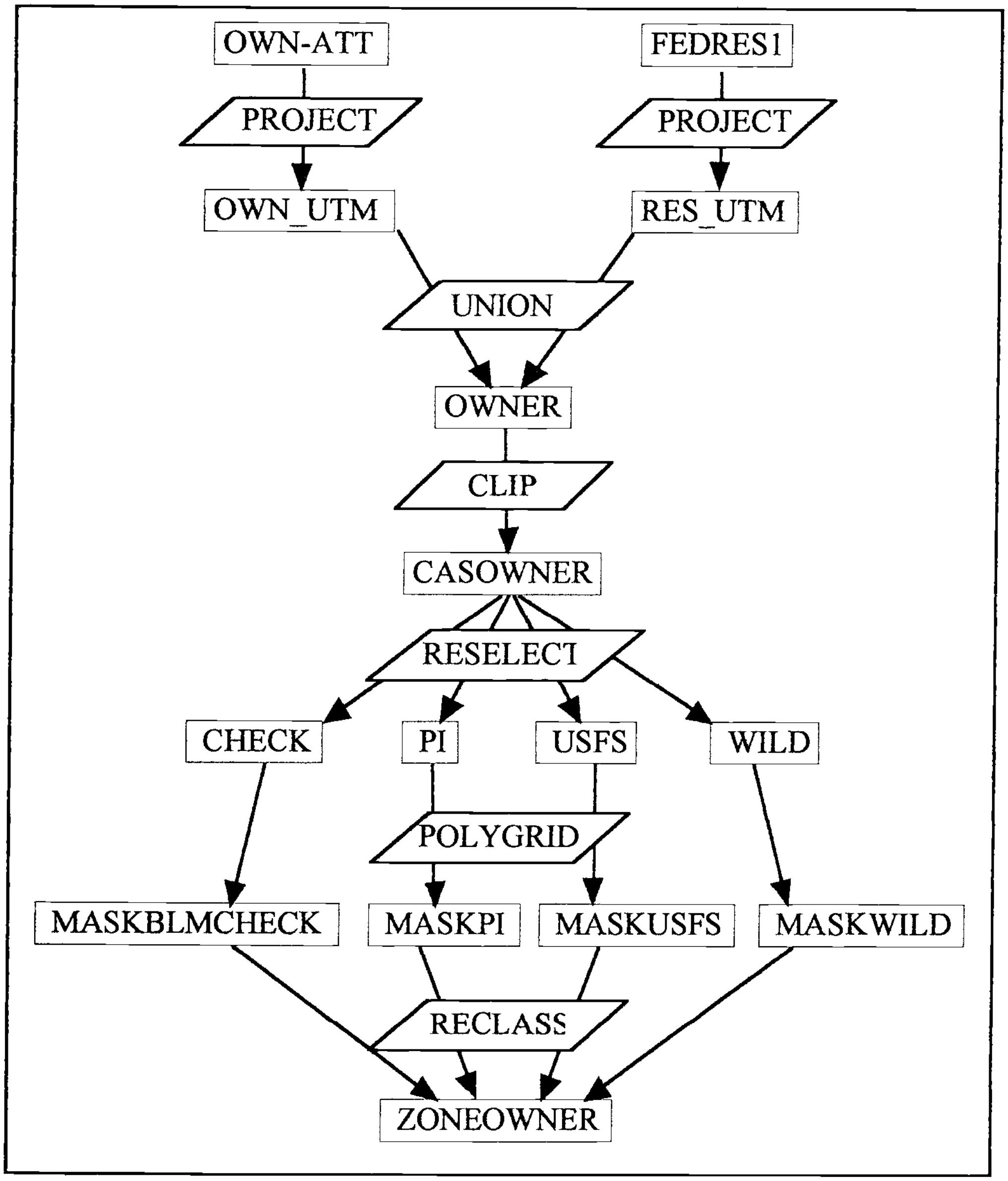

Figure C.1. Flowchart of land owner data manipulation in GIS. Rectangles are data layers; parallelograms are procedures performed on the data.

Appendix D: LADS Input Layers (Figure D.1)

Three layers were created for input to the LADS model: BUFFER, CLIMATE and TOPO. The BUFFER layer delineated the study area boundary, and a buffer zone around the study area in which a fire could ignite and/or burn, but which was excluded from analysis. The purpose of the buffer zone was to reduce edge effects. The BUFFER layer was created with GRIDEDIT, by adding a buffer zone around the study area, which was converted to a raster layer with POLYGRID. The buffer area was coded 1, the analysis area coded 2.

The CLIMATE and TOPO layers were created based on regression models relating topographic parameters to fire frequency, developed by Weisberg (1998). Topographic layers were constructed from a 30 meter digital elevation model (WORDEM), which was clipped to the buffered study area extent (CASDEM), and resampled to 200 meter resolution (CASDEM200). An aspect layer was calculated as using the ASPECT function (CASASP200), and converted to a measure in radians:

$$\text{NORTH} = \cos((\text{ASPECT}/360)*2\pi$$

A slope layer was created from the SLOPE function (CASSLOPE200), and reclassifed into two layers, STEEP (20 - 30) and VERYSTEEP (> 30). Hillslope position was determined from an AML script in the Forest Service Databank, hillslope.aml. The resulting layer is continuous numeric, ranging from valleys (0) to ridges (100). The hillslope layer was reclassified into upper slope (CASUPSLOPE) and mid slope (CASMIDSLOPE) layers.

The above layers were used to derive two additional layers based on regression models developed by Weisberg (Weisberg, 1998):

$$\text{WCLASS} = -0.99 + 0.0015\ (\text{Elevation}) + 0.30\ (\text{Northness}) - 0.85\ (\text{Midslope}) - 0.71\ (\text{Upper slope})$$

WMAXFI = 376.70 + 0.0005 (Elevation) + 30.65 (Northness) – 72.44 (Midslope) – 68.59 (Upper Slope) – 186.83 (Moderately Steep) –310.01 (Very Steep) + 0.1401 (Elevation:Moderately Steep) + 0.2642 (Elevation:Very Steep)

The WCLASS layer is a continuous layer relating fire frequency to topographic properties. The WCLASS layer was reclassified into three zones, high, mid, and low. Break points were determined by visual comparison with the zones identified in Weisberg (1998). The zone boundaries were simplified, using the SMOOTH function. The layer was edited with GRIDEDIT, to modify the location of the boundaries in the northern and southern parts of the study area. The final layer was named CLIMATE, as required by the LADS model. WMAXFI was reclassified into three fire susceptibility classes (TOPO), with longer MAXFI representing less susceptible sites.

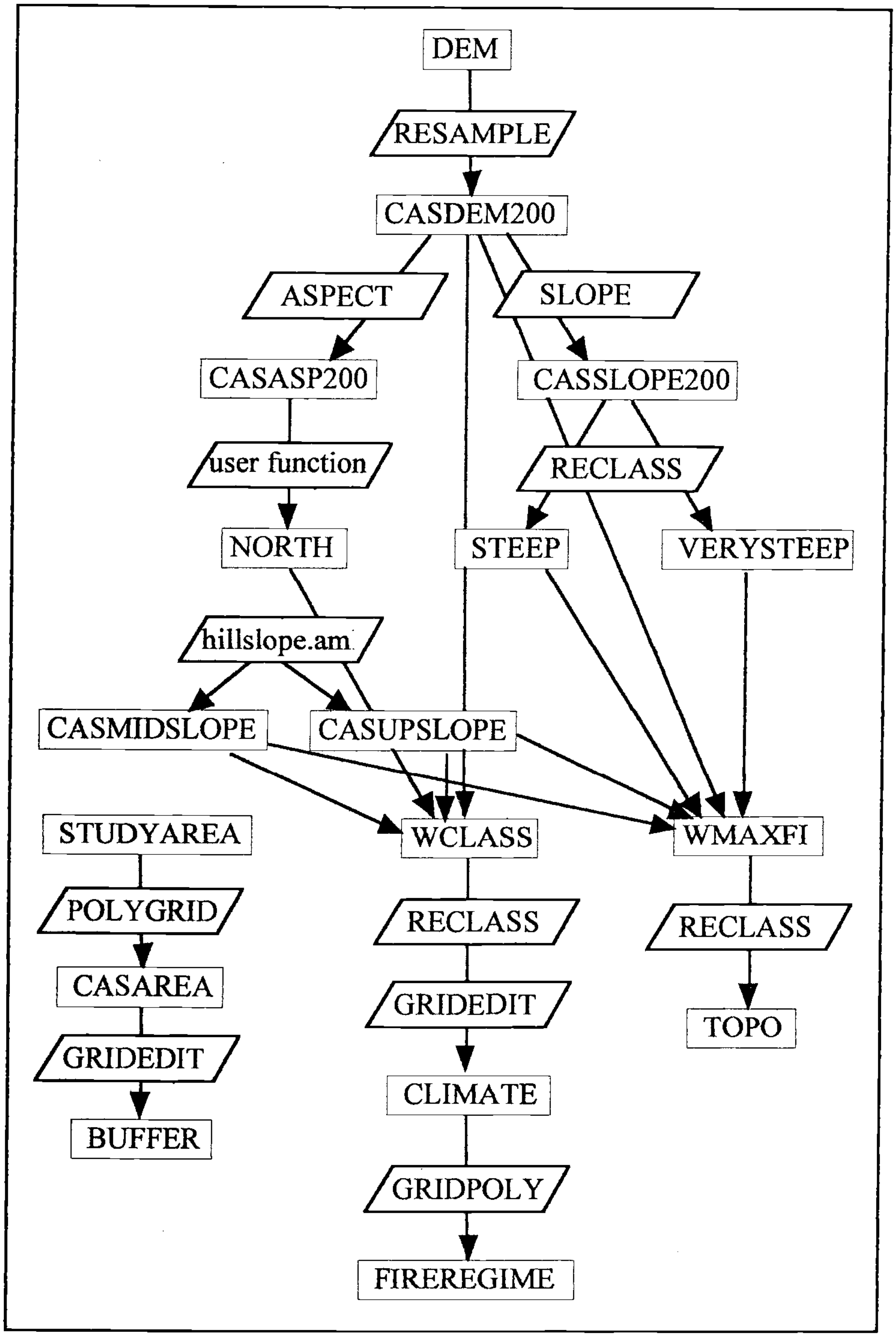

Figure D.1. Flowchart of data manipulation of fire layers. Rectangles are data layers; parallelograms are procedures performed on the data.

Appendix E: 1995 Layers (Figure E.1)

Three primary data layers were retrieved from the Forest Service Databank: LARS88VEGMAP, LARS95DISTURB, and LARS88CONAGE, which were imported into ArcInfo. LARS88VEGMAP was clipped to the study area extent and renamed CASVEG. It is a classified map of vegetation class, derived from 1988 Thematic Mapper imagery using a Tasseled Cap transformation (Cohen et al.; 2001; 1995a; 1995b). It is a categorical layer with six classes:

1. Open (<30% green veg cover (GVC))
2. Semi-open (30-70% GVC)
3. Broadleaf (> 70% Broadleaf cover (BC))
4. Mixed (>70% GVC, < 70% BC & < 70% CC)
5. Young conifer (> 70% Conifer cover (CC), < 80 years)
6. Mature conifer (> 70% CC, 80-200 years)
7. Old conifer (> 70% CC, > 200 years)

LARS95DISTURB was clipped to the study area extent and renamed CASDIST. It is a categorical layer of time and type of disturbance from change analysis (Cohen et al., 1998). The original categories were renumbered to descending time, consistent with the sequential order in CASVEG. CASDIST has five time periods from 1972 to 1995, with two disturbance types:

- 1991-95 harvest
- 1991-95 fire
- 1988-91 harvest
- 1988-91 fire
- 1984-88 harvest
- 1984-88 fire
- 1977-84
- 1972-77
- Non-forest

LARS88CONAGE was clipped to the study area extent, and renamed CASCONAGE. It is a map of conifer age in years as a continuous numeric between 0 and 800, derived from multiple linear regression (Cohen et al.; 2001; 1995a; 1995b) analysis of 1988 remotely sensed Thematic Mapper imagery. CASCONAGE was renumbered from the 1988 age, to the expected conifer age in 1995 (time of CASDIST) by adding 7, and renamed CASAGE.

CASAGE and CASVEG were both derived from 1988 imagery, and were internally consistent with each other. These were compared with the 1995 CASDIST, to detect major differences. CONAGE and CASVEG were unioned into a single layer , and CASDIST with CASVEG using the formulas:

$$AGEDISDIFF = CONAGE * 10 + CASDIST$$

$$VEGDISDIFF = CASDIST * 10 + CASVEG$$

This resulted in each cell containing one class code in the units place, and the other class code in the second and third places, which enabled analysis of class combinations.

CASAGE and CASDIST were combined into a single layer, DISTAGE, yielding post 1972 stand initiation dates from the disturbance data, and pre-1958 initiation dates from conifer age (30 years regenerating to conifer; 1988 – 30 = 1958). The continuous conifer age data was reclassified again into 20 year age classes, and renamed DISTCONAGE. The gap from 1958 to 1972 was filled by combining DISTCONAGE with CASVEG, where the pixel was unassigned in DISTCONAGE but classified as open, semi-open, or broadleaf in CASVEG. These pixels were assumed to fall in the 1955 to 1975 20 year bin, pre-dating the disturbance map. Pixels not determined in this manner were left as NODATA, and included a substantial number of mixed pixels in the CASVEG layer. The final layer was resampled to 200 meter resolution, reclassified into four age classes (0-30, 30-80, 80-200, >200), and named HARV1995.

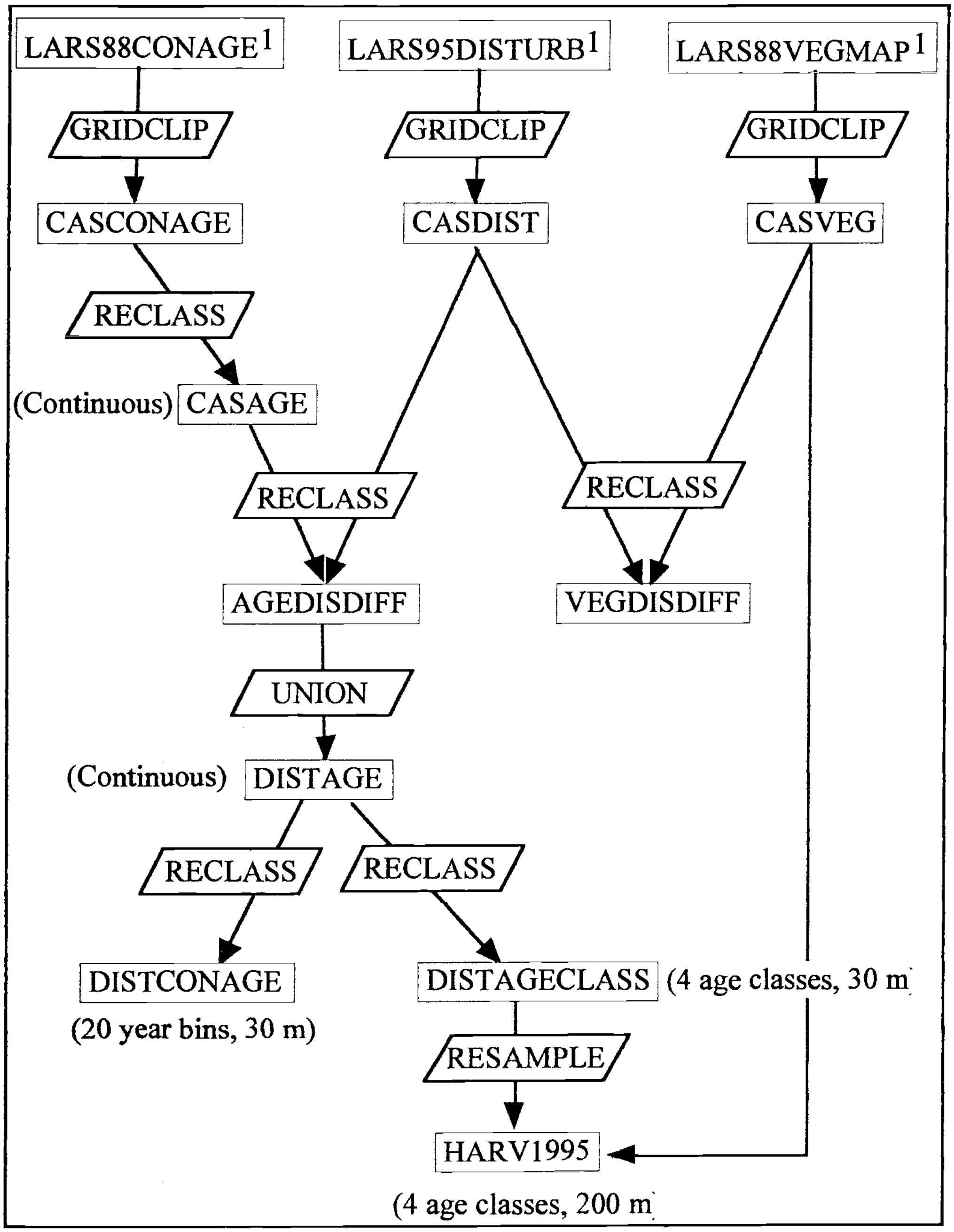

Figure E.1. Flowchart of 1995 data manipulation in GIS. Rectangles are data layers; parallelograms are procedures performed on the data.

Appendix F: SIMMAP 2.0 Pure Pattern Layers

Simmap 2.0 (Saura, 1999; Saura and Martínez-Millán, 2000) is a Windows based program that generates 32-bit bitmaps of randomly placed classes, in user-specified amounts and patch sizes. The map is generated over a square with a specified number of pixels, which was set to 1500, greater than the number of pixels in the 200 meter data.

Maps were simulated for nine landscape patterns representing varying harvest rotations (40, 80, 100, 120, 160, 180, 200, 240, and 260 year rotations; Table F.1). Class amounts were calculated as:

$$\text{Percentage} = \text{Duration of age class} * 100 / \text{Rotation length}$$

The class amounts were distributed in evenly sized patches, according to an aggregation factor P, specified by the user. The aggregation factor determined the number of pixels grouped together, and varied depending on the amount of a given class present in the landscape. Ultimate patch size was calculated based on a 200 meter scale associated with the number of grouped pixels in the 240 year rotation simulation (Table F.2). Although five aggregation factors were simulated, only three were ultimately used in analysis, corresponding to an aggregated patch size similar to the pattern on PI lands, a dispersed patch size similar to the pattern on USFS lands, and an intermediate pattern.

The resultant bitmaps were imported into Irfanview graphics converter, to downgrade the image to a 24 bit grayscale jpeg file, which could be imported into ArcInfo 7.2. In ArcInfo, the images were registered to the study area and rectified. Each ArcInfo image was converted to a series of stacked grids using IMAGEGRID, and were consolidated into a single grid using COMBINE. The resultant grid was resampled to 200 meters, clipped to the study area boundary, and named according to the schema HARVXXXPT, where XXX is the rotation, and PT is the pattern (aggregated: AG, moderate: MD, or dispersed: DSP). Each grid had to be reclassifed into the four age classes (1 regen, 2 young, 3 mature and 4 old) age classes. ArcInfo assigned grid values based on the amount of each class type present in the landscape, so that the correct reclassification could be identified and made.

Table F.1. Class amounts and aggregation factors used in the Simmap 2.0 simulations. Each rotation was simulated five times with varying aggregation (P) factors: 0.05, 0.25, 0.35, 0.45 and 0.55. The resultant bitmap was named according to the rotation and P factor used: RR-PP, where RR = rotation and PP = decimal digits of the P factor.

Rotation	Regen %	Young %	Mature %	Old %
40	75	25	0	0
80	38	62	0	0
100	30	50	20	0
120	25	42	33	0
160	19	31	50	0
180	17	28	55	0
200	15	25	60	0
240	13	21	50	16
260	12	19	46	23

Table F.2. Aggregation parameter (P) variation, number of contiguous pixels produced by the model, and calculated patch size in the 240 year rotation simulation.

P	Number of aggregated pixels				Patch size (ha)				Pattern
	0-30	30-80	80-200	> 200	0-30	30-80	80-200	> 200	
0.55	28	44	134	34	112	176	536	136	
0.45	15	22	118	16	60	88	472	64	Aggregated
0.35	10	14	88	10	40	56	352	40	
0.25	7	10	60	7	28	40	240	28	Moderate
0.05	2	3	13	2	8	12	52	8	Dispersed

Appendix G: Riparian Buffer Layers (Figure G.1)

Riparian buffers were needed for three different rule sets: state rules from the Oregon Forest Practices Act (OFPA), Northwest Forest Plan (NWFP) rules and Blue River Plan (BRP) rules, (Table G.1). All three rule sets define riparian zones based on the presence or absence of fish in the stream. Currently, that information is not known for most of the study area. Therefore, a method had to be devised that would approximate likely conditions. The assumption was made that the low order streams, high in the watershed, with low flow and limited access would be barren of fish. A procedure was devised that approximated low order, non fish-bearing streams in the Blue River AMA, where fish-bearing status is known. That procedure was then used across the remainder of the study area.

Table G.1. OFPA, NWFP and BRP riparian rules for fish-bearing and non fish-bearing streams. Stated buffer width is applied to each side of stream.

	Fish-bearing	Non fish-bearing
Oregon Forest Practices Act	50, 70 or 100 feet, depending on stream size (average: 75 feet = 23 meters)	50 or 70 feet, depending on stream size (average: 60 feet = 18 meters)
Northwest Forest Plan	2 tree heights = 104 meters	1 tree height = 52 meters
Blue River Plan	70-200 meters (average: 135 meters)	No buffer required

A number of experimental methods were tested in the Blue River watershed, until one was found that approximated known riparian area. All of the tests used various combinations of filters, cell aggregation and resampling. Raster methods were used in order to identify not only the amount of riparian area (which would be more easily calculated with vector analysis), but also to identify the age class of each cell on each simulated landscape that was partially or wholly replaced by riparian conditions. The approach used was to identify the riparian areas on the higher resolution 30 meter data, then maintain that information at the lower resolution 200 meter simulation scale. In order to do that, the AGGREGATE function was used to combine 30 meter cells into larger 180 meter cells that specified the percentage of the 180 meter cell that was riparian. The AGGREGATE function includes a "count" option, that was used to count the number of 30 meter cells that were riparian, and store that count as the 180 meter cell value, which could then be converted to a percentage. The AGGREGATE function will only allow the combination of whole cells (2x2, 3x3, etc.), therefore the 30 meter cells had to be aggregated into 6x6 (180 meter resolution) matrices and then resampled to achieve a 200 meter scale. Details of the methodology follow.

The FILL function was run on the 30 meter DEM, to remove any sinks. Then the FLOWACCUMULATION function was run, which counts the number of upstream cells draining into any given cell. Streams are identified by extracting cells draining a high number of cells. The minimum threshold is set by the user; a high minimum will identify only higher order streams, a low minimum includes lower order streams. Various thresholds were tested in the Blue River watershed until two were found that approximated fish-bearing streams (higher threshold) and all streams (lower threshold). The higher threshold used was 1000 cells. Therefore, the fish-bearing streams were assumed to be those streams that drained at least a 900 ha area (1000 cells x 30 m x 30 m). All streams were identified with a 100 cell threshold, draining a 400 ha area. Although smaller, intermittent streams certainly exist, this cutoff approximated the streams identified with field work as applicable to buffers associated with the NWFP. The final layers were overlaying with a 30 meter TM layer that identified water, to exclude reservoirs themselves from the riparian analysis. Remaining cells were flagged as riparian.

Buffers of different sizes were created around the fish-bearing and non fish-bearing riparian cells, approximating the OFPA, NWFP and HRV buffer rules designated in Table G.3. For OFPA rules, the full width of the riparian area for non fish-bearing streams averages 36 meters. Since this is approximately the width of a single, 30 meter cell, no buffering was conducted. Fish-bearing riparian areas average 46 meters across. To approximate this, a custom filter was created that flagged an additional one cell as riparian buffer for every two riparian cells.

Fish-bearing streams under the NWFP require a 104 meter buffer, or 208 meter total riparian width. To achieve this, a 5x5 filter was run on the data, where if one cell within the 5x5 analysis window was riparian, all were flagged as riparian. This resulted in widening the riparian zone. The resultant layer was combined into a 180 meter resolution layer, using the AGGREGATE function to count the number of 30 meter riparian cells in each group of 36 cells that was combined to produce a 180 meter cell. That count, then, was divided by 36, to estimate the percentage of the 180 meter cell in the riparian zone. Lastly, the layer had to be resampled to 200 meter resolution. This was done using nearest neighbor methodology, to ensure that the riparian area was not further smoothed, although any resampling technique introduces additional error. The same methodology was used on non fish-bearing streams, except that a 3x3 filter was used.

The filter, aggregate and resample steps were repeated for both fish-bearing and non fish-bearing riparian zones multiple times using different filters, aggregation and resampling techniques, until one was found that approximated conditions in the Blue River (exclusive of the H.J. Andrews Experimental Site), as determined from a vector GIS coverage of the area. The final methods produced 3893 ha of riparian buffer, compared with 3922 ha from the vector analysis.

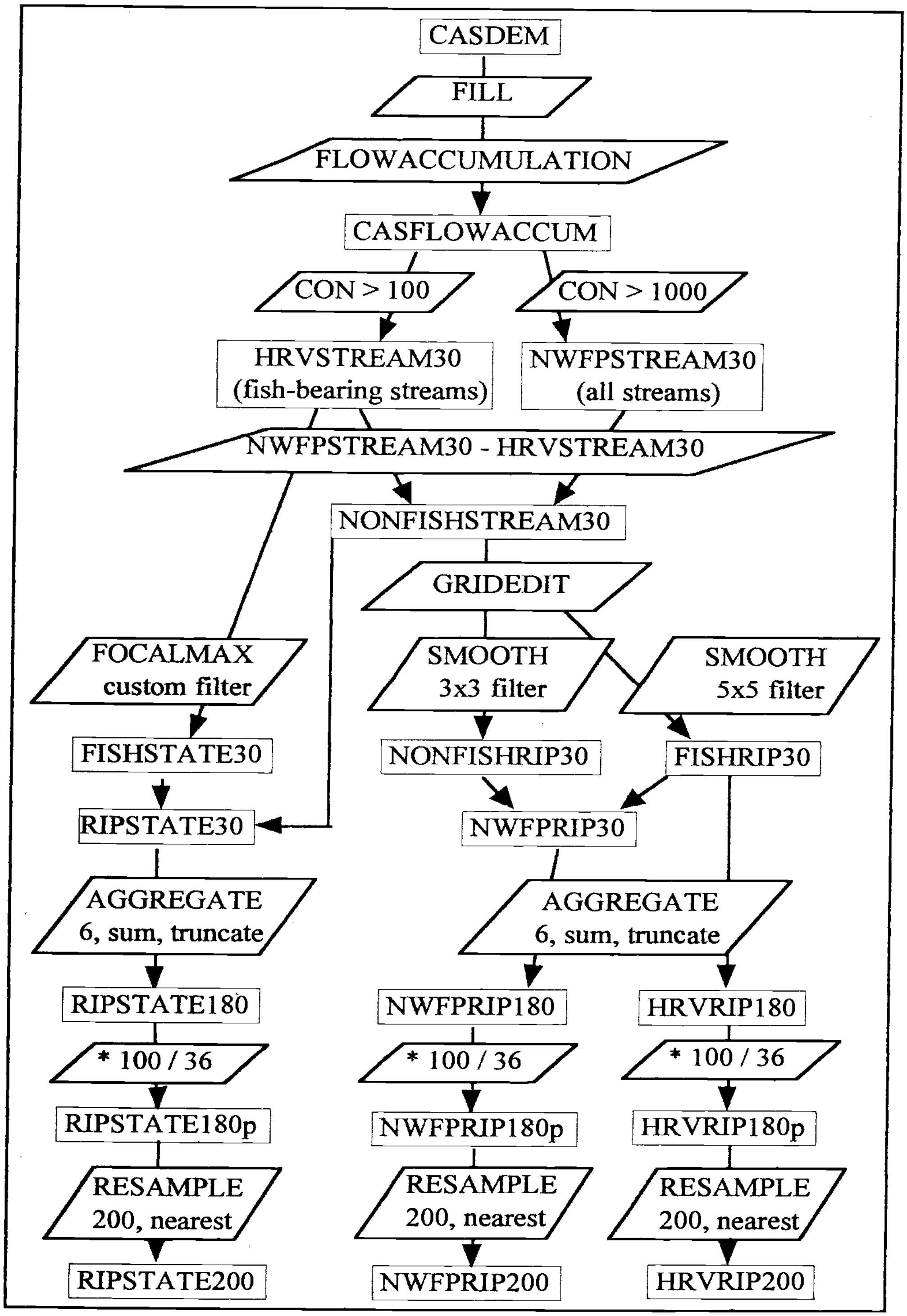

Figure G.1. Flowchart of riparian buffer creation in GIS.

Appendix H: Topographic Layers (Figure H.1)

CASDEM was manipulated to identify six topographic components; ridge, valley, north, south, east and west slopes. Hillslope position was identified using an Arc Macro Language (AML) program available in the Forest Service Databanks, slopeposition.aml. This AML resulted in a continuous numeric (0-100) grid of slope position (CASSLOPEPOS). That grid was resampled to 200 meter resolution (CASSLOPEPOS200), on which the FOCALMAJORITY function was run, to smooth the data and remove isolated pixels. The data were reclassified into three classes, upper slope (> 86), mid slope (10-86), and lower slope (< 10, CASHILLSLOPE), based on visual examination of the data.

The lower slope zone was vectorized using GRIDLINE to create the STREAMS coverage. The upper slope zone was vectorized using GRIDLINE to create the RIDGES coverage. The mid slope zone was further subdivided by aspect. Aspect was derived from CASDEM using the ASPECT function (CASASP), and resampled to 200 meter resolution (CASASP200). The resultant layer was reclassified into four aspect classes: north (315-45 degrees), east (45-135 degrees), south (135-225 degrees) and west (225-315 degrees). The final topographic component map (CASCOMP) consisted of six classes: valley, north slope, east slope, south slope, west slope and ridge.

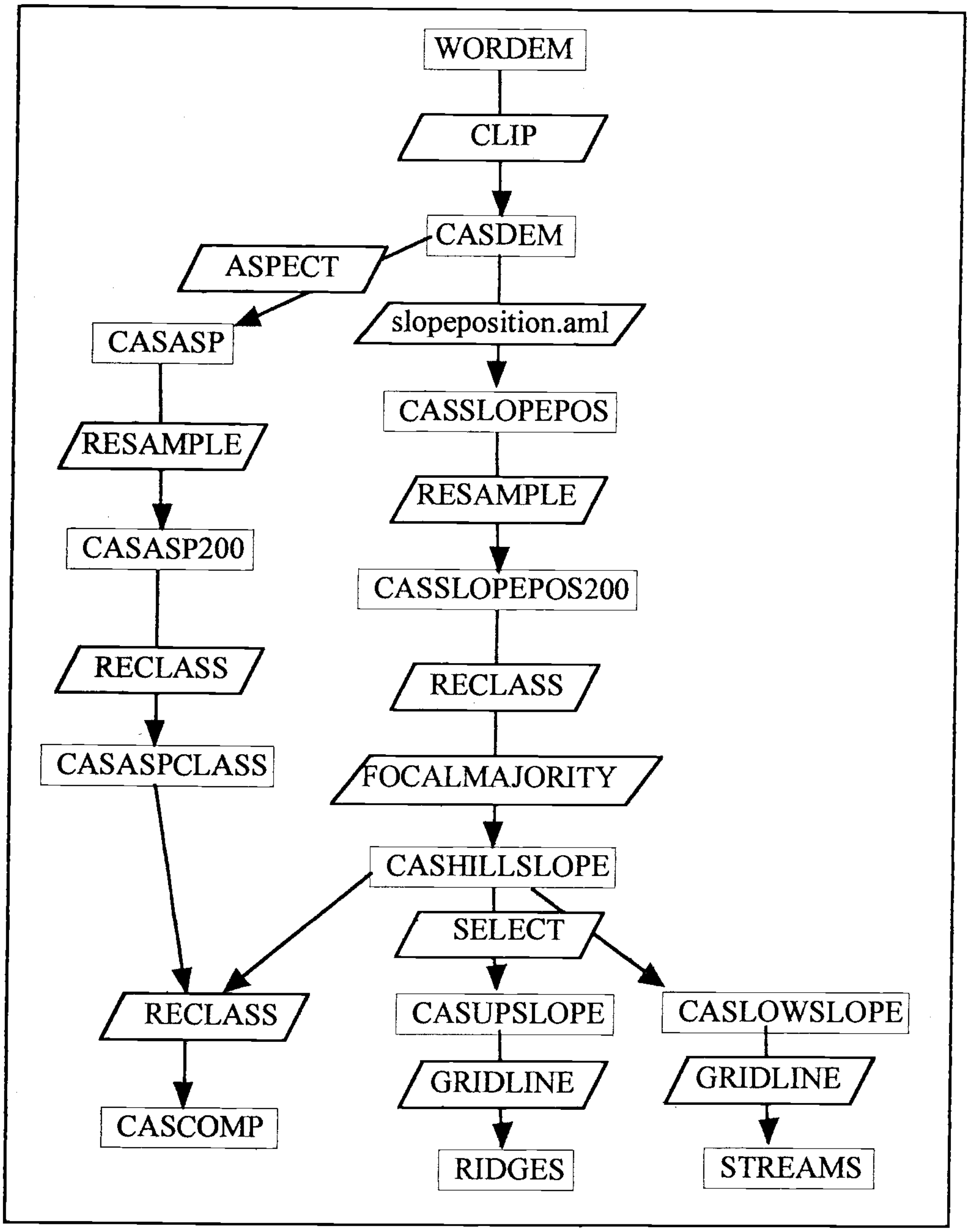

Figure H.1. Flowchart of topographic data manipulation in GIS. Rectangles are data layers; parallelograms are procedures performed on the data.

Appendix I: Managed Landscapes (Table I.1; Figure I.1)

Each of the Simmap simulations was used individually, as an example of a "pure" landscape of a given pattern. An additional pure landscape representing all old forest was creating by assigning every cell in the study area to the 4th age class (> 200 years). More complex simulations were created by combining different pure patterns with varying retention rates and varying riparian designations.

The riparian-rule landscape (RIP) was created by assigning the 40 year rotation aggregated pattern to private industrial lands, all old forest to wilderness areas, and 80 year rotations with dispersed patterns to other public lands. The landscape was overlain by the OFPA riparian buffer. Cell values are 3 digits, with the first digit representing the primary age class and the 2nd and 3rd digits representing the percentage of riparian area in the cell. The riparian-rule plus reserves landscape (RIP/RES) included large areas designated as late successional reserves, which were retrieved from a layer provided by the Regional Ecosystem Analysis website and assigned to the old forest age class. Private industrial lands were assigned 40 year rotations and aggregated patterns. Other public lands were assigned 80 year rotations with dispersed patterns. The entire landscape was overlain by the NWFP riparian buffer. Lastly, public lands in matrix areas were assigned a 15 percent green tree retention rate. Cell values are 5 digits; the first three correspond to those in the RIP landscape, the last two were "15", representing the green tree retention rate.

Table I.1. Harvest landscapes constructed, showing landscape pattern and disturbance scenario abbreviations used in figures, and patterns applied to owner/allocation types. Small, low elevation areas of miscellaneous or unknown owner/allocation type were included with PI.

Pattern	Scenario	BLM/Check	PI / Other	USFS	WIL D
Pure Pattern	40 AG	Single pattern landscapes. Age class amounts and aggregation factors defined in Tables F.1 and F.2.			
	80 DSP				
	100 AG, MD, DSP				
	120 MD				
	160 MD				
	180 AG, MD, DSP				
	200 MD				
	240 MD				
	260 AG, MD, DSP				
	ALLOLD	Age class 4: Old Forest (> 200 years)			
Man-aged	RIP	80 DSP; OFPA riparian	40 AG; OFPA riparian	80 DSP; OFPA riparian	ALL OLD
	RIP/RES	80 DSP; NWFP riparian	40 AG; OFPA riparian	80 DSP; NWFP riparian; NWFP late successional reserves = Age class 4: > 200 years	ALL OLD
	RIP/RES/ ROT	80 DSP; State riparian	40 AG; State riparian	100, 180 and 260 AG, MD and DSP; HRV rip.; NWFP late successional reserves = Age class 4: > 200 years	ALL OLD
1995	HARV 1995	Actual age classes, resampled from 30 meter TM classified imagery.			

Creation of the riparian-rule plus reserves and mixed-rotation landscape (RIP/RES/ROT) was complex, and hence is presented in detail (Figure H.1). Essentially, the strategy consists of identifying natural wildfire regimes on the landscape, and attempting to incorporate the frequency, size, and severity characteristics of the natural fire regime into harvest management goals (Cissel et al., 1999). This management strategy has been worked out in detail in the Blue River watershed, and the goal of this study was to attempt to spread that plan out across the broader landscape. In practice, this was difficult to accomplish because the rules used in the Blue River Plan are site specific, and require substantial field based information. The methodology used attempted to incorporate the major concepts of the Blue River Plan strategy, recognizing that part of the strategy includes flexibility to modify the plan for site specific criteria.

The plan consists of two general classes, reserves that are not subject to harvest, and "landscape areas" that are subject to varying degrees and types of harvest, that in part emulate wildfire disturbance. Reserves consist both of discrete areas set aside as late successional reserves by the NWFP or as special area reserves that are "unique." Aquatic reserves are also designated around streams and reservoirs, but these depend on management objectives for late successional forest conditions rather than depending on an identifiable set of rules, and may include entire small watersheds where desired to meet site specific habitat objectives. Landscape areas are designated partly based on a fire regime study that was accomplished in the area (Weisberg, 1998; Weisberg, 1999), and partly based on known ecological conditions and identifiable landforms.

Therefore, a method had to be developed that would approximate the conditions prescribed by the Blue River Plan, without the site specific, field based knowledge that is an integral part of that plan. The approach used was to create a rule set based on those discrete rules that are stated by the plan, combined with rules that approximate some of the field based knowledge. These were applied to the local Blue River area to determine the degree to which the resultant distribution of age classes matched the Blue River plan. The rules were then applied across the study area. Notably, "unique" , "scenic", or other subjective criteria could not be incorporated, and would change the results that were obtained. However, this is an interesting first attempt at establishing a base rule set, that could then be modified as desired by the site managers.

The first step was to delineate natural fire regimes comparable to those used in the Blue River Plan. In that study, a statistical model was developed based on topographic explanatory variables that resulted in a continuous variable quantifying fire frequency, which was then classified into three fire regimes (Weisberg, 1998). The three fire regimes were used as a reference in the Blue River Plan, in delineating contiguous landscape areas that could be assigned similar harvest characteristics. For this study, the Weisberg model was calculated across the entire landscape (WMODEL). Because the model resulted in non-integer numbers that are not easily manipulated in ArcInfo, the results were scaled to positive integers starting with zero, by multiplying by 100 and subtracting 185 (WMODELSCALED). The result was highly variable even within local areas of the landscape. Therefore, a method was devised to average model results across topographically related features.

The CASCOMP layer (Appendix H) was vectorized, to identify adjacent cells of the same orientation, and to eliminate small areas that could be merged with surrounding areas (landform elements). This was accomplished by eliminating polygons (Arc ELIMINATE) if they were a slope area (not ridge or stream) and consisted of less than 400,000 square meters (400 ha; 10 cells), or if they were a ridge or valley and the polygon area was less than 200,000 square meters (200 ha; 5 cells). The resultant polygons were converted back to a grid (ZONELSCOMP), using the unique polygon number as the cell value, which allowed cells to be grouped together (ZONED) that were part of the same topographic element.

The cells within each element, identified by zone value, were associated with a range of numbers from the Weisberg model output, identified in

WMODELSCALED. These were averaged for the whole zone using ZONALMEAN, which used the averaged the value in WMODELSCALED for each of the topographic elements identified in ZONELSCOMP, and output the grid LSCOMPWMOD, which contained the averaged value for each cell in each element. The average was then used to assign all cells in the topographic element to one of three harvest regimes (LSCOMPWCLASS), or "landscape areas", from the Blue River HRV plan (Table H.2). Numerical cutoffs for each area were determined by visual examination of the designated landscape areas in the Blue River AMA and their associated values in WMODELSCALED. Layers (masks) were created consisting of just cells from each landscape area within the USFS owner allocation type (USFSWCLASS1, 2 and 3). The landscape area class was attached to the LSCOMP vector coverage by converting the grid back into a vector coverage (WCLASS) and joining the WCLASS value to the LSCOMP coverage using the IDENTITY function.

Within each landscape area, topographic elements and all of their associated cells were selected at random to meet the percentage requirements for the different aggregation patterns given by the Blue River Plan (Table H.2). This was accomplished by selecting one cell to represent the entire topographic element, and assigning a random value to it. A layer of random values between 1 and 1000 was created using the RANDOM function (CASRANDOM). The representative cell was selected using the ZONALCENTROID function on ZONELSCOMP, resulting in ZONELSCENTER. If ZONELSCENTER was greater than 0 (it is the representative cell), the random value was passed (ZONELSRAND). ZONELSRAND, therefore, consisted of a layer where a single cell from each topographic element was assigned a random number between 1 and 1000, and all other cells were NODATA.

Table I.2. Landscape area prescription elements (Cissel et al., 1999).

	Rotation age (years)	Percentage of landscape area			Retention level (%)
		Small block (< 40 ha)	Medium block (40-80 ha)	Large block (80-160 ha)	
Landscape area 1: WMODELSCALED < 150	100	60	20	20	50
Landscape area 2: WMODELSCALED 150-175	180	40	40	20	30
Landscape area 3: WMODELSCALED > 175	260	20	40	40	15

ZONELSRAND was overlain by the landscape area masks (USFSWCLASS1, 2 and 3) each in turn, to isolate the random cell assignments within each landscape area (USFSW1RAND, USFSW2RAND, and USFSW3RAND). Then, using the percentages in Table H.2, the random cells in each landscape area were assigned to aggregation patterns. For example, there were 500 representative cells in landscape area 1 (USFS1RAND), with 500 random values between 1 and 1000. In landscape area 1, 20% of the area is in a large block (aggregated) pattern. The first 500 random values in USFS1RAND were assigned to this pattern (USFSWC1AG). In this way, nine layers were created, three in each landscape area, one for each pattern within each area (USFSWC1AG, USFSWC1MD, USFSWC1DSP, USFSWC2AG, USFSWC2MD, USFSWC2DSP, USFSWC3AG, USFSWC3MD, USFSWC3DSP). Note that this methodology assigned the percentages in Table H.2 to the same percentage of representative cells, rather than using the area of the topographic element. To simplify a rather complex process, it was assumed that on average, topographic element area should be the same across the landscape area, since the landscape areas were designed taking major elevational and topographic trends into account.

The rotation age and aggregation pattern was applied by overlaying the appropriate SIMMAP simulations for the different prescriptions across the entire HRV landscape. Private industrial lands were overlain with the 40AG landscape and low elevation BLM/private industrial checkerboard lands with the 80DSP landscape. Riparian buffers were then applied by overlaying the appropriate riparian layers. Retention levels, which vary by landscape area in the USFS owner/allocation type, were incorporated into the HRV layer by overlaying the landscape area masks, and adding the retention level as the last two digits of the value. Lastly, late successional reserves and wilderness areas were overlain as ALLOLD. The resultant layer consisted of the specified landscape prescription elements assigned to whole landform elements based on their average natural fire regime characteristics embedded in old age classed riparian, aquatic, late successional and wilderness reserves.

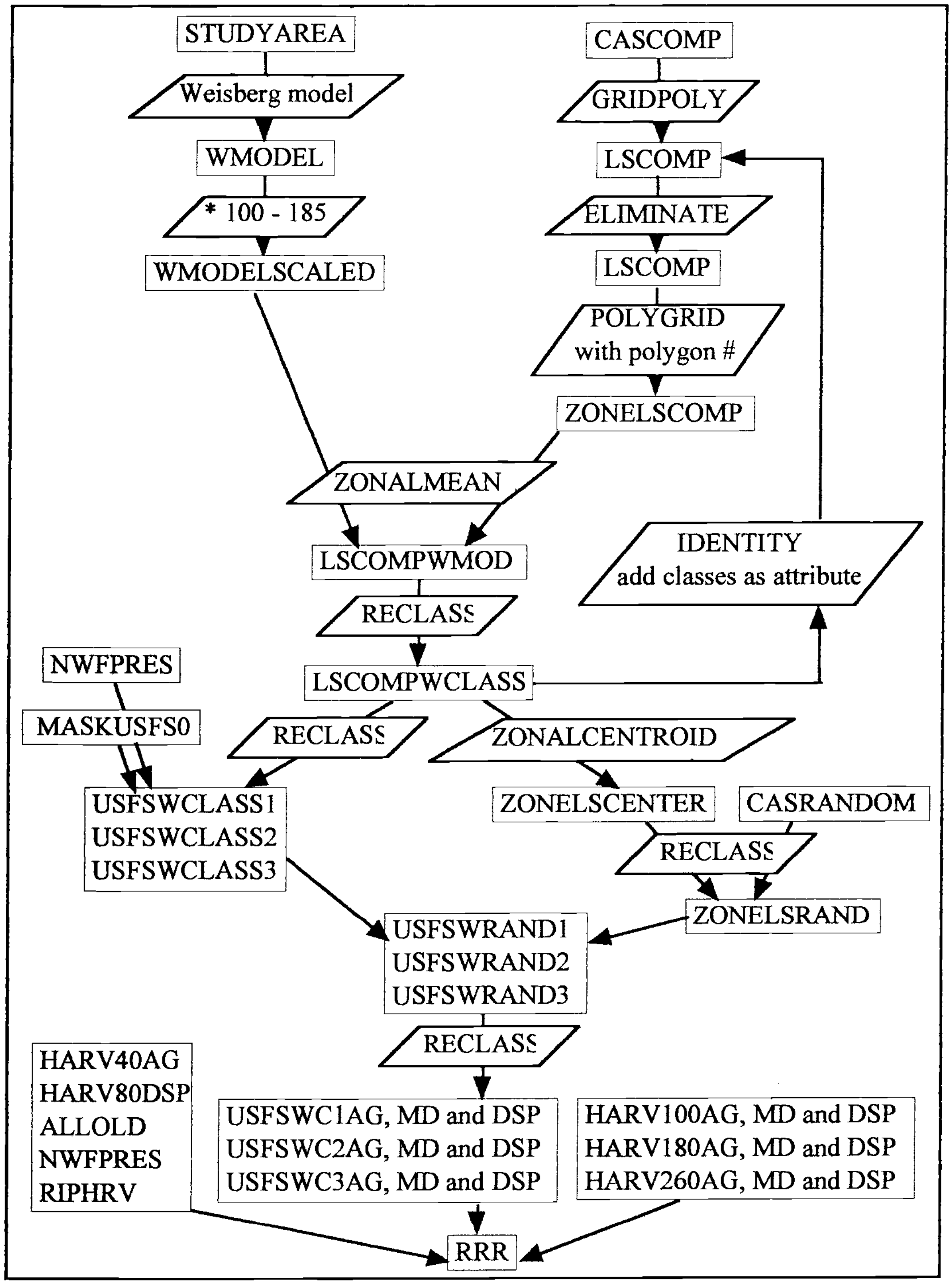

Figure I.1. Flowchart of methods used to create RIP/RES/ROT scenario.

Appendix J: Patch Proximity Analysis (Figure J.1)

For each pixel in every landscape, layers were created that contained a count of pixels of the same age class and of other age classes within eight distance classes (Table J.1). To accomplish this, an AML was written (Appendix A) that constructed circles of increasing radii around each pixel in the landscape, and counted the number of pixels of a given forest type within each circle using the FOCALSUM function. Steps included:

- Construction of four landscapes for each scenario, one for each age class. Each pixel was flagged with a "1" if it contained that age class, "0" if not. For example, the HRVOLD landscape consisted of a "1" in every pixel that was age class 4 in the HRV landscape, "0" if not. For landscapes with riparian buffers, a partially riparian pixel was flagged as both the original age class and as old forest.
- Creation of eight landscapes for each of the four landscapes in step 1, to count the number of same age class pixels for eight distance classes (1,2,4,5,10, 15, 20, 25 pixel radii). For example, the HRVOLD landscape was used to construct an HRVOLOL10 landscape, in which each old forest pixel in the historical range of variability landscape contained a count of the number of additional old forest pixels within a circle of radius 10 pixels.
- Creation of twenty four landscapes for each combination of the four landscapes in step 1 and the landscapes created in step 2, to count the number of different age class pixels for eight distance classes. For example, the HRVOLD landscape was used to construct an HRVOLYO10 landscape (old-young), in which each old age class pixel in the historical range of variability landscape contained a count of the number of young forest pixels within a circle of radius 10 pixels.

Therefore, for each of the 29 fire and harvest landscapes, an additional 32 landscapes were created.

Table J.1. Distance classes used in patch proximity analysis. Classes were constructed in terms of number of cells along the radius of a circle around the target pixel. All cell centers that were within the specified number of cells of the target cell center were included in the count. Therefore, with a 200 m resolution, circles were constructed with radii equal to 200 x the number cells in the radius. The distance class area listed, then, is the area of the cells included, slightly greater than the area of the constructed circle.

Cell distance class	Circle radius (m)	Number of cells	Total cell area
1	200	4	16 ha
2	400	12	48 ha
4	800	48	192 ha
5	1000	80	360 ha
10	2000	316	1264 ha
15	3000	708	2832 ha
20	4000	1256	5024 ha
25	5000	1960	7840 ha

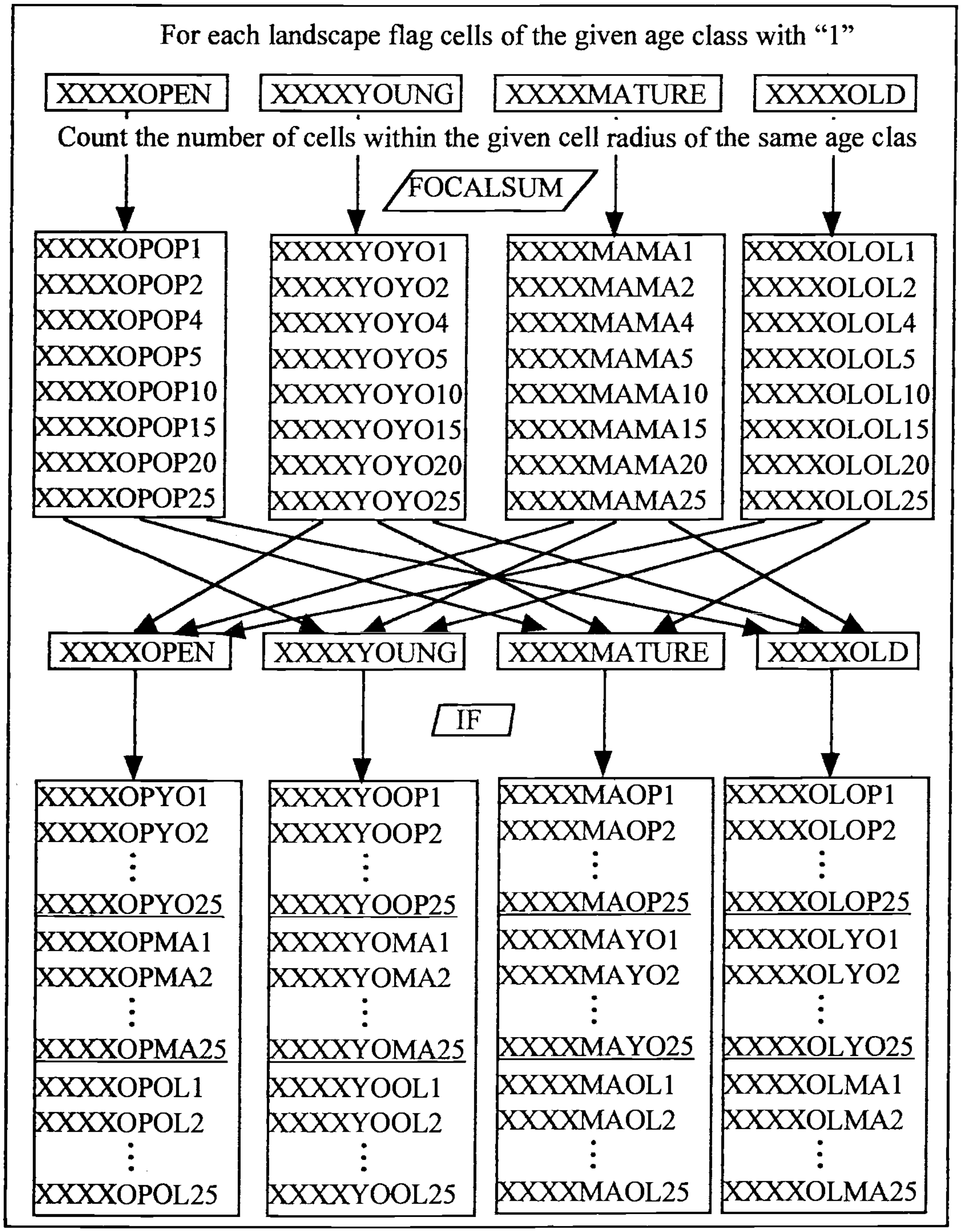

Figure J.1. Flowchart of patch proximity analysis in GIS. Rectangles are data layers; parallelograms are procedures performed on the data.

Appendix K: Stream Distance Classes (Figure K.1)

Stream distance classes were created by first identifying streams using the FILL, FLOWDIRECTION and FLOWACCUM functions, starting with the 200 m DEM. FILL removes sinks from the grid (CASFILL200). FLOWDIRECTION identifies the direction of flow on each pixel (CASFLOWDIR200). FLOWACCUM counts the number of upstream pixels that flow into each pixel. A 50 cell cut-off was used on the flow accumulation grid (CASFLOWACCUM200) to identify streams for this analysis (CASSTREAMS). Then, the STREAMLINK function was used. Stream link identifies contiguous stream segments, and assigns a unique number to each segment (CASSTREAMLINK). For each cell in the grid, the distance to the nearest stream segment was calculated with the EUCDISTANCE function, which outputs two grids: a grid of distance (CASSTREAMDIST) and a grid of the cell value of the nearest stream (CASSTRMLNKZONE), which in this case was the unique segment number from CASSTREAMLINK. For each cell in the grid, the distance to the nearest stream and a unique identifying number for that stream segment is known. CASSTREAMDIST was then classified into five categories: 0 to 200, 201 to 500, 501 to 1000, 1001 to 2000 and 2001 to 3000 meters. No cells were more than 3000 meters from a stream segment.

For each cell in the grid, the length of the nearest stream segment was needed. Stream length was approximated by the count of the number of pixels in each streams segment, identified by the unique number in CASSTREAMLINK. The VAT file from CASSTREAMLINK, listing each unique link value and the count of each value, was used to create a remap table applied against CASSTRMLNKZONE, so that each cell in the grid contained a count of the number of pixels in the nearest stream segment (CASSTRMLENZONE), and against CASSTRMLINK to create a grid of stream length for cells from each stream segment (CASSTRMLEN).

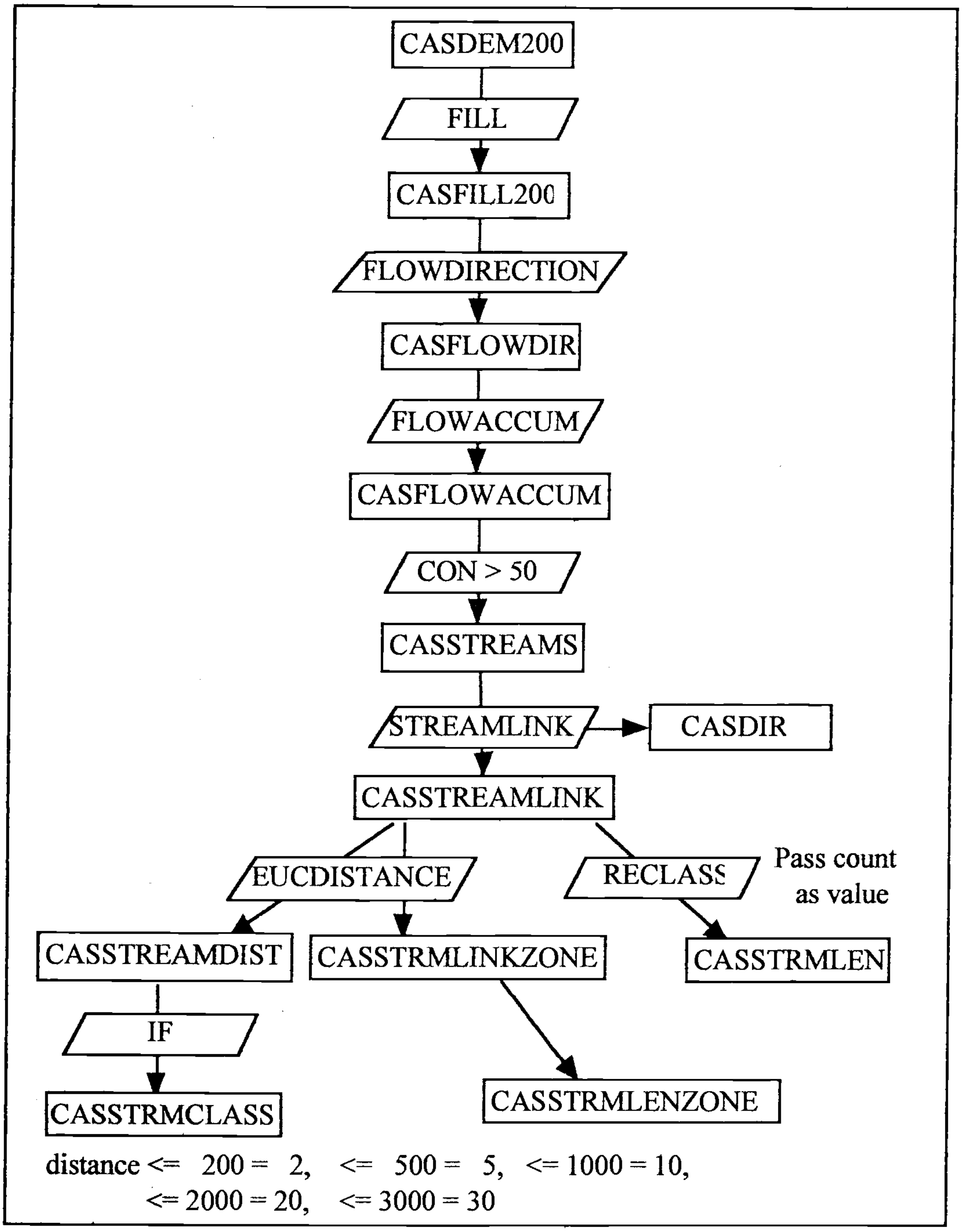

Figure K.1. Flowchart of stream manipulation in GIS. Rectangles are data layers; parallelograms are procedures performed on the data.

Appendix L: Amphibian Species

X = Associated

CA = Closely Associate

Species	Maximum Elevation (m)	Range (ha)	Open	Young	Mature	Old
Northern Leopard Frog	500		X	X	X	X
Oregon Spotted Frog	1000	1	X	X	X	X
Bullfrog	1000	1	X	X	X	X
Tiger Salamander	1000		X	X	X	X
Cope's Giant Salamander	1000		X	X	X	X
Dunn's Salamander	1500		X	X	X	X
Larch Mountain Salamander	1500	1	X	X	X	X
Del Norte Salamander	1500	1	X	X	CA	CA
Columbia Torrent Salamander	1500			X	CA	CA
Cascade Torrent Salamander	1500			X	CA	CA
Foothill Yellow-legged Frog	1500	1	X	X	X	X
Western Red-backed Salamander	1500	1	X	X	X	X
Oregon Slender Salamander	1500			X	X	X
Ensatina	1500	1	X	X	X	X
Clouded Salamander	1500	1			CA	CA
Black Salamander	1500		X	X	X	X
Siskiyou Mountains Salamander	1500		X	X	X	CA
Southern Torrent Salamander	1500	1		X	CA	CA
Red-legged Frog	1500		X	X	X	X
Great Basin Spadefoot	2000		X	X	X	X
Van Dyke's Salamander	2000	1	X	X	X	X
Pacific Giant Salamander	2000		X	X	X	X
Tailed Frog	2000	1	X	X	X	X
Rough-skinned Newt	2000	1	X	X	X	X
Northwestern Salamander	2000		CA	CA	CA	CA
Cascades Frog	2000		X	X	X	X
Pacific Treefrog	2500		X	X	X	X
Western Toad	2500	1	X	X	X	X
Columbia Spotted Frog	2500	1	X	X	X	X
Long-toed Salamander	2500			X	X	X
Olympic Torrent Salamander	2500	1	X	X	CA	CA

Appendix M: Bird Species

X = Associated

CA = Closely Associate

Bird Species	**Maximum Elevation (m)**	**Range (ha)**	**Open/ Semi-open**	**Young Forest**	**Mature Forest**	**Old Forest**
Palm Warbler	500	10	X			
White-tailed Kite	500	100		X	X	X
Northwestern Crow	500	?	X	X	X	X
Barn Owl	500	10000	X			
Purple Martin	500	?	X	X	X	X
Northern Mockingbird	500	10	X	X	X	
Mourning Dove	500	1000	X	X	X	X
Hutton's Vireo	500	10	X	X	X	X
Flammulated Owl	500	50		X	**CA**	**CA**
Green Heren	1000	?	X	X	X	X
Allen's Hummingbird	1000	1	X	X	X	X
Bewick's Wren	1000	10	X	X	X	X
Oak Titmouse	1000	10	**CA**	**CA**	**CA**	X
Western Scrub-jay	1000	10	X	X	X	X
Bushtit	1000	10	X	X	X	X
Wrentit	1000	10		X	X	X
Purple Finch	1000	?		X	X	X
House Finch	1000	?	X	X	X	X
American Goldfinch	1000	500	X	X	X	X
Lewis's Woodpecker	1000	10		X	X	X
Black Phoebe	1000	10	CA	X	X	X
Gray Catbird	1000	10	X	X	X	X
White-throated Swift	1000	1	X	X	X	X
Calif. Quail	1500	50	**CA**	**CA**	**CA**	X
Least Flycatcher	1500	1	X	X	X	X
Red-eyed Vireo	1500	1		X	X	X
Black-capped Chickadee	1500	50	X	X	X	X

Cooper's Hawk	1500	10000	X	X	X	X
Harlequin Duck	1500	?			**CA**	**CA**
Common Goldeneye	1500	1		X	X	X
Ring-necked Pheasant	1500	500	CA	X	X	X
Western Screech-owl	1500	100	X	X	X	X
Ash-throated Flycatcher	1500	10	**CA**	**CA**	**CA**	X
Black-throated Gray Warbler	1500	?	X	X	X	X
Pileated Woodpecker	1500	1000	X	X	X	CA
Hooded Merganser	1500	?			X	**CA**
American Black Duck	1500	1000	C		X	X
Bufflehead	1500	?		X	X	X
Red-shouldered Hawk	1500	1000			X	X
Wild Turkey	1500	1000	CA	X	X	CA
Anna's Hummingbird	1500	?	X	X	X	X
Downy Woodpecker	1500	10	X	X	X	X
Western Kingbird	1500	500	X	X	X	X
Cassin's Vireo	1500	?		**CA**	**CA**	**CA**
Black-billed Magpie	1500	?	X	X	X	X
Spotted Towhee	1500	?	X	X	X	X
Bullock's Oriole	1500	1		X	CA	CA
Sharp-tailed Grouse	1500	500	**CA**	**CA**	**CA**	X
Mountain Quail	1500	500	CA	X	X	X
Calif Towhee	1500	?	**CA**	X	X	
Turkey Vulture	2000	10000	X	X	X	X
Great Blue Heron	2000	10000			X	X
Ferruginous Hawk	2000	10000	X	X	X	
Rough-legged Hawk	2000	10000	X			
Long-eared Owl	2000	1000	X	X	CA	
Common Poorwill	2000	?	CA	X	X	X
Acorn Woodpecker	2000	?		X	X	X
Pacific-slope Flycatcher	2000	1		X	X	CA
Eastern Kingbird	2000	10	X	X	X	X
Northern Rough-winged Swallow	2000	?	X	X	X	X
Bank Swallow	2000	?	X	X	X	X
White-breasted Nuthatch	2000	50	X	X	X	X
Western Bluebird	2000	1	CA	X	X	X
European Starling	2000	10000	X	X	X	X
Yellow-breasted Chat	2000	10	CA	X		
Blue-gray Gnatcatcher	2000	10	**CA**	**CA**	**CA**	
Great Gray Owl	2000	10000	**CA**	X	**CA**	**CA**
Black-chinned Hummingbird	2000	1	X	X	X	X

Band-tailed Pigeon	2000	10000	X	X	X	X
Barred Owl	2000	1000	X	X	**CA**	**CA**
Common Nighthawk	2000	50	CA	X	X	X
Willow Flycatcher	2000	1	X	X		
Say's Phoebe	2000	?	CA	X	X	X
Yellow Warbler	2000	10	X	X	X	
Common Yellowthroat	2000	10	X	X	X	X
Wilsons' Warbler	2000	10	X	X	X	X
Cordilleran Flycatcher	2000	1		X	X	X
Pygmy Nuthatch	2000	10				CA
American Redstart	2000	1	X	X	X	X
Plumbeous Vireo	2000	10		X	X	X
Great Egret	2000	10000			X	X
Killdeer	2000	?	CA			
Spotted Owl	2000	10000	X	X	X	CA
Belted Kingfisher	2000	?	X	X	X	X
Western Wood-pewee	2000	10	X	X	X	X
Warbling Vireo	2000	10	X	X	X	X
American Crow	2000	?	X	X	X	X
Tree Swallow	2000	10000	X	X	X	X
Veery	2000	10	X	X	X	X
Swainson's Thrush	2000	?	X	X	X	X
Nashville Warbler	2000	10	X	X	X	X
Chipping Sparrow	2000	1	X	X	X	X
Brewer's Sparrow	2000	1	X			
Lark Sparrow	2000	10	X	X	X	X
Golden-crowned Sparrow	2000	50	X	X	X	X
Western Meadowlark	2000	10	X	X	X	X
Brown-headed Cowbird	2000	100	X	X	X	X
Boreal Owl	2000	10000	X	X	X	X
Common Merganser	2000	?			X	X
Double-crested Cormorant	2000	10000			X	X
Barrow's Goldeneye	2000	10		X	X	X
Yellow-billed Cuckoo	2000	50			**CA**	**CA**
Barn Owl	2000	1000			X	X
Red-naped Sapsucker	2000	10	X	X	X	X
Loggerhead Shrike	2000	50	**CA**	**CA**	**CA**	X
Varied Thrush	2000	?		X	X	CA
Western Tanager	2000	10	X	CA	X	**CA**
Song Sparrow	2000	10	X	X	X	X
Lazuli Bunting	2000	10	CA	X	CA	X
Brewer's Blackbird	2000	?	X	X	X	X
Pine Siskin	2000	?	X	X	X	X

Calliope Hummingbird	2000	?	X	X	X	X
Gray Flycatcher	2000	10	X	X	CA	X
Juniper Titmouse	2000	10		X	X	
Merlin	2500	10000	X	X	X	X
Vaux's Swift	2500	?	X	X	X	CA
Osprey	2500	10000			X	X
Sharp-shinned Hawk	2500	1000	X	CA	X	CA
Northern Goshawk	2500	10000	X	X	X	X
Swainson's Hawk	2500	1000	X	X	X	X
Red-tailed Hawk	2500	500	X	**CA**	**CA**	X
Chukar	2500	500	X	X	X	
Great Horned Owl	2500	1000	X	X	X	X
Northern Pygmy-owl	2500	500	X	X	**CA**	**CA**
Steller's Jay	2500	?	X	X	**CA**	**CA**
Cliff Swallow	2500	10000	X	X	X	X
Chestnut-backed Chickadee	2500	10	X	X	X	X
Rock Wren	2500	?	X	X	X	X
House Wren	2500	1	X	X	X	X
Winter Wren	2500	1	X	X	CA	CA
Black-headed Grosbeak	2500	10	X	X	X	X
White-winged Crossbill	2500	100	X	X	X	X
Lesser Goldfinch	2500	?	X	X	X	X
Gray Jay	2500	100	X	X	X	X
Green-tailed Towhee	2500	10	**CA**	**CA**	**CA**	X
Pinyon Jay	2500	10000	X	X	X	X
Boreal Chickadee	2500	10	X	X	X	X
Ruffed Grouse	2500	50	**CA**	**CA**	**CA**	X
Blue Grouse	2500	50	**CA**	**CA**	**CA**	CA
Dusky Flycatcher	2500	10	X	X	X	X
Cedar Waxwing	2500	?	X	X	X	X
Orange-crowned Warbler	2500	?	CA	X	X	X
Hermit Warbler	2500	1	X	X	X	X
Vesper Sparrow	2500	1	CA	X	X	X
Hammond's Flycatcher	2500	1		X	X	X
Pine Grosbeak	2500	10	X	X	X	X
Broad-tailed Hummingbird	2500	?	X	X		
Bald Eagle	2500	10000	X	X	X	X
Peregrine Falcon	2500	10000	X	X	X	X
Prairie Falcon	2500	10000	X	X	X	X
Marbled Murrelet	2500	?				CA
Northern Saw-whet Owl	2500	500	X	X	X	X
Rufous Hummingbird	2500	?	X	X	X	X
Williamson's Sapsucker	2500	50		X	X	X

Hairy Woodpecker	2500	10	X	X		
Olive-sided Flycatcher	2500	50	**CA**	**CA**	**CA**	X
Red-breasted Nuthatch	2500	10	X	X	X	X
American Dipper	2500	100	X	X	X	X
Ruby-crowned Kinglet	2500	10	X	X	X	X
Mountain Bluebird	2500	10	CA	X	X	X
Townsend's Solitaire	2500	50	X	X	X	X
American Pipit	2500	10	X	X	X	X
Bohemian Waxwing	2500	?	X	X	X	X
Yellow-rumped Warbler	2500	10	X	X	X	X
Townsend's Warbler	2500	?	X	X	**CA**	**CA**
Fox Sparrow	2500	1	CA	CA	CA	X
Lincoln's Sparrow	2500	?	**CA**	**CA**	**CA**	CA
Dark-eyed Junco	2500	10	**CA**	**CA**	**CA**	**CA**
Cassin's Finch	2500	1	X	X	X	X
Red Crossbill	2500	10	X	X	X	X
Evening Grosbeak	2500	100		X	X	X
Mountain Chickadee	2500	10	X	X	X	X
Sage Grouse	2500	500	X			
Spruce Grouse	2500	50	**CA**	**CA**	**CA**	**CA**
White-tailed Ptarmigan	2500	50	X	X	X	X
White-crowned Sparrow	2500	1	X	X	X	X
Golden Eagle	3000	10000	X	X	X	X
American Kestrel	3000	50	X	X	X	X
Barn Swallow	3000	10000	X			
Macgillivray's Warbler	3000	?	X	X	X	X
Northern Flicker	3000	50	X	X	X	X
Golden-crowned Kinglet	3000	10	X	**CA**	**CA**	**CA**
Hermit Thrush	3000	?	X	X	X	X
American Robin	3000	10	X	X	X	X
Black-backed Woodpecker	3000	1000	CA	X	X	X
White-headed Woodpecker	3000	500	X	X	X	X
Red-breasted Sapsucker	3000	10	X	X	X	X
Three-toed Woodpecker	3000	500	CA	X	X	X
Wood Duck	3000	500			X	CA
Brown Creeper	3000	10	X	X	X	**CA**
Common Redpoll	3000	?	X	X	X	X
Black Swift	3000	?	X	X	X	X
Common Raven	3000	10000	X	X	X	X
Violet-green Swallow	3000	?	X	X	X	X
Savannah Sparrow	3000	10	X	X	X	X
Clarks' Nutcracker	3000	500	X	X	X	X

Appendix N: Mammal Species

X = Associated

CA = Closely Associated

Mammalian Species	Maximum Elevation (m)	Range (ha)	Open/ Semi	Young Forest	Mature Forest	Old Forest
Keen's Myotis	500	?	X	X	X	CA
European Rabbit	500	1	X	X	X	X
Dusky-footed Woodrat	500	1	CA			CA
Virginia Opossum	1000	50	X	X	X	X
Townsend's Mole	1000	1	X	X		
Eastern Cottontail	1000	1	X	X	X	X
Columbian White-tailed Deer	1000	500	X	X	X	
Brush Rabbit	1000	1	X	X	X	X
Ringtail	1000	1000	X	X	X	CA
Spotted Bat	1000	?	X	X	X	X
White-footed Vole	1500	?	X	X	X	X
Long-tailed Vole	1500	1	X	X	X	X
Cascade Golden-mantled Ground Squirredl	1500	?	X	X	X	X
Montane Vole	1500	1	X	X	X	X
Brazilian Free-tailed Bat	1500	?	X			
Pacific Water Shrew	1500	1	X	X	X	X
Yuma Myotis	1500	?	X	X	X	X
Fringed Myotis	1500	?	X	X	X	X
Western Pipistrelle	1500	?	X	X	X	X
Western Gray Squirrel	1500	10	X	X	**CA**	**CA**
Raccoon	1500	10000	X	X	X	X
Mink	1500	50	X	X	X	X
Northern River Otter	1500	10000	X	X	X	X
Pallid Bat	1500	?	X		X	X
Baird's Shrew	2000	1		X	X	X
Pacific Shrew	2000	1		X	CA	CA
California Myotis	2000	?	X	CA	X	X

Townsend's Big-eared Bat	2000	?	X	X	X	X
Townsend's Chipmunk	2000	1	X	CA	CA	CA
California Ground Squirrel	2000	1	CA			
Eastern Fox Squirrel	2000	50	X	X	X	X
Botta's (Pistol River) Pocket Gopher	2000	1	X	X	X	X
Red Tree Vole	2000	?	X	X	X	CA
Common Porcupine	2000	100	**CA**	**CA**	**CA**	**CA**
White-tailed Deer (Eastside)	2000	1000	X	X	X	X
California Kangaroo Rat	2000	?	X			
Pygmy Shrew	2000	1	CA	X	X	X
Coast Mole	2000	1	CA	X	X	X
Nuttall's (mountain) Cottontail	2000	?	X	X	CA	X
Siskiyou Chipmunk	2000	1			X	CA
Ord's Kangaroo Rat	2000	10	X	X		
Red Squirrel	2000	1	X	X	CA	CA
Desert Woodrat	2000	1		X		
Masked Shrew	2000	0.6	X	CA	CA	CA
Fog Shrew	2000	1		CA	CA	CA
Trowbridge's Shrew	2000	1	X	X	X	X
Shrew-mole	2000	1	X	X	X	X
Western Small-footed Myotis	2000	?	X	X	X	X
Silver-haired Bat	2000	?	X	X	**CA**	**CA**
Big Brown Bat	2000	?	X	X	**CA**	**CA**
Columbian Mouse	2000	?	X	X	X	X
Townsend's Vole	2000	1	X	X		
Striped Skunk	2000	500	CA	X	X	X
Roosevelt Elk	2000	1000	X	X	X	X
Moose	2000	1000	X	X	X	X
Mountain Caribou	2000	10000	X		X	X
Olympic Marmot	2000	1	X	X	X	X
Long-legged Myotis	2000	?	**CA**	**CA**	X	CA
Hoary Bat	2000	?	X	X	X	X
Pacific Jumping Mouse	2000	?	CA	X		
Bobcat	2000	10000	X	X	X	X
Montane Shrew	2500	1	X	X	X	X

Little Brown Myotis	2500	?	X	X	X	X
Long-eared Myotis	2500	?	X	X	X	X
White-tailed Jackrabbit	2500	1000	X			
Mountain Beaver	2500	1	CA	X	X	X
Deer Mouse	2500	1	CA	X	X	X
Western Red-backed Vole	2500	10			**CA**	**CA**
American Marten	2500	500		X	X	X
Mountain Lion	2500	10000	X	X	X	X
Broad-footed Mole	2500	1	CA			
Red-tailed Chipmunk	2500	10	X	X	CA	X
Vagrant Shrew	2500	1	X	X	X	X
American Beaver	2500	?	X	X	X	X
Southern Red-backed Vole	2500	1	X	X	X	CA
Fisher	2500	10000		X	X	X
Heather Vole	2500	1	X	X	X	X
Northern Bog Lemming	2500	1	X			
Feral Horse	2500	10000	X	X	X	X
Pronghorn Antelope	2500	500	CA	X	X	X
Water Shrew	2500	1	X	X	X	X
Snowshoe Hare	2500	10	**CA**	**CA**	**CA**	X
Western Pocket Gopher	2500	?	**CA**	**CA**	**CA**	**CA**
Creeping Vole	2500	1	CA	X	X	X
Coyote	2500	10000	X	X	X	X
Gray Wolf	2500	10000	X	X	X	X
Gray Fox	2500	500		X	X	X
Ermine	2500	50	X	X	X	X
Black-tailed Deer	2500	100	X	X	X	X
Mule Deer	2500	10000	X	X	X	X
Northern Flying Squirrel	2500	10	X	X	X	CA
Calif Bighorn Sheep.	2500	10000	X		X	X
Western Jumping Mouse	2500	1	CA	X	X	X
Wolverine	2500	10000	X	X	X	X
Lynx	2500	10000	X	X	X	X
Hoary Marmot	2500	1	X	X	X	X
Columbian Ground Squirrrel	3000	1	CA	CA	CA	X
Black Bear	3000	10000	CA	X	X	CA
Western Spotted Skunk	3000	10000	X	X	X	X
Mountain Goat	3000	50	X	X	X	X

Rocky Mountain Bighorn Sheep	3000	1000	X		X	X
Rocky Mountain Elk	3000	10000	X	X	X	X
Wild Burro	3000	1000	X	X	X	
American Pika	3000	1	CA			
Yellow-bellied Marmot	3000	10	X	X	X	X
Northern Pocket Gopher	3000	?	**CA**	**CA**	X	X
Great Basin Pocket Mouse	3000	1		X	X	X
Pinon Mouse	3000	1		CA	CA	CA
Long-tailed Weasel	3000	50	X	X	X	X
Yellow-pine Chipmunk	3000	10	X	X	X	
Grizzly Bear	3000	10000	X	X	X	X
Allen's Chipmunk	3000	1		CA	CA	CA
Black Rat	3000	?			X	
Belding's Ground Squirrel	3000	1	X			
Douglas' Squirrel	> 3000	1		X	X	CA
Western Harvest Mouse	> 3000	1	X			
Brushy-tailed Woodrat	> 3000	1		X	X	X
Red Fox	> 3000	500	X	X	X	X
American Badger	> 3000	500	CA	X	X	X
Water Vole	> 3000	1	X	X	X	X
Least Chipmunk	> 3000	10	**CA**	**CA**	**CA**	**CA**
Golden-mantled Ground Squirrel	> 3000	10	**CA**	**CA**	**CA**	X
Meadow Vole	> 3000	1	X			
California Vole	> 3000	1	CA			

Appendix O: Reptile Species

X = Associated

CA = Closely Associated

Reptile Species	Maximum Elevation (m)	Range (ha)	Open Forest	Young Forest	Mature Forest	Old Forest
Snapping Turtle	500	10	X	X	X	X
Red-eared Slider Turtle	500	?	X	X	X	X
Plateau Striped Whiptail	500	?		X	X	
Sharptail Snake	1000	?	X	X	X	X
Pacific Coast Aquatic Garter Snake	1000	?	X	X	X	X
Ringneck Snake	1000	1	X	X	X	X
Common Kingsnake	1000	1	X	X	X	X
Calif. Mountain Kingsnake	1000	?	X	X	X	X
Southern Alligator Lizard	1500	?	X	X	X	
Painted Turtle	1500	?	X	X		X
Night Snake	1500	?		X	X	X
Western Pond Turtle	2000	10	X		X	X
Short-horned Liz	2000	10	X	X	X	X
Western Fence Liz	2000	1	X	X	X	X
Western Skink	2000	1	X	X	X	X
Striped Whipsnake	2000	50	X	X	X	X
Western Whiptail	2000	1	X	X	X	X
Gopher Snake	2000	10	X	X		X
Northern Alligator Lizard	2000	?	X	X	X	X
Sagebrush Liz	2000	1	X	X	X	X
Side-blotched Lizard	2000	1	X			
Racer	2000	1	X	X	X	X
Northwestern Garter Snake	2000	?	X	X	X	X
Common Garter Snake	2000	50	X	X	X	X
Rubber Boa	2000	10	X	X	X	X
Western Rattlesnake	2500	10	X	X	X	X
Western Terrestrial Garter Snake	3000	1	X	X	X	X

Appendix O: Reptile Species

X = Associated

CA = Closely Associated

Reptile Species	Maximum Elevation (m)	Range (ha)	Open Forest	Young Forest	Mature Forest	Old Forest
Snapping Turtle	500	10	X	X	X	X
Red-eared Slider Turtle	500	?	X	X	X	X
Plateau Striped Whiptail	500	?		X	X	
Sharptail Snake	1000	?	X	X	X	X
Pacific Coast Aquatic Garter Snake	1000	?	X	X	X	X
Ringneck Snake	1000	1	X	X	X	X
Common Kingsnake	1000	1	X	X	X	X
Calif. Mountain Kingsnake	1000	?	X	X	X	X
Southern Alligator Lizard	1500	?	X	X	X	
Painted Turtle	1500	?	X	X		X
Night Snake	1500	?		X	X	X
Western Pond Turtle	2000	10	X		X	X
Short-horned Liz	2000	10	X	X	X	X
Western Fence Liz	2000	1	X	X	X	X
Western Skink	2000	1	X	X	X	X
Striped Whipsnake	2000	50	X	X	X	X
Western Whiptail	2000	1	X	X	X	X
Gopher Snake	2000	10	X	X		X
Northern Alligator Lizard	2000	?	X	X	X	X
Sagebrush Liz	2000	1	X	X	X	X
Side-blotched Lizard	2000	1	X			
Racer	2000	1	X	X	X	X
Northwestern Garter Snake	2000	?	X	X	X	X
Common Garter Snake	2000	50	X	X	X	X
Rubber Boa	2000	10	X	X	X	X
Western Rattlesnake	2500	10	X	X	X	X
Western Terrestrial Garter Snake	3000	1	X	X	X	X

Appendix P: Age Class Amounts for Wildfire-affected Landscapes: Whole Landscape

Table P.1. Age class amounts for 25 wildfire-affected landscapes, 3 managed landscapes and the 1995 landscape. Amounts are listed for each landscape individually. Wildfire-affected landscapes are from 5 simulation runs, 4 along a fire frequency range and 1 based on the empirical data. Average amounts for the 5 landscapes for each simulation run are shown.

Landscape	Age Class Amounts (percent of landscape)			
	Early Seral (0-30 years)	Young Forest (31-80 years)	Mature Forest (81-200 years)	Old Forest (> 200 years)
Very Infrequent Fire Landscapes				
firevc1300	3.4	23.7	19.3	53.6
firevc1450	10.0	4.8	16.1	69.0
firevc1800	11.0	5.3	6.6	77.1
firevc600	7.3	32.3	17.3	43.1
firevc550	29.6	19.9	15.3	35.2
Mean for very infrequent	12.3	17.2	14.9	55.6
Infrequent Fire Landscapes				
firec2350	8.3	22.3	20.7	48.6
firec2900	14.5	23.8	14.8	47.0
firec3000	14.8	34.1	20.4	30.7
firec750	15.6	30.0	21.6	32.8
firec700	31.2	19.5	12.9	36.4
Mean for infrequent	16.9	25.9	18.1	39.1
Moderate Frequency Fire Landscapes				
firem1600	17.2	37.0	8.1	37.7
firem1650	26.7	14.9	19.2	39.2
firem2050	23.0	19.5	18.0	39.5
firem2400	25.0	15.8	12.1	47.1
firem850	37.7	24.6	12.7	25.0
Mean for moderate	25.9	22.4	14.0	37.7

Appendix Q Age Class Amounts by Owner/Allocation Type for Wildfire-affected, 1995 and Managed Landscapes

Age class amounts by owner/allocation type for 25 wildfire-affected landscapes, 3 managed landscapes and the 1995 landscape. Amounts are listed for each landscape individually. Wildfire-affected landscapes are from 5 simulation runs, 4 along a fire frequency range and 1 based on the empirical data. Average amounts for the 5 landscapes for each simulation run are shown.

Table Q.1. Age class amounts for the U.S. Forest Service wilderness owner/allocation type.

Landscape	Age Class Amounts (percent of landscape)			
	Early Seral (0-30 years)	Young Forest (31-80 years)	Mature Forest (81-200 years)	Old Forest (> 200 years)
Very Infrequent Fire Landscapes				
firevc1300	2.2	9.7	21.4	66.7
firevc1450	1.3	3.8	7.3	87.6
firevc1800	5.2	3.0	0.7	91.2
firevc600	1.2	30.3	9.3	59.2
firevc550	29.4	10.5	9.1	51.0
Mean for very infrequent	7.9	11.5	9.5	71.1
Infrequent Fire Landscapes				
firec2350	4.4	13.9	21.5	60.2
firec2900	6.6	11.7	12.8	68.9
firec3000	3.3	27.2	32.0	37.5
firec750	6.6	28.6	17.1	47.7
firec700	27.7	19.2	4.4	48.7
Mean for infrequent	9.7	20.1	17.5	52.6

Table Q.1, continued.

Moderate Frequency Fire Landscapes				
firem1600	9.6	18.2	12.1	60.1
firem1650	10.0	10.9	11.1	68.0
firem2050	11.1	7.0	31.9	50.1
firem2400	15.6	15.5	5.6	63.2
firem850	21.5	23.0	2.7	52.8
Mean for moderate	13.5	14.9	12.7	58.8
Frequent Fire Landscapes				
firew550	24.1	28.6	15.2	32.1
firew700	20.8	31.9	15.3	32.0
firew1900	25.4	26.8	5.2	42.5
firew2000	25.6	22.0	25.1	27.2
firew1400	34.0	17.9	2.6	45.5
Mean for frequent	26.0	25.5	12.7	35.9
Empirically-Based Fire Landscapes				
firehist550	8.0	24.6	29.6	37.8
firehist2500	14.9	12.5	18.2	54.4
firehist2750	13.2	18.0	12.1	56.8
firehist700	10.7	11.9	13.8	63.5
firehist1700	15.6	11.6	19.0	53.7
Mean for empirical	12.5	15.7	18.5	53.2

Table Q.1, continued.

Managed Landscapes				
RIP	0	0	0	100
RIP/RES	0.6	0.9	0	98.4
RIP/RES/ROT	0.8	1.2	0.4	97.6
Current Landscape				
1995	2.8	8.8	49.0	39.4

Table Q.2. Age class amounts for the U.S. Forest Service non-wilderness owner/allocation type.

Landscape	Age Class Amounts (percent of landscape)			
	Early Seral (0-30 years)	Young Forest (31-80 years)	Mature Forest (81-200 years)	Old Forest (> 200 years)
Very Infrequent Fire Landscapes				
firevc1300	3.2	20.5	10.0	66.3
firevc1450	6.6	3.6	10.4	79.4
firevc1800	6.7	3.2	11.9	78.3
firevc600	4.2	20.6	19.1	56.1
firevc550	20.0	19.9	12.7	47.3
Mean for very infrequent	8.2	13.6	12.8	65.5
Infrequent Fire Landscapes				
firec2350	6.9	14.9	22.2	56.0
firec2900	7.5	20.6	15.4	56.5
firec3000	13.9	31.7	16.9	37.5
firec750	7.1	20.6	27.2	45.1
firec700	19.0	22.0	11.6	47.4
Mean for infrequent	10.9	22.0	18.6	48.5
Moderate Frequency Fire Landscapes				
firem1600	12.3	33.4	9.3	45.0
firem1650	15.2	15.0	19.1	50.6
firem2050	12.9	22.2	17.8	47.2
firem2400	13.1	16.1	10.0	60.8
firem850	29.7	24.5	13.0	32.8
Mean for moderate	16.6	22.2	13.8	47.3

Table Q.2, continued.

Frequent Fire Landscapes				
firew550	23.5	30.8	18.9	26.8
firew700	28.5	29.9	11.0	30.5
firew1900	26.6	26.1	4.9	42.3
firew2000	31.8	26.9	14.6	26.8
firew1400	34.0	25.2	6.3	34.5
Mean for frequent	38.9	27.8	11.2	32.2
Empirically-Based Fire Landscapes				
firehist550	8.3	28.8	22.3	40.5
firehist2500	15.8	18.0	30.9	35.4
firehist2750	17.8	22.1	12.9	47.2
firehist700	14.2	19.7	10.7	55.3
firehist1700	25.9	15.5	17.8	40.7
Mean for empirical	16.4	20.8	18.9	43.8
Managed Landscapes				
RIP	34.6	53.0	0	12.5
RIP/RES	14.3	20.5	0	65.1
RIP/RES/ROT	6.1	10.2	18.8	64.9
Current Landscape				
1995	22.5	9.3	31.4	36.8

Table Q.3. Age class amounts for the private industrial owner/allocation type.

Landscape	Age Class Amounts (percent of landscape)			
	Early Seral (0-30 years)	Young Forest (31-80 years)	Mature Forest (81-200 years)	Old Forest (> 200 years)
Very Infrequent Fire Landscapes				
firevc1300	3.3	20.8	32.0	44.0
firevc1450	11.5	6.1	15.4	67.0
firevc1800	16.9	7.2	1.3	74.6
firevc600	7.1	49.2	15.7	28.0
firevc550	45.6	19.3	23.5	11.6
Mean for very infrequent	16.9	20.5	17.6	45.0
Infrequent Fire Landscapes				
firec2350	9.0	27.1	24.6	39.3
firec2900	19.4	28.8	20.1	31.8
firec3000	14.2	38.1	19.0	28.7
firec750	19.4	48.5	12.9	19.1
firec700	52.8	13.4	11.3	22.5
Mean for infrequent	23.0	31.2	17.6	28.3
Moderate Frequency Fire Landscapes				
firem1600	23.8	37.5	7.8	30.9
firem1650	45.5	14.2	15.6	24.7
firem2050	27.5	21.3	14.8	36.4
firem2400	40.7	15.0	13.4	30.9
firem850	52.9	19.2	11.8	16.1
Mean for moderate	38.1	21.4	12.7	27.8

Table Q.3, continued.

Frequent Fire Landscapes				
firew550	38.0	41.3	10.6	10.1
firew700	48.3	29.4	9.6	12.7
firew1900	46.9	27.0	7.8	18.3
firew2000	43.0	31.7	13.3	11.9
firew1400	58.0	21.0	5.6	15.3
Mean for frequent	46.8	30.1	9.4	13.7
Empirically-Based Fire Landscapes				
firehist550	13.8	14.9	24.2	47.0
firehist2500	22.3	20.7	26.0	31.1
firehist2750	18.6	19.9	34.4	27.0
firehist700	23.3	20.1	5.3	51.3
firehist1700	28.2	16.6	23.6	31.5
Mean for empirical	21.2	18.4	22.7	37.6
Managed Landscapes				
RIP	68.4	22.3	0	9.3
RIP/RES	65.8	21.4	0	12.7
RIP/RES/ROT	58.4	21.7	3.5	16.4
Current Landscape				
1995	49.8	26.2	17.6	6.3

Table Q.4. Age class amounts for the Bureau of Land Management/private industrial checkerboard owner/allocation type.

Landscape	Age Class Amounts (percent of landscape)			
	Early Seral (0-30 years)	Young Forest (31-80 years)	Mature Forest (81-200 years)	Old Forest (> 200 years)
Very Infrequent Fire Landscapes				
firevc1300	4.3	39.9	21.4	34.4
firevc1450	7.9	8.3	34.2	49.5
firevc1800	12.1	10.0	0.0	77.9
firevc600	19.1	36.3	25.0	19.6
firevc550	33.5	34.3	15.4	16.8
Mean for very infrequent	15.4	25.8	19.2	39.6
Infrequent Fire Landscapes				
firec2350	12.7	36.5	17.2	33.6
firec2900	35.7	28.6	8.9	26.8
firec3000	21.1	35.5	28.6	14.8
firec750	23.3	43.1	21.3	12.3
firec700	48.8	22.0	12.7	16.6
Mean for infrequent	28.3	33.1	17.7	20.8
Moderate Frequency Fire Landscapes				
firem1600	27.4	50.1	3.9	18.6
firem1650	47.7	17.7	20.3	14.3
firem2050	42.1	18.4	16.1	23.4
firem2400	42.8	17.3	12.5	27.5
firem850	58.4	22.3	12.3	7.1
Mean for moderate	43.7	25.1	13.0	18.2

Table Q.4, continued.

Frequent Fire Landscapes				
firew550	42.9	32.5	13.1	11.5
firew700	52.0	26.3	10.3	11.4
firew1900	56.1	25.7	6.5	11.8
firew2000	49.9	28.8	8.7	12.6
firew1400	69.5	20.0	3.2	7.3
Mean for frequent	54.1	26.7	8.4	10.9
Empirically-Based Fire Landscapes				
firehist550	20.6	19.9	24.9	34.6
firehist2500	24.7	16.6	17.1	41.5
firehist2750	22.2	16.0	30.4	31.4
firehist700	25.6	21.4	8.9	44.1
firehist1700	22.5	16.0	20.4	41.1
Mean for empirical	23.1	18.0	20.4	38.5
Managed Landscapes				
RIP	37.1	53.7	0	9.2
RIP/RES	22.1	31.0	0	46.9
RIP/RES/ROT	23.9	37.5	0.4	38.2
Current Landscape				
1995	34.3	25.3	27.5	12.9

Appendix R Patch Characteristics for Wildfire-affected, 1995 and Managed Landscapes: Whole Landscape

Patch characteristics for wildfire-affected, 1995 and managed landscapes. Wildfire-affected landscapes include 25 wildfire-affected landscapes from 5 simulation runs along a fire frequency range. Each simulation consists of 5 landscapes that were grouped for these statistics. Average, high and low values are the 5 landscape group. Patch characteristics were calculated using APACK 2.0 (Mladenoff, 1995).

Table R.1. Patch characteristics for the wildfire-affected landscapes.

Age Class	Patch Characteristics		Simulated Fire Frequency Range				Empirically Based Simulation
			Very Infrequent	Infrequent	Moderate	Frequent	
Early Seral	Mean patch size (ha)	Average	1427	1051	1262	1236	876
		High	3288	1793	1984	1709	1151
		Low	535	503	746	902	588
	Largest patch (ha)	Average	126,950	96,670	135,042	149,998	64,934
		High	412,256	163,340	304,104	206,896	107,252
		Low	6488	12,256	45,288	104,456	29,340
	Number of patches	Average	129	249	329	483	328
		High	141	273	362	525	345
		Low	100	229	298	423	319

Table R.1, continued.

	Edge density (m/ha)	Average	1.36	2.26	3.34	5.49	2.89
		High	2.47	3.09	3.65	5.82	3.33
		Low	0.64	1.69	3.09	5.07	2.41
Young Forest	Mean patch size (ha)	Average	593	371	194	110	227
		High	1154	477	364	148	321
		Low	155	188	118	85	142
	Largest patch (ha)	Average	176,048	128,598	123,966	98,240	55,878
		High	447,668	187,752	299,040	168,704	115,964
		Low	5340	78,380	27,296	63,308	27,024
	Number of patches	Average	468	1175	1884	3966	1410
		High	654	1622	2283	4145	1703
		Low	311	772	1578	3597	1190
	Edge density (m/ha)	Average	1.82	3.37	3.80	6.09	3.67
		High	2.80	3.79	4.76	6.79	3.92
		Low	1.01	2.81	3.23	5.17	3.21
Mature Forest	Mean patch size (ha)	Average	628	159	113	62	164
		High	2145	226	165	71	203
		Low	98	104	65	57	128

Table R.1, continued.

Mature forest Cont'd	Largest patch (ha)	Average	178,731	115,800	87,937	27,179	85,202
		High	234,468	193,784	124,424	37,612	163,044
		Low	102,452	54,276	41,156	18,152	32,708
	Number of patches	Average	1051	1977	1998	2679	1879
		High	2439	3083	2477	3665	2363
		Low	48	1024	1446	1579	1178
	Edge density (m/ha)	Average	1.53	2.67	2.30	2.53	3.18
		High	2.17	3.22	3.17	3.65	3.81
		Low	0.61	2.00	1.60	1.37	1.83

Table R.1, continued.

Old Forest	Mean patch size (ha)	Avera ge	328	146	150	71	121
		High	538	190	215	96	130
		Low	108	99	123	50	110
	Largest patch (ha)	Avera ge	702,242	335,359	339,618	104,740	354,66 4
		High	1,167,92 0	423,796	495,880	139,124	667,68 8
		Low	230,608	210,000	164,848	58,396	230,46 8
	Number of patches	Avera ge	3773	4584	4591	5619	4913
		High	5219	5022	5257	6206	5322
		Low	2246	4019	3425	5130	4154
	Edge density (m/ha)	Avera ge	2.91	3.59	4.00	4.48	4.78
		High	3.35	3.84	4.41	5.05	5.01
		Low	2.39	3.18	3.71	4.21	4.53

Table R.2. Patch characteristics of the 1995 and managed landscapes. R = riparian-rule, RR = Riparian-rule plus reserves, RRR = riparian-rule plus reserves and mixed-rotation landscapes.

Age Class	Patch Characteristic	Landscape			
		1995	R	RR	RRR
Early Seral	Mean patch size (ha)	27	109	107	96
	Largest patch (ha)	9320	191,600	168,672	129,608
	Number of patches	10,977	6312	4959	4494
	Edge density (m/ha)	6.4	10.5	7.4	3.0
Young Forest	Mean patch size (ha)	14	535	336	73
	Largest patch (ha)	4952	418,788	147,828	21,704
	Number of patches	11,757	1476	1617	4528
	Edge density (m/ha)	4.7	10.6	7.6	3.3
Mature Forest	Mean patch size (ha)	18	0	0	110
	Largest patch (ha)	6756	0	0	11,072
	Number of patches	16,708	0	0	1975
	Edge density (m/ha)	8.9	0	0	2.1
Old Forest	Mean patch size (ha)	19	497	503	287
	Largest patch (ha)	2584	18,092	157,804	158,832
	Number of patches	13,564	177	983	1874
	Edge density (m/ha)	7.7	0.3	0.9	1.1

Appendix S Patch Characteristics by Owner/Allocation Type for Wildfire-affected Landscapes

Patch characteristics by owner/allocation type, for 25 wildfire-affected landscapes from 5 simulation runs along a range of fire frequency frequencies. Each simulation consists of 5 landscapes that were grouped for these statistics. Average, high and low values are the 5 landscape group. Patch characteristics were calculated using APACK 2.0 (Mladenoff, 1995).

Table S.1. Patch characteristics for the U.S. Forest Service wilderness owner/allocation type.

Age Class	Patch Characteristics		Simulated Fire Frequency Range				Empir-ically Based Simulati on
			Very Infre-quent	Infre-quent	Mod-erate	Frequent	
Early Seral	Mean patch size (ha)	Average	257	220	195	216	205
		High	734	526	264	277	273
		Low	63	114	158	181	142
	Edge density (m/ha)	Average	0.06	0.09	0.17	0.29	0.14
		High	0.17	0.20	0.23	0.31	0.17
		Low	0.02	0.04	0.11	0.27	0.10
Young Forest	Mean patch size (ha)	Average	325	253	131	94	124
		High	617	360	187	130	191
		Low	157	121	82	72	82

Table S.1, continued.

Mature cont'd	Edge density (m/ha)	Average	0.09	0.17	0.17	0.33	0.18
		High	0.19	0.23	0.24	0.39	0.20
		Low	0.04	0.14	0.10	0.25	0.17
Mature Forest	Mean patch size (ha)	Average	312	211	181	72	142
		High	675	287	321	117	209
		Low	82	89	61	46	114
Mature Cont'd	Edge density (m/ha)	Average	0.07	0.14	0.10	0.16	0.18
		High	0.14	0.22	0.21	0.30	0.25
		Low	0.01	0.05	0.03	0.04	0.12
Old Forest	Mean patch size (ha)	Average	355	139	169	79	145
		High	648	236	222	103	197
		Low	135	92	116	57	95
	Edge density (m/ha)	Average	0.28	0.32	0.35	0.33	0.35
		High	0.32	0.36	0.38	0.37	0.38
		Low	0.24	0.28	0.28	0.29	0.29

Table S.2. Patch characteristics for the U.S. Forest Service non-wilderness owner/allocation type.

Age Class	Patch Characteristics		Simulated Fire Frequency Range: Very Infre-quent	Infre-quent	Mod-erate	Freque nt	Empir-ically Based Simulat ion
Early Seral	Mean patch size (ha)	Average	1393	939	885	794	828
		High	2578	1708	1843	1040	1407
		Low	714	546	578	585	421
	Edge density (m/ha)	Average	0.55	0.93	1.45	2.68	1.44
		High	0.99	1.21	1.72	2.74	1.75
		Low	0.32	0.76	1.29	2.58	1.07
Young Forest	Mean patch size (ha)	Average	678	453	287	137	258
		High	1021	572	455	161	447
		Low	230	310	186	118	135
	Edge density (m/ha)	Average	0.78	1.57	1.96	3.28	2.07
		High	1.15	1.85	2.30	3.56	2.35
		Low	0.39	1.44	1.71	2.97	1.80
Mature Forest	Mean patch size (ha)	Average	887	256	177	90	155
		High	2130	337	273	115	202
		Low	146	106	86	76	119

Table S.2, continued.

Mature cont'd	Edge density (m/ha)	Average	0.66	1.40	1.15	1.36	1.69
		High	0.91	1.73	1.64	2.24	2.50
		Low	0.55	0.92	0.69	0.59	1.03
Old Forest	Mean patch size (ha)	Average	355	158	174	85	139
		High	601	202	292	125	203
		Low	165	111	95	66	94
	Edge density (m/ha)	Average	1.59	2.30	2.46	3.02	2.72
		High	1.76	2.41	2.69	3.45	2.82
		Low	1.30	1.97	2.36	2.72	2.53

Table S.3. Patch characteristics for the private industrial owner/allocation type.

Age Class	Patch Characteristics		Simulated Fire Frequency Continuum				Empir-ically Based Simulation
			Very Infre-quent	Infre-quent	Mod-erate	Freq-uent	
Early Seral	Mean patch size (ha)	Average	435	386	472	394	273
		High	1014	877	639	563	363
		Low	179	181	288	293	186
	Edge density (m/ha)	Average	0.47	0.69	1.12	1.56	0.81
		High	1.03	1.16	1.28	1.71	0.97
		Low	0.15	0.43	0.94	1.42	0.65
Young Forest	Mean patch size (ha)	Average	262	214	94	70	111
		High	598	375	173	100	125
		Low	108	64	57	49	99
	Edge density (m/ha)	Average	0.59	1.00	0.99	1.53	0.88
		High	1.12	1.24	1.32	1.73	1.02
		Low	0.30	0.62	0.82	1.24	0.75
Mature Forest	Mean patch size (ha)	Average	230	89	59	37	124
		High	474	144	72	41	159
		Low	69	42	52	32	63

Table S.3, continued.

Mature cont'd	Edge density (m/ha)	Average	0.49	0.70	0.61	0.58	0.85
		High	0.87	0.82	0.78	0.87	1.13
		Low	0.04	0.51	0.42	0.36	0.28
Old Forest	Mean patch size (ha)	Average	177	85	75	32	92
		High	336	132	99	42	137
		Low	25	57	41	21	60
	Edge density (m/ha)	Average	0.91	0.85	0.98	0.81	1.23
		High	1.21	1.01	1.10	0.95	1.42
		Low	0.68	0.72	0.81	0.69	1.05

Table S.4. Patch characteristics for the Bureau of Land Management/private industrial checkerboard owner/allocation type.

Age Class	Patch Characteristics		Simulated Fire Frequency Range: Very Infre-quent	Infre-quent	Mod-erate	Freq-uent	Empir-ically Based Simula tion
Early Seral	Mean patch size (ha)	Average	234	221	298	248	181
		High	444	348	480	347	219
		Low	114	121	165	189	152
	Edge density (m/ha)	Average	0.34	0.66	0.87	1.26	0.60
		High	0.63	0.91	0.93	1.35	0.64
		Low	0.13	0.43	0.80	1.18	0.53
Young Forest	Mean patch size (ha)	Average	200	128	72	46	75
		High	334	171	141	57	91
		Low	114	75	50	36	66
	Edge density (m/ha)	Average	0.52	0.85	0.79	1.07	0.64
		High	0.75	1.00	1.22	1.25	0.71
		Low	0.27	0.62	0.65	0.82	0.58
Mature Forest	Mean patch size (ha)	Average	106	56	43	25	87
		High	255	71	58	32	108
		Low	12	47	16	17	56

Table S.4, continued.

Mature Cont'd	Edge density (m/ha)	Average	0.42	0.54	0.48	0.39	0.59
		High	0.60	0.78	0.69	0.61	0.80
		Low	0.00	0.29	0.24	0.18	0.33
Old Forest	Mean patch size (ha)	Average	113	59	44	25	80
		High	278	92	71	32	93
		Low	35	32	20	21	63
	Edge density (m/ha)	Average	0.72	0.52	0.56	0.50	0.92
		High	1.05	0.71	0.76	0.56	0.99
		Low	0.53	0.43	0.32	0.34	0.86

Appendix T Patch Characteristics by Owner/Allocation Type for the 1995 and Managed Landscapes

Patch characteristics by owner/allocation type, of the 1995 and managed landscapes. Patch characteristics were calculated using APACK 2.0 (Mladenoff, 1995). R = riparian-rule, RR = Riparian-rule plus reserves, RRR = riparian-rule plus reserves and mixed-rotation landscapes.

Table T.1. Patch characteristics for the U.S. Forest Service wilderness owner/allocation type.

Age Class	Patch Characteristic	Landscape			
		1995	R	RR	RRR
Early Seral	Mean patch size (ha)	7	0	13	12
	Edge Density (m/ha)	0.1	0	0	0
Young Forest	Mean patch size (ha)	8	0	15	14
	Edge Density (m/ha)	0.2	0	0	0
Mature Forest	Mean patch size (ha)	36	0	0	16
	Edge Density (m/ha)	0.7	0	0	0
Old Forest	Mean patch size (ha)	24	1366	1351	1347
	Edge Density (m/ha)	0.6	0.2	0.2	0.1

Table T.2. Patch characteristics for the U.S. Forest Service non-wilderness owner/allocation type. R = riparian-rule, RR = Riparian-rule plus reserves, RRR = riparian-rule plus reserves and mixed-rotation landscapes.

Age Class	Patch Characteristic	Landscape			
		1995	R	RR	RRR
Early Seral	Mean patch size (ha)	18.0	72.8	60.6	22.3
	Edge Density (m/ha)	3.5	6.7	3.9	1.1
Young Forest	Mean patch size (ha)	9.0	1081.1	504.0	40.4
	Edge Density (m/ha)	1.9	6.8	4.1	1.5
Mature Forest	Mean patch size (ha)	19.3	0	0	117.6
	Edge Density (m/ha)	5.4	0	0	2.0
Old Forest	Mean patch size (ha)	24.3	219.7	592.0	243.5
	Edge Density (m/ha)	6.0	0.1	0.7	1.0

Table T.3. Patch characteristics for the private industrial owner/allocation type. R = riparian-rule, RR = Riparian-rule plus reserves, RRR = riparian-rule plus reserves and mixed-rotation landscapes.

Age Class	Patch Characteristic	Landscape			
		1995	R	RR	RRR
Early Seral	Mean patch size (ha)	51.6	683.1	717.2	338.4
	Edge Density (m/ha)	1.6	1.4	1.3	0.9
Young Forest	Mean patch size (ha)	20.0	74.3	74.9	60.5
	Edge Density (m/ha)	1.4	1.0	1.0	0.7
Mature Forest	Mean patch size (ha)	10.3	0	0	41.3
	Edge Density (m/ha)	1.2	0	0	0.2
Old Forest	Mean patch size (ha)	7.0	27,4	117.1	60.0
	Edge Density (m/ha)	0.5	0.0	0.1	0.1

Table T.4. Patch characteristics for the Bureau of Land Management/private industrial checkerboard owner/allocation type. R = riparian-rule, RR = Riparian-rule plus reserves, RRR = riparian-rule plus reserves and mixed-rotation landscapes.

Age Class	Patch Characteristic	Landscape			
		1995	R	RR	RRR
Early Seral	Mean patch size (ha)	27.8	42.8	38.3	34.8
	Edge Density (m/ha)	1.1	2.0	1.7	0.9
Young Forest	Mean patch size (ha)	17.2	185.0	146.6	130.0
	Edge Density (m/ha)	1.1	2.0	1.7	1.0
Mature Forest	Mean patch size (ha)	13.8	0	0	11.4
	Edge Density (m/ha)	1.3	0	0	0.0
Old Forest	Mean patch size (ha)	9.4	12.7	149.6	190.0
	Edge Density (m/ha)	0.7	0.0	0.2	0.1