AN ABSTRACT OF THE THESIS OF

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Analysis of the long-term spatial pattern and dynamics of hardwood patches in the Coast Range of Oregon provides numerous ecological insights. Natural and anthropogenic disturbances have contributed to the development of a patchy mosaic of vegetation types in the area. Some hardwood patches in the Coast Range may be the precursors to stable vegetation states. The five objectives for the study were to: 1) develop the methodology for studying patch dynamics at landscape scales; 2) describe changes in the areal extent and occurrence of hardwood patches; 3) characterize the sizes and shapes, and size and shape changes of hardwood patches in the west-central Coast Range of Oregon; 4) describe the shift in within-patch heterogeneity and within-patch vegetation composition features of hardwood patches; and 5) characterize patches occurring in riparian areas. A viable methodology was developed for the detailed study of the change in vegetation patches across landscapes using scanned, georeferenced aerial photos, aerial photo interpretation of hardwood patches, and GIS techniques.

Patch locations and characteristics were compared to a suite of environmental and other variables. The hardwood patch mosaic was not a stable landscape feature. The total area covered by hardwood patches, the weighted mean size of hardwood patches, and the number of patches sampled declined from 1939 to 1993. Forest Service lands showed the most dramatic drop in hardwood area, while private non-industrial lands showed the most dramatic increase in hardwood area. Most patches present in 1939 either disappeared or decreased in size. In 1993, hardwood patches were found closer to streams and on lower slope positions than in 1939. This may be associated with historic disturbance patterns of fire, logging, and grazing that occurred on the upper slopes, allowing for alder establishment on these sites. Hardwood patch shapes became more complex over time, especially in riparian areas. Core area:edge area ratios increased. Hardwood patches were less heterogeneous in within-patch composition than expected, with large conifers the main non-hardwood cover type within patches; within-patch heterogeneity declined during the study period. Recent management practices are likely increasing hardwood fragmentation and shape complexity, and restricting the landscape distribution of hardwood patches.

Spatial Pattern and Dynamics of
Hardwood Patches
in the
Coast Range of Oregon,
1939-1993

by

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Dean of Graduate School

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

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Rebecca Susan Hess, Author

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SPATIAL PATTERN AND DYNAMICS OF HARDWOOD PATCHES IN THE COAST RANGE OF OREGON, 1939-1993

INTRODUCTION

Patches of deciduous and broadleaved hardwood trees are important to biodiversity and vegetation dynamics in Oregon's Coast Range. Hardwood tree species present in the west-central portion of the coastal mountains in Oregon typically include red alder (*Alnus rubra* Bong.) bigleaf maple (*Acer macrophyllum* Pursh), pacific madrone (*Arbutus menziesii* (Pursh)), giant chinkapin (*Castanopsis chrysophylla* Dougl. A. DC.), black cottonwood (*Populus trichocarpa* Torr. & Gray), Oregon ash (*Fraxinus latifolia* Benth.), and the occasional Oregon white oak (*Quercus garryana* Dougl.). Patches, or stands, of hardwoods are often dominated by red alder, with small groups of bigleaf maple present as a less common but important secondary patch type. Black cottonwood and Oregon ash are customarily found along wider valley bottoms in alluvial areas (DeBell 1990; Owston 1990).

Hardwood trees contribute to the region's biodiversity and can determine the rate and pathway of forest development. As early successional species, they play a considerable role in forest succession and forest regeneration, and can reflect the history of disturbance of an area, either from landslide or flood-related soil disturbance or management disturbance. Hardwood trees provide habitat and contribute to the nitrogen enrichment of soils. Hardwood trees provide food and cover for a variety of birds, small mammals, rodents, and invertebrates (McComb 1994) and serve as crucial riparian corridors, where red alder is a common overstory tree on alluvial landforms (Hawk and Zobel 1974). Their fallen leaves and downed wood provide high quality litter (Perry et. al 1987; Fried et al. 1990), downed wood for streams, and shade crucial for salmonids and other fish in riparian areas. Hardwood tree species can enhance the stability of soils in landslide and flood-prone areas (Minore and Weatherly 1994), persisting where conifer species may not tolerate periodic high water levels, and regenerating rapidly on disturbed sites (Haeussler et al. 1995; DeBell 1990; McDonald and Tappeiner 1990; Owston 1990). Stands of red alder trees serve as effective fire breaks between conifer patches, enhance soil fertility by raising nitrogen levels in the soil (Tarrant and Trappe 1971; Perry et al. 1987; Tarrant et al. 1969; Berg and Doerksen 1975), and are also effective inhibitors of the spread of *Phellinus weirii*, the root rot fungus which can cause extensive mortality in Douglas-fir patches throughout the Coast Range (for more information on biological characteristics of hardwoods, please consult Appendix A). Higher richness of herbaceous species was found under a 40-year-old canopy comprised of red alder hardwood trees than under a Douglas-fir canopy of similar age (Franklin and Pechanec 1968).

While many individual tree-level studies of hardwoods exist (see, for example, Hibbs et al. 1994; Trappe et al. 1968), no broad-scale studies of hardwood patches in the Pacific Northwest have been undertaken. This is not surprising given the dearth of studies on the regional dynamics of plant patches, and the difficulty of studying processes operating at large temporal and spatial scales (Eriksson 1996). As a result, though, we know relatively little about how hardwood patches are distributed across the landscape or how hardwood patches vary in size, shape, or within-patch heterogeneity. Taking a landscape perspective in the study of hardwood patches augments the individual tree- or stand-level approach. The landscape-level patch perspective enhances tree- or stand-level data with spatially explicit patch pattern information. Links can be made to within-patch analyses in which experiments or other fine-scale analyses have been carried out, if stands where experiments or fine-scale analyses have been undertaken are also sampled during the landscape-level analysis. Considering the patch as the unit of measure provides insights into the dynamics of a population of patches. Over broad scales such as the Coast Range of Oregon, taking the patch perspective allows for explorations of how the population of hardwood patches is distributed and how it has changed over time. This perspective enhances the common understanding of how hardwood patches may reflect disturbance patterns on the landscape, and can increase the accuracy of predictions about future hardwood patch distributions. Understanding the spatial distribution of hardwood patches in an area can also aid in determining successional trajectories in the area. Scaling up from the stand-level examination of hardwoods to the examination of the regional dynamics of hardwood patches can also aid in resolving concerns derived from stand-level studies about potential stable states of hardwood stands. Patch sizes, shapes, and spatial distributions are also important to understand from a forest dynamics modelling perspective. The distribution, size and shape of hardwood patches may also reflect hydrological properties, as they often occur in riparian areas, which are prone to floods and landslides; an absence of hardwood patches in an area might imply an infrequency of this kind of disturbance, while irregularities in the size or shape of patches in riparian areas may reflect finer scale disturbances. Tracking the changes in hardwood patches over time allows for the long-term spatial dynamics of patches to be better understood, and renders explicit many features of hardwood stands that have to date only been inferred from stand- and individual tree-level studies. The patch perspective allows for detailed analyses of the dynamics of individual patches and of all patches of a particular type, whereas the landscape perspective would more commonly consider that patch type in relation to other patch types.

Hardwood stands are an early successional stage, establishing readily after disturbance, especially logging, landslide or flood (Harrington et al. 1994). In the Pacific Northwest, barring further stand replacement disturbances, hardwood stands with a salmonberry component in the understory typically develop over time into stands dominated by large conifers (Franklin and Dyrness 1988), which represent a later successional stage or sere. This typically occurs with the release of suppressed shade-tolerant conifer trees in the hardwood stand as hardwood trees die and leave gaps in the canopy. The transition from hardwoods to conifer stands occurs throughout the landscape as a function of environmental variability and disturbance.

Disturbance has become accepted in recent years (see, for example, Pickett and White 1985) as a critical factor constraining the successional process. Disturbance affects succession by setting the vegetation back to an earlier successional stage, and the time since last disturbance is the primary determinant of patch characteristics. Differences in disturbance and environmental variability, such as seed availability or site productivity, result in the potential for multiple pathways (Hemstrom and Logan 1986) in the development of these stands.

Multiple pathways are determined largely by the size, shape, type, and location of disturbance events. For example, if no fire occurs in a hardwood stand, salmonberry are present in the understory, and shade tolerant conifer seed is unavailable in the stand, the stand may eventually become a salmonberry field. If the stand undergoes fire or other stand replacement disturbance and Douglas-fir seed is available within the first few years following fire, the stand could become a Douglas-fir/salmonberry stand. If no Douglas-fir seed is available following a fire event, the stand is likely to again develop as a hardwood/salmonberry stand. These are three of the multiple pathways of forest development that are possible in Coast Range hardwood stands (Hemstrom and Logan 1986).

Recent theoretical work also indicates the potential for quick transitions between alternate stable vegetation states (Hobbs 1994). Transitions between vegetation states might occur because of historic disturbances, environmental changes, or management activities (Figure 1). Transitions can occur quickly because of sudden changes in the environment or disturbance regime, such as increased rainfall or a fire event. These transitions have the potential to result in relatively stable vegetation conditions. Different stable vegetation states are possible, given the history of the stand. The current condition of the vegetation of a particular area may be the result of myriad, spatially distinct historical events (e.g. disturbances) occurring at different scales (after Levin 1992) and with different frequencies. Thus, different vegetation conditions are possible, even though environmental conditions within the area are relatively uniform.

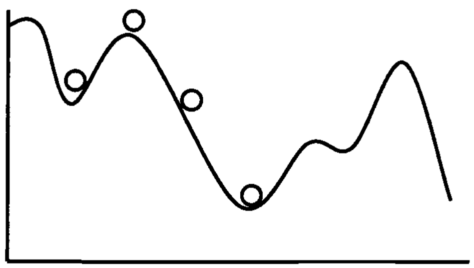

Figure 1. Conceptual model of alternate stable states. (Modified from DeAngelis and Waterhouse 1987, Fig. 1: types of equilibrium points.) Ball indicates different vegetation conditions at a site. Peaks indicate energy required in the form of disturbance/ environmental change/ management activity (analogous to transition probability) to shift from one vegetation condition to another. Without input, stable vegetation stays in the given condition (stable state; ball is in trough). Ball follows a higher energy path to reaches another stable state or vegetation condition. If transition probability is high, ball is more likely to reach top of peak and change from one stable state to another. Ball at top of peak is in unstable equilibrium or metastable condition, requiring little energy change to shift states. Ball on side of hill is in transition between vegetation conditions (not at equilibrium). A particular vegetation condition may occur on the basis of different combinations of historical events. Different vegetation conditions are possible even if environmental conditions at the site are similar.

Some hardwood patches in the Coast Range may be the precursors to stable vegetation states. Hardwood stands could be devoid of conifer seedlings based on past disturbance (e.g., fire or clear-cut logging) and competition that entirely removed conifers from the site. Conifer-devoid hardwood stands have been documented in the Coast Range of Oregon (Carlton 1988; Shrader 1998; Monleon, unpublished data). If there is a prominent shrub component in the understory, hardwood seedlings could have difficulty establishing and surviving. When the hardwood trees present in the stand die, the stand could undergo a transition into large shrub fields, which would then remain relatively stable if the dense shrub cover prevents the establishment of tree seedlings and disturbance events do not alter the site (Newton and Cole 1994; Tappeiner et al.

1991). Thus, hardwood patches could develop into shrub patches which remain on the landscape indefinitely as stable landscape features until the next large-scale disturbance event.

Understanding the long-term dynamics of hardwood patches not only has the potential to provide ecological insights, it also can inform forest policy-makers and managers. Hardwoods historically have received less attention than the conifers in research, perhaps because conifers predominate in large portions of the Coast Range landscape and are the primary source of timber revenues in the region. However, new policy emphases on fish and wildlife (FEMAT 1993) and the broad scale conservation of biodiversity in the region, exemplified by the recent additions of nine Pacific Northwest salmon and steelhead species to the endangered species list, require a comprehensive understanding of the ecological role of hardwoods and other species groups at watershed and landscape scales. The knowledge of the spatial dynamics of Coast Range hardwood trees, which are common in many streamside areas, may be important to regional salmonid recovery success and watershed management.

Hardwood patches in the Coast Range of Oregon also occur in a multi-owner landscape. Forest practices in the state of Oregon currently operate under a variety of policy mandates (FEMAT 1993; Oregon Department of Forestry 1997), which themselves are subject to review and revision (see, for example, Johnson 1999). This condition creates a shifting mosaic of management plans at the landscape level. The diversity of management approaches and applications is reflected in the vegetation patterns on the landscape, and has consequences for biodiversity via the presence and size of critical patch types, the formation of wildlife corridors, and the like. For example, epiphytic lichens were found at 25 to 40 percent higher abundances in areas with hardwood tree- and shrub-filled gaps in the conifer canopy, remnant large conifers, and "wolf" trees (trees with large-diameter lower branches) than in randomly selected plots in the more homogeneous forest (Neitlich and McCune 1996). Managing for these kinds of areas (e.g., the formation of canopy gaps) may enhance future lichen diversity (Neitlich and McCune 1996).

In addition, a recent increase in the economic demand for hardwoods, especially for red alder and bigleaf maple (please see Appendix B for more details), requires an enhanced understanding of the distribution and spatial and temporal dynamics of hardwood patches in order to provide a reliable source of wood to these markets. Counter to the opinion that hardwoods are increasing in abundance, hardwood species currently are declining in abundance in Oregon (Ohmann, personal communication). Having explicit information about where persistent patches occur and where hardwood patch sizes are declining on the landscape (by topography or ownership, for example) may allow managers to better understand and plan for the spatially-related constraints of future wood supplies. Understanding the factors that affect the spatial patterning of hardwood tree patches, then, has important consequences for forest policy makers and managers in both the public and private sector.

Understanding the distribution of hardwood patch size structure also has important implications for the spatial modeling of forest dynamics. Spatial models require that a minimum area for spatial resolution of the model elements be set prior to running the model. It is important to choose the largest feasible size for this unit area, so that the model may be run over the largest area and in the shortest time, without losing any key landscape components. However, these models must also accommodate the goal of realistic depiction of landscape components. The critical minimum resolution size and size distribution structure for hardwood patches remains unknown. Because hardwoods are an important landscape component, it is important to determine this minimum patch size threshold and the structure of the patch size distribution, so that the hardwood component in the landscape will be represented accurately in these spatial models.

Patch Dynamics Described

A patch has been defined as any relatively homogeneous nonlinear surface area that differs in appearance from its surroundings, with any internal microheterogeneity present repeated in similar form throughout the area of a patch (Forman 1995). Patch dynamics can be defined generally as the suite of changes these patches undergo over time and space. Patch dynamics has become a widely accepted concept in application to forested landscapes. Disturbance is a crucial component to the concept of patch dynamics, with the bulk of forest patch dynamics literature focused on canopy gap formation and closure and the effects of disturbances on forest structure (see, for example, Franklin and Forman 1987, Hibbs 1982, Canham et al. 1990, Runkle and Yetter 1987). Pickett and White (1985) emphasize that patch dynamics should be considered as a general term, differing from the shifting mosaic concept, in which patches are at an equilibrium when examined at a landscape level (Bormann and Likens 1979) However, most patch mosaics are rarely in equilibrium. In contrast, the patch dynamics concept should be used in the vast number of cases wherein a shifting equilibrium condition has not been demonstrated. Measures of patch dynamics, or the rate, trajectory and duration of change in the size, shape, composition, and distribution of forest patches, can be influenced by a variety of factors. Forest patches may be affected by the vegetation occurring in and near the patch (which affects growing conditions and propagule availability), the soils present at the site, the amount and timing of water availability, the functioning of heterotrophs, climatic and microclimatic conditions, disturbance factors such as fire, landslides, floods, windstorms, and logging, and by the time elapsed since the occurrence of these disturbances (Figure 2).

Patch Dynamics (size, shape, composition, distribution)	=	***Patch Vegetation + Nearby Matrix Vegetation + Soils + Heterotroph Activity + Available Moisture + Climate/Microclimate + Disturbance (e.g. floods, landslides, windstorms, logging, fire, climate change) + Time since Disturbance***

Figure 2. A Conceptual Model of Patch Dynamics.

Many studies have been undertaken on patch fragmentation and the distribution of patch types in landscapes (see, for example, McGarrigal and McComb 1995; Spies et al. 1994; Ranta et al. 1998; Gibbs 1998). One of two approaches is common for these kinds of studies. Either a relatively restricted area such as a watershed, riparian zone, or rocky intertidal zone, may be mapped exhaustively and all patch types designated, with little emphasis on broad-scale landscape patterns or temporal changes. Or, the converse, a very large area may be mapped but without attention to detail on precise patch boundaries or within-patch heterogeneity. In the Pacific Northwest, for example, the region's vegetation has been mapped historically at coarse scales (see, for example, the 1936 "Forest Type Map of the State of Oregon") and historic vegetation patterns inferred from historic maps based on General Land Office survey notes from the 1850s-1880s (Teensma et al. 1991). Both of these broad scale analyses have their strengths, but neither provides a thorough diagnosis of the temporal, spatial, and within-patch dynamics of particular patch types across broad scales. As a result, little is known, for example, about the conditions surrounding hardwood tree patch size, shape, and composition changes.

Anecdotal remarks indicate that the spatial extent of hardwood tree patches across the Coast Range landscape has increased since the onset of European settlement through a combination of catastrophic fire and logging (Carlton 1988; Hibbs 1994), either of which would be likely to set back the successional stage of a patch from conifer to hardwood. However, the supposed expansion of hardwood patches has not been substantiated through landscape analysis of hardwood patch patterns and dynamics, nor have the ecological mechanisms or spatial patterns underlying the successional transitions of hardwood tree patches, particularly alder, been described (Tarrant et al. 1994). This study bridges the gap between the broad, regional approach and the fine-scale, within-stand approach to patch analysis in its examination of the regional dynamics of hardwood patches, providing an example of an approach that can be applied to any area.

Disturbance Effects

Natural and anthropogenic disturbances have contributed to the development of vegetation patterns in the study area. The most influential historic natural disturbance type in the Coast Range has been catastrophic fire, at intervals of 200-300 years (Impara 1997; Agee 1993; Long et al. 1998). Other common natural disturbances occurring at finer scales include floods, landslides, laminated root rot fungus, and windthrow (Spies and Cline 1988; Orr 1963; Gedney 1981; Strome 1986). The primary anthropogenic disturbances prior to European settlement were the frequent fires initiated by Native Americans to clear areas of shrubs in order to promote hunting (Hays 1976). With the arrival of European settlers, fires set to clear land for grazing and homesteading, and logging, replaced these other disturbance types as the most influential disturbance features on the landscape (Strome 1986). During the time period encompassed by this study, further alterations to the disturbance regime have occurred. Fire suppression has become common practice, clear-cut harvest methods have replaced the selective harvest techniques used more commonly by early settlers, recent regulations have caused a reduction in the allowable size of harvest units (Oregon Department of Forestry 1997), and agriculture has seen a decline (Lettman, personal communication). Clear-cut logging and associated road building have replaced the other forms of disturbance to become most common forms of disturbance in the area. These shifts in disturbance types and the associated shifts in the temporal and spatial extent of disturbances have contributed to the patchy mosaic of vegetation types in the area.

Questions and Objectives

What have been the dynamics and pattern of hardwood stands under these conditions? The general objective for this study is to characterize the spatial pattern and dynamics of hardwood patches in the Coast Range of Oregon. Hardwoods, as early successional species, would have established quickly following patchy wildfires and landslides. They are likely to have established in areas that had been previously burned by Native Americans or European settlers, once this burning had ceased. In this context of the shift in types and sizes of disturbance, a complex mosaic of forest stands could have resulted. Several questions arise about hardwood stands in this context of disturbance. How are hardwood stands distributed across the landscape? Is more of the area in hardwoods now than was the case in the earlier part of the century? Where do most of the hardwoods occur? Are there more, smaller patches now than there were earlier in the century, or are there fewer, larger patches? Have the earlier patches fragmented?

This study evaluates the long-term dynamics of hardwood stands in the west-central portion of Oregon's coastal mountains using a chronosequence of aerial photographs, from 1939 and 1993. The five objectives for the study are to:

- **Develop the methodology for studying patch dynamics at landscape scales.**
- **Describe changes in the areal extent and occurrence of hardwood patches.**
- **Characterize the sizes and shapes, and changes in size and shape of hardwood patches in the west-central Coast Range of Oregon.**
- **Describe the shift in within-patch heterogeneity and within-patch vegetation composition features of hardwood patches.**
- **Characterize patches occurring in riparian areas.**

My first objective is to develop the methodology for studying patch dynamics at landscape scales. To date, aerial photo-based landscape scale studies have encompassed a broad range of topics, including exhaustive mapping of particular areas and consideration of inter-patch type dynamics over long time periods. However, most commonly, they have not rendered photos into digital form and analyzed a time series of photos using computer-based Geographic Information Systems technology (e.g., Brown and Carter 1998, Zampella and Lathrop 1997). This has led to an absence of procedural guidelines when one undertakes a broad scale, detailed patch analysis of this kind. The development of repeatable procedures may be of use to others who seek to undertake highly detailed, patch-level studies across geographically expansive landscapes.

My second objective is to describe changes in the areal extent and occurrence of hardwood patches. How might the apparent conversion of forest stands in recent decades to young conifer stands, by planting and the application of broadleaf herbicides, have affected the extent and distribution of hardwood stands? Differences in the number of patches, in the locations of patches, and in the total area covered by hardwood patches, are likely to occur over the 54-years covered by this study. I expect that private lands will show a somewhat static trend in hardwood patch areal extent as private industrial lands show a decrease the amount of hardwoods as lands are converted to young conifer plantations, and as private non-industrial lands show an increase in the amount of hardwoods. It is also possible that on some private industrial lands that were harvested prior to the advent of the Oregon Forest Practices Act hardwoods could occur at higher frequencies, if these areas were not reforested with conifers following harvest. The increase of hardwoods on private non-industrial lands is likely to occur for two reasons: a large proportion of these lands occur in valley bottoms, where hardwoods have a stronger ecological advantages, and this ownership group holds very diverse and currently largely unpredictable management objectives. Federal lands, on the other hand, will show a moderate decline in hardwood extent as hardwoods succeed to conifers in areas reserved from logging and other federallyowned areas are logged. These combined patterns could result in no net change in hardwood extent in the landscape. However, given the large portion of the landscape occupied by private industrial and Forest Service landowners and the advent of the Oregon Forest Practices Act during the time period of this study, I expect to see a decline in hardwood area over the study period as forested areas are converted to young conifer stands. I also expect to see a decline in the number of hardwood patches as the time since catastrophic fire disturbance increases.

My third objective is to characterize the sizes and shapes, and size and shape changes of hardwood patches in the west-central Coast Range of Oregon. Have average patch sizes decreased in the area? Have patches become more simplified in shape, either as their irregular, fire-initiated borders are constrained by logging or as hardwoods fill in clear-cuts after logging? Under what topographic conditions do these shifts in size and shape of hardwood patches occur? Are patches more likely to fragment on certain ownerships or topographic conditions? How many hardwood patches have disappeared, and how many new hardwood patches have arisen? Are there more, smaller patches now than there were in 1939? Fragmentation, usually considered as the combination of a decrease in overall size accompanied by an increase in the number of sub-units of the patch, is an important feature to consider in hardwood stands. If large isolated hardwood blocks occur, propagules strongly associated with hardwood stands that have short dispersal distances, such as some lichen species, may decline in abundance in the area. If small fragments of patches remain and are scattered throughout the landscape but occur under severely restricted conditions, such as in riparian areas, the nitrogen fixation benefits of stands or the spread of some species with restricted dispersal distances may not be as readily available outside these areas. If hardwood stands are restricted in area or size, other early successional species, such as salmonberry, may gain a stronger competitive foothold and out-compete other more economically desirable species, such as conifers. Given the dominance of hardwood stands in many riparian areas and the ability for alder trees to survive floods, I expect that hardwood patches would be larger and less fragmented in areas of more moisture, such as on north-facing slopes, because these aspects receive less solar radiation; and at lower elevations, in wetter microsites such as concave areas, and closer to the ocean, which has higher annual rainfall levels (Haeussler et al. 1995). Patches are more likely to fragment or disappear on private industrial ownerships, and most likely to enlarge or coalesce on private non-industrial ownerships, and at low elevations and near streams. I expect that overall hardwood patch size was smaller in 1993 than in 1939, and that patch shape, where affected by linear clear-cut harvest boundaries, simplified. I expect that, coincident with this simplification in shape and decrease in size, core area:edge area ratios decreased through the study period as the drop in size removes core area from patches at higher rates than edge areas. This may provide important consequences for bird species that prefer hardwood patch interiors as nest sites.

My fourth objective is to describe the shift in within-patch heterogeneity and within-patch vegetation composition features of hardwood patches. Because hardwood stands comprised primarily of red alder may have an average lifespan of from 80-120 years, I expect that any hardwood stands that had established in the late 1800s or early 1900s would be beginning to fragment. Given the patchy, intermittently open nature of the pre-European settlement landscape that resulted from both catastrophic wildfires and Native American burning, I would expect that the persistent large shrub fields that had survived as non-hardwood islands within hardwood patches would occupy more of the patch over time (Tappeiner et al. 1991), resulting in a decrease in the proportion of hardwood composition and an increase in the proportion of shrub composition in the patch, as trees in the patch die and the canopy structure breaks apart. If large conifers had remained within the hardwood patch as remnant trees following catastrophic wildfire that had become surrounded by hardwoods, I would expect the patch to increase in conifer composition as any suppressed conifer seedlings and saplings persisting beneath the hardwood canopy emerges as the hardwoods die and leave gaps. The forests of the Pacific Northwest are conifer dominated, potentially because hardwoods have nutrient and moisture constraints during the dry growing season exceeding those of conifers, and the mild winter temperatures permit photosynthesis by evergreen conifers, while the cool summer nights allow for larger biomass components, common to conifers, to be maintained (Waring and Franklin 1979). The dominance of the region by conifers might increase the heterogeneity within hardwood patches if conifers invade hardwood patches. As a result of the shrub and conifer patch component increases, then, I expect that overall patch heterogeneity would increase through the study period. I also expect that this heterogeneity would be positively associated with an increase in shape complexity, as patch edge structure breaks apart. This increase in shape complexity may or may not be offset by the effects of clear-cut harvesting on the perimeter of the patch.

Because hardwoods are considered to be an important component to the vegetation of riparian areas, **my fifth objective is to characterize patches occurring**

in riparian areas. Do more patches occur in riparian areas than in upslope areas? Do larger patches occur in riparian areas? Are patches larger along higher-order streams? Preliminary surveys of the area indicate that long, narrow strips of hardwood patches occur along riparian areas. These might be reflected in more complex patch shapes. Are patches more complex in shape in riparian areas than in upslope areas, and along the wider, valley bottom streams, than they are in upslope areas, or even riparian hillslopes? These riparian patch characteristics might be a reflection of ownership in these areas. Who owns the flat, valley bottom patches, and who tends to own the hillslope patches? It is likely that private non-industrial landowners own most of the large, valley bottom patches, while private industrial landowners own more of the patches along smaller streams, and these differences in ownership could be reflected in differences in patch size and shape, with private non-industrial landowners maintaining more of their riparian hardwood patches and having larger patches.

METHODS

The Study Area

The study area is located in the west-central portion of the Coast Range in Oregon. It is bounded roughly by the Lincoln County line (Figure 3). The Central Coast Range was selected from other areas in the Coast Range because of the mix of ownerships present. The location of the study area within the Central Coast Range was determined by the extent of the early aerial photograph set. This set of aerial photos, obtained in 1939, provided the largest geographic area of coverage available for any date within a 20-year timespan around that photo date (for the subset of photos used, please see Figure 4).

Uplifting marine sedimentary and volcanic rock formed the central coastal mountains in Oregon (Franklin and Dyrness 1988). The coastal mountains in Oregon are low in elevation; elevations in the study area ranged from near sea level to approximately 700 meters (Figure 5). The mountains are steep and dissected by a dense network of intermittent and perennial streams. Precipitation in the area is high (2500-3000 mm/yr in the Alsea area) (Worthington 1979), with most of the precipitation coming in the form of rain in winter months. The study area has a dry, moderate-to-warm summer climate, with an increase in seasonal temperature variation corresponding to distance from the ocean. Precipitation is highest along the western sides of mountains, intermediate near the coast, and lowest on the eastern side of the mountains (Taylor 1993). At higher elevations, precipitation may take the form of snow. Fog along the coastal strip is common even in the dry summer months and can

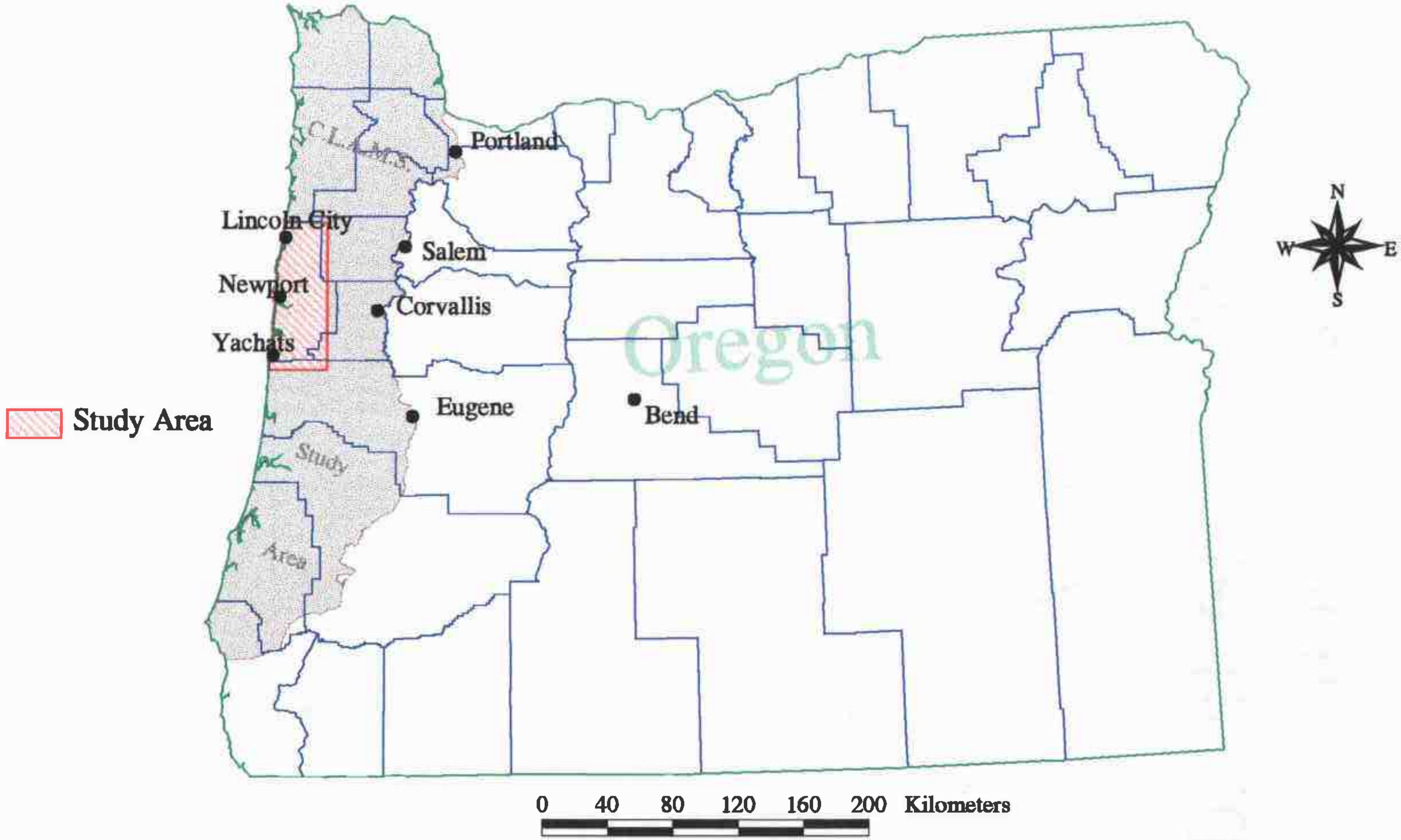

Figure 3. Study Area Location.

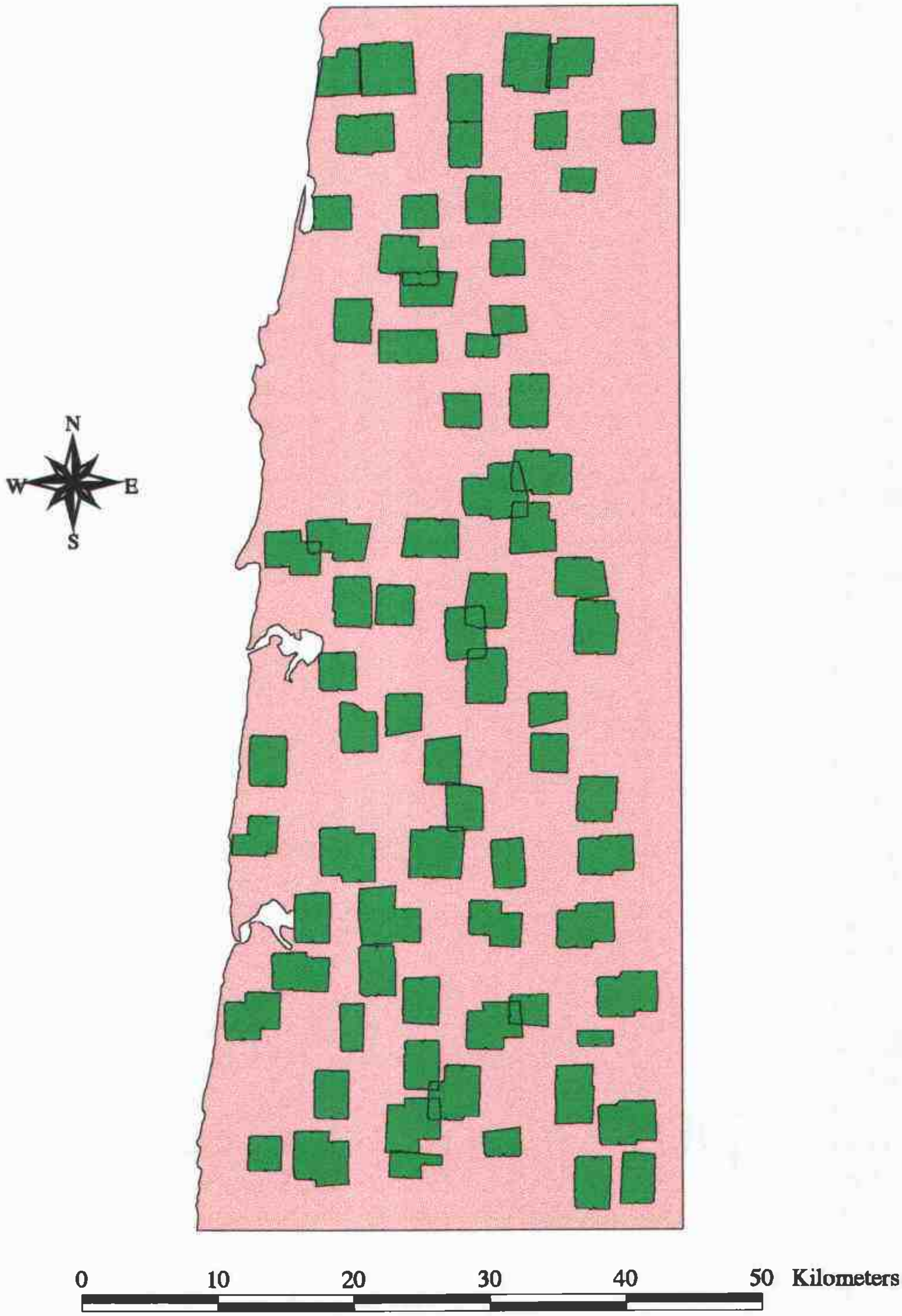

Figure 4. Aerial Photograph Coverage of Study Area.

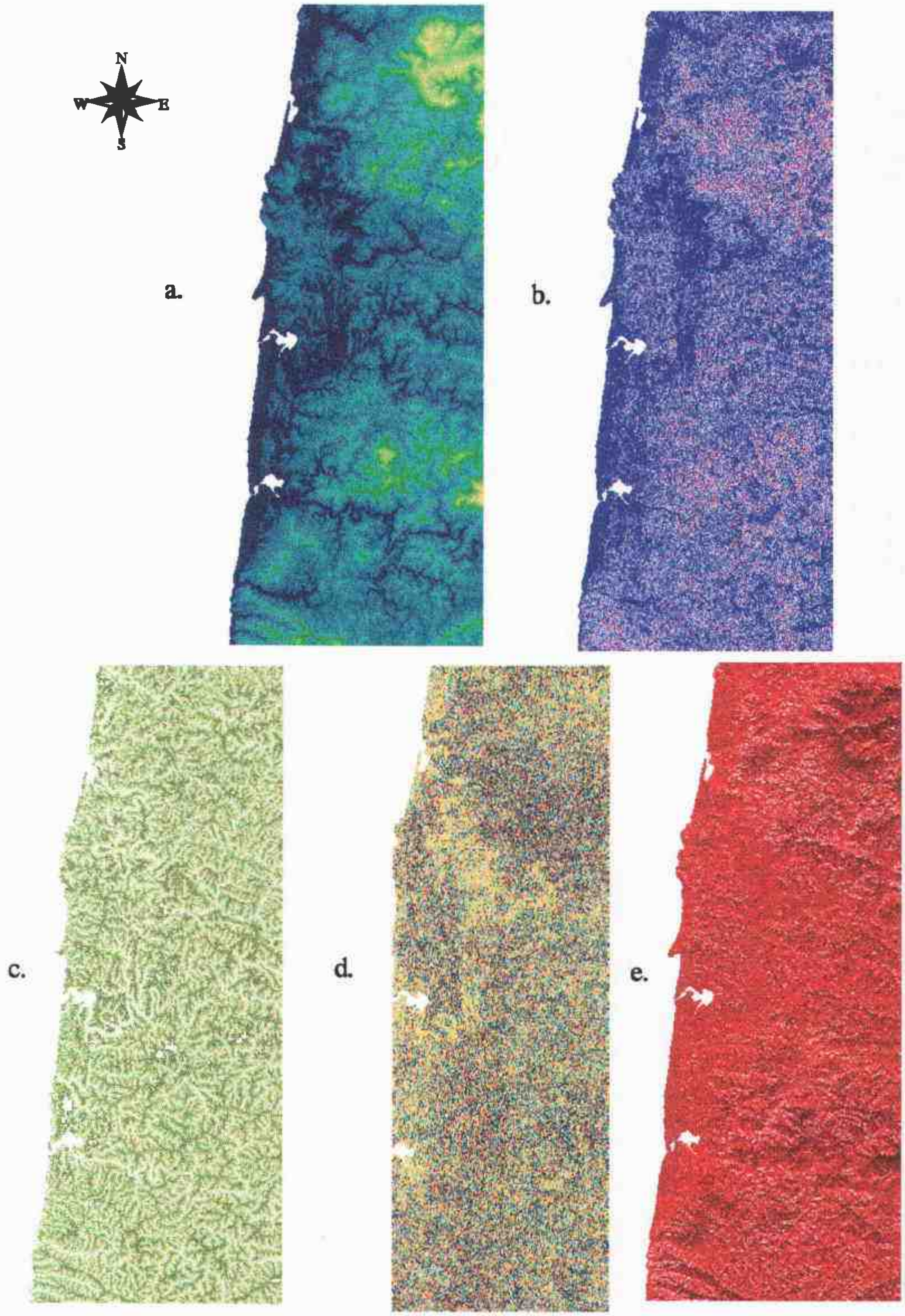

Figure 5. Environmental Gradients in Study Area
a. Elevation. Deep blue is lower elevation; mint green is higher elevation.
b. Slope. Deep blue is gentlest slope; redder hues are steeper slopes.
c. Slope position. Deep green is lower slope position.
d. Topographic curvature. Blue-yellow-red transition is concavity-convexity gradient.
e. Annual solar radiation. Deeper red is higher radiation.

contribute to precipitation in the form of fog drip. The Sitka spruce [*Picea sitchensis* (Bong.) Carr.] vegetation type occurs along this coastal strip, while the western hemlock [Tsuga heterophylla (Raf.) Sarg.] zone occurs in the interior (Franklin and Dyrness 1988). The most widespread, frequent, and intense disturbance during the years of the study period was extensive clearcut logging and associated road building. These activities have resulted in a landscape consisting primarily of managed forest blocks of varying age classes, and remnant patches of unmanaged forest, occurring most often on public lands. Land ownerships vary in the study area, with the U.S. Forest Service and private industrial landowners being the primary landowner groups (Figure 6).

Disturbance History

Disturbance, both natural and anthropogenic, is a key factor determining the distribution and characteristics of hardwood patches in the central Coast Range. Catastrophic natural disturbance historically has occurred in the form of large, stand-replacing fires, with windthrow occurring as secondary disturbance source (Agee 1993). These fires have had a heterogeneous nature, with reburns a common occurrence, and patches of unburned forest remaining in some areas. Fires in the Coast Range of Oregon occur at approximately 200-300 year intervals (Impara 1997; Long et al. 1998). The most recent large-scale, catastrophic fires in the study area occurred in the mid-1800s. Unmanaged stands establishing after these fires are mostly 130-150 years old (Poage 1994). For example, a large fire was recorded in the central part of the study area (Toledo, OR) in 1848 (Parry 1985), with second growth timber recorded as present there in 1906 (Strome 1986). In 1854, a large fire was reported to have burned over

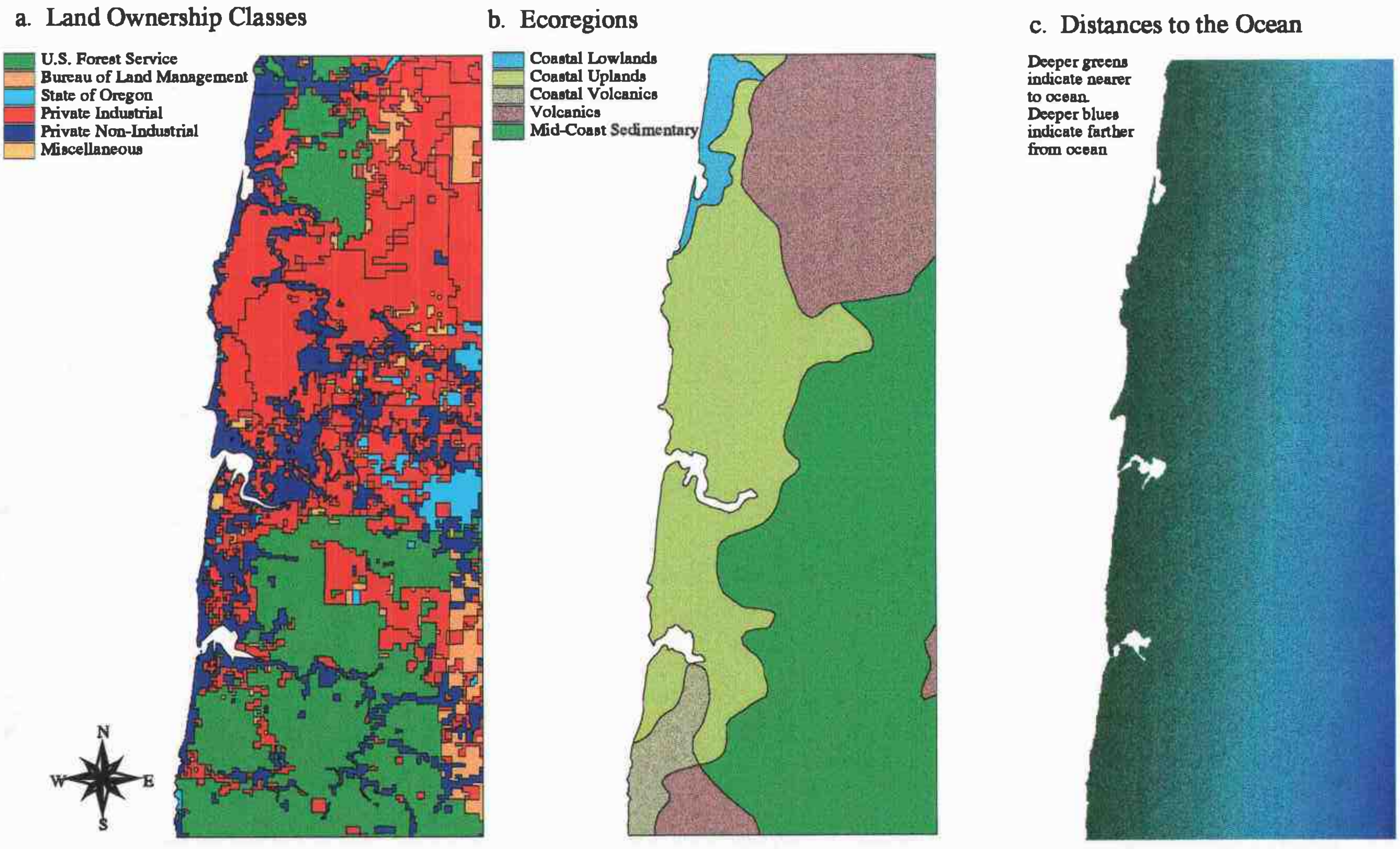

Figure 6. Land Ownership Classes, Ecoregions, and Distances to the Ocean.

450,000 acres from Coos Bay to Tillamook, with repeated burns in the area in 1857 and 1867 (Crane 1951). Windthrow, initiated by seasonally strong gale force winds, also has caused extensive damage to forest stands, especially in the 1950s and 1960s (Orr 1963; Ruth and Yoder 1953). In addition, periodic floods and landslides on steep slopes alter the vegetation structure and deposit alluvial soils in riparian areas. Extensive floods in the early 1920s and 1960s have been recorded (Strome 1985). The laminated root rot fungus *Phellinus weirii*, which is associated with the death of small [0.6 hectare (Gedney 1981)] stands of Douglas-fir or western redcedar (*Thuja plicata* Donn) and replacement by red alder, has also contributed to the patchy mosaic of forest stands in the region.

Anthropogenic disturbance in the study area also has been widespread, both before and after European settlement. Upon European arrival to the central Oregon Coast, large numbers of Native Americans lived in the area. In 1855 and shortly thereafter, the Grande Ronde and Siletz Indian Reservations were established (collectively known as the Coast Reservation); at that time there were approximately 4000 Native Americans residing there (Crane 1951). The Native Americans are reported to have repeatedly burned the forest hillslopes to clear the ferns and shrubs, in order to create openings which promoted game habitat. This has been recorded for the Drift Creek-Gopher Creek and Toledo areas, among others (Hays 1976, Strome 1985). In 1866 an act of Congress opened the reservation to European settlement. White settlers continued to burn the lands to promote grazing for livestock. The settlers also cleared the land for dairy farming, orchards, and grazing. These actions resulted in a patchy mosaic of bald, grassy areas, especially on hilltops. In 1905, the first sawmills in Lincoln County were established, on Drift Creek and 10 miles up the Siletz River from the ocean (Hays 1976). Logging soon replaced salmon fishing as the primary source of income for many Lincoln County settlers (Strome 1985). The Siuslaw National Forest was established in 1908 through consolidation of the Tillamook and the Coast Range Umpqua Divisions. In 1930, with a population of 9903 (Moe 1993), Lincoln County, with its mosaic of vegetation types, reflected the various goals of its residents and the diversity of ownership types and disturbance histories of the area.

In recent decades, including those encompassed by this study, several shifts in the disturbance regime have occurred. In the early decades of logging in the Coast Range, it was common for some form of selective harvest to have been utilized, where the larger trees were removed from the site and other trees were left standing. With the recent rise in industrial forestry in the area, large tracts of land are often owned by a few landowners, and clear-cut harvest methods are most commonly utilized. In 1971, the advent of the Oregon Forest Practices Act, the first law of its kind to establish guidelines for reforestation and to address water, soil, and air resources (Oregon Department of Foresty 1997, b) brought a downturn in the allowable size of the harvest unit. This size restriction has resulted in a shift in the size distribution of clear-cuts on the landscape, and has created a mosaic of smaller landscape units having more complex shape than in the decades prior to the Act or its revisions. Several floods have also impacted the area in recent years; the most severe flood that occurred during the years spanned by this study took place in 1964. As in several other areas of the state, a downturn in the numbers of small farmers and ranchers practicing agriculture has also occurred in the Central Coast Range. This has resulted in a decrease in grazing in the area, and a lessening of cultivation of the large valley bottoms. Further, in recent decades, effective fire suppression throughout the region has prevented the occurrence of catastrophic fires in this part of the coastal mountains. Thus, clearcut logging and associated road building is now the primary large-scale disturbance type in the area.

Rationale for Development of Methodology for Digital Analysis of Aerial Photos

One of the objectives of this study was to develop methodologies for the digital analysis of time series-related patch data on aerial photographs. Current aerial photo analytical techniques are most often restricted to the manual viewing of printed aerial photos and the mapping of cover types using such prints. For example, the spatial and temporal patterns of exotic shrub invasion in an Australian grassland were mapped by laying a transparent grid over 1:12,000 and 1:17,000 scale aerial photos and recording the number of trees in each cell (Brown and Carter 1998). In another time-series patch change study, Atlantic white cedar abundance changes were mapped by selecting one photo date as the reference date, mapping the white cedar patches using transparencies laid over hard copy photos from this date, then transferring the resultant map to a GIS, printing out transparent sheets of this map at the appropriate scales for each of the other photo dates (Zampella and Lathrop 1997), and mapping changes onto these transparent sheets. Many other studies in which researchers delineate patches and utilize these patches in further spatial analyses provide no details of how patches were delineated using the aerial photos (see, for example, Powers et al. 1999; Kitzberger and Veblen 1999); it can only be assumed that manual mapping using transparencies and hardcopy photos, and in some cases, subsequent digitization and import into GISs, were performed. These mapping methods on hard copy photos of moderate scales (such as 1:17,000) are likely to omit small patches from the analysis (Powers et al. 1999), and because of the relatively low level of resolution available, are more likely to misrepresent cover types than digital photo interpretation methods where the viewer can closely view, up to the grain size of the scanned image, areas on the photos.

While it may be that alder stands and isolated conifer trees within the stands are easier to delineate on color photos taken during the fall (Avery and Berlin 1985) because of the color distinction between deciduous and evergreen trees, photos in the Coast Range of Oregon customarily are taken during the summer months to avoid cloud cover. However, even on black and white photographs or on photographs taken during the summer months, hardwood patches may be accurately delineated (Heller 1952). Alder stands have characteristic features: "The red alder type can be recognized by the relatively even crown canopy, light tone, and 'wooly' texture," (Berstein 1962). Bigleaf maple have a more rounded, lumpy texture, resembling broccoli heads. In color photographs, they may appear brownish during the summer months, in comparison to red alder or conifers.

Several studies have examined the relative accuracies of evaluation of vegetation types and characteristics using natural color, color infrared, black and white infrared and black and white photography at different scales (Marshall and Meyer 1978, Latham 1970, Haack 1962, Morton et al 1983). While some of the results related to scale would not directly apply if a digital analysis procedure were employed, the relative merits of each film type and the limits of cover type designation are important to consider, especially because different film types were used in the hardwood patch study. Haack (1962) evaluated color, infrared and panchromatic photos at a scale of 1:5000 with respect to land and forest classes and height measurements. For species and stand size class recognition, there was no significant difference between film types. However, on all film types, the number of hardwood stands incorrectly classified was much higher than the misclassification of softwood stands. This is likely due to the misregistration of shadows in the openings of hardwood stands as conifers (Spurr 1948).

Morton et al. (1983) determined the accuracy of density, height, and species composition identification in forest stands in Alberta, Canada, using natural color and color-infrared photographs at scales of 1:30,000, 1:50,000, and 1:70,000, and black and white infrared photos at a scale of 1:15000. Species composition identification accuracy, while low on all photos (average 52 percent), ranked as relatively high on the black and white infrared film (59 percent). Height and species composition measurements were compared with field-measured stand characteristics, with average dominant stand height estimated from 40 height observations in each stand and species composition described from basal area estimations made in 10 sample plots in each stand. Actual stand density was derived from Alberta Forest Service cover type maps (Morton et al. 1983). Identification accuracy was highest for density using 1:15,000 black and white infrared film (79 percent accuracy), for height using 1:30,000 color infrared film (66 percent accuracy), and for species using 1:30,000 or 1:50,000 color infrared film (both 65 percent accuracy). Interpretation accuracy may be higher if digital methods are employed, because the interpreter has the ability to zoom in to the grain size of the image, to move around on the photo to seek textural and contrast cues, and to compare readily between scales and photos. These enhancements greatly increase the flexibility of the interpretation method. However, relative accuracies of film types for density, composition, and height would likely be similar to those found by Morton et al. (1983).

Aerial Photograph Collection and Preparation

My study of the long-term dynamics of hardwood patches was based on aerial photographs from 1939 and 1993, and a Geographic Information System (GIS). First, I gathered aerial photographs from the two dates, selecting a sample of photos for closer study. I then scanned and registered the photos. The early aerial photos came from the 1939 United States Geological Survey (USGS) Newport Project (U.S. Geological Survey 1939). These photos were panchromatic (black and white) and had a scale of 1:27,000. This photo set was chosen because it had the broadest coverage area and finest scale of any available photos covering a large portion of the Coast Range within a 15-year timespan around 1940. The 1939 aerial photos were borrowed from the University of Oregon Map Library and were scanned at a resolution of 400 dots per inch. The 1993 aerial photos, a Bureau of Land Management (BLM)-coordinated project, were in true color and had a scale of 1:12,000 (Bureau of Land Management 1993). The 1993 photos were gathered from numerous cooperators on the BLM aerial photo flight, including the Siuslaw National Forest, the Salem District Bureau of Land Management, and Simpson Timber Company, and were scanned at a resolution of 200 dots per inch. Differences of scale between the aerial photo sets, which might have been somewhat problematic if conventional aerial photo interpretation techniques had been utilized, were mitigated via scanning and my ability to zoom in and examine particular areas at very fine scales on the georeferenced, computerized images. Scanner settings were chosen in order to balance file size and resulting resolution of scanned images, so that information present on parent photographs would not be lost through scanning. The 1939, 1:27,000 photos, scanned at 400 dots per inch, yielded a grain size (the size of the minimum distinguishable element (Forman 1995)) of 1.7 meters. The 1993, 1:12,000 photos, scanned at 200 dots per inch, yielded a grain size of 1.5 meters. The scanned photo (image) grain size of 1.5 to 1.7 meters falls well below the average size of a red alder tree crown of 4.8 meters for dense-grown trees and 7.9 meters for open-grown trees (Smith 1967). One-third of the 1939 aerial photos were selected at random by first subdividing the study area into rough longitudinal thirds, and then selecting one-third of the aerial photos from each area, based on the results of a random number generator and the rule that no adjacent aerial photos could be selected. This insured even coverage of the study area. There was some difficulty obtaining photos from 1993 that covered parts of the north-central portion of the study area. A large proportion of this area is under private industrial ownership. Photos covering some of these lands were not available. The photos from 1939 corresponding to these areas were therefore not included in the analysis. However, much of the geographic area of the study area was covered by both aerial photo sets (Figure 4).

I registered the photo images using the interactive REGISTER command in ARC, followed by IMAGEGRID (ESRI 1992), which applied the REGISTER transformation to the image. This procedure allows the operator to assign to a collection of photo points of unknown location corresponding locations having known coordinates from a GIS coverage, and then transform, or warp, the image so that the coverage and image features are in alignment. I chose this method because other methods, such as the registration module in IMAGINE (ERDAS 1991), and orthoregistration techniques, required photo information that was unavailable for the 1939 photos (focal length and the known location of up to eight points per photo, for example (Lillisand and Keifer 1979)). Although this type of information was either available or could have been obtained for the 1993 photo set, I used the same method for both photo sets in order to have uniform levels of registration-related error. In ARC REGISTER, I chose an average of 26 links to join photo and GIS coverage locations. The coverages used included a 1:100,000-scale streams coverage (from the Environmental Protection Agency's River Reach Database) and two roads coverages: the 1:100,000-scale U.S. Census TIGER/Line roads file for 1995, and a Siuslaw National Forest roads coverage derived and updated in 1991 from Cartographic Features Files (CFF) digitized from quadrangle maps and supplied by the Geometronics Service Center. These three coverages are considered to be moderately to highly accurate and have been used in many other studies (Moses, personal communication). Accuracy of registration was measured using the root mean squared error (RMS error) for the image, and the distance between calculated x,y and true x,y coordinates for each link (ESRI 1992). Images were re-registered (links added and dropped iteratively) until the following two criteria were met: any single link could not have an RMS error greater than 30 meters, and the mean RMS error for the entire image could not exceed 25 meters. This resulted in RMS errors for individual links customarily falling within the 5-20 meter range and mean errors for images having values of approximately 15 meters. Once an acceptable set of links was obtained for each photo image, the image was rectified, or warped, using IMAGEGRID so linked features on the photo would be assigned the corresponding locations from the linking coverage, and areas between links located respectively. It should be noted that registration of aerial photos in areas of great topographic relief, such as the study area, is complicated by the high degree of variable distortion which is present on aerial photographs; this may limit the registration accuracy available even under optimal registration conditions. In addition, the registration of the photo is only as good as the coverage to which it is linked. I used either of the roads coverages, which are considered to be of higher accuracy than the EPA streams coverage, in preference to the streams coverage, whenever possible. This procedure produced high-resolution images of registration quality sufficient for the purposes of this study. In all, I registered 74 1939 photos and 160 1993 photos, for a total of 234 photos. More 1993 photos were registered because each photo covered less area than each 1939 photo. Most often, two 1993 photos were selected and registered to span the area covered by a single 1939 photo.

Development of Shared Photo Area Coverage and GIS "Fishnet" Vector Coverages

Once I had gathered, scanned, and registered the aerial photos, I selected the area of study and followed a series of steps prior to delineating the hardwood patches. First, I determined and demarcated the shared area between the photo sets of different dates to obtain the shared coverage area. To do this, I used the Vector module in Imagine (ERDAS 1991), outlining the area shared by each 1939 photo and its associated 1993 photo(s). I then merged the vector coverages of the area shared by each 1939 and associated 1993 photo set, forming a single ARC coverage of the entire geographic area shared by the photos from the two dates.

Now that I had determined the area covered by the aerial photos, I generated a vector coverage of uniformly-sized and shaped cells that spanned this shared aerial photo coverage area. To do this, I used the GENERATE "fishnet" command in ARC (ESRI 1992). A fishnet is a vector coverage that has a uniform cell size, a designated trajectory (allowing the creator to make non-square cells), and a designated origination point or extent. I chose to use a square cell with a size of 20 meters on a side (400 m^2 area, considered to be "20 meter cells"). This cell size would determine the minimum resolution for all further cover type-based designations and would be uniform across the study area. In order to determine vegetation cover within each of these pixels, there needed to be adequate resolution within each cell and between cells to determine the contents of the cell. Under natural conditions, based on the average spacing of 50-year-old alder trees (Hibbs, personal communication), approximately two to five alder trees can be found in a 20 x 20 meter area. The choice of the 20 meter cell size allowed for the inclusion of very small alder patches in the analysis, but also allowed for a large area of cells to be examined. It balanced the resolution of rectified images and the pertinent attributes of species under examination. Using the GENERATE "fishnet" command (ESRI 1992), then, I generated three "fishnet" vector coverages. These three ARC "fishnets" were adjacent to one another, one over each third of the study area, from north to south. I had to generate three "fishnets" because my study area was too large for ARC to process a single "fishnet" over the entire area with a cell size of 20 meters.

Once I had created the three "fishnet" vector coverages, I clipped them using the GIS coverage outlining the shared area between aerial photo sets to remove cells outside the photo coverage area. I also eliminated all cells having an area less than 400 square meters (20 x 20 meters), in order to remove any edge fragment remnants that had resulted from this clipping procedure. I then merged the three clipped fishnet coverages, and divided this coverage into several narrow "fishnet" strips that ran east-west across the study area, to speed coverage display on the computer screen. In combination, the "fishnet" vector coverages of the area shared by the aerial photos from the two dates provided over 1.6 million 20 meter cells for potential analysis.

Patch Initiation Plots

When working with historic aerial photos of variable quality, (variable under- and over-exposure within and between photos, variable levels of photo deterioration, variable heights of flight between photos and tilt within a single photo) such as the 1939 aerial photo set, digitally-based fine-scale cover typing and patch delineation must be done manually to minimize errors. I applied a random sampling procedure to obtain patches in order to cover a broad landscape area.

From the 1.6 million cells in the "fishnet" coverage, I selected a random sample of 1508 20 meter cells. I considered these cells to be cover type plots, with the potential to be patch initiation plots. I located each of these 20 meter plots on one of the "fishnet" strips, and then, in ARCEDIT, I displayed the relevant photo images in the background of each strip coverage. Because only the outlines of each cell in the "fishnet" were drawn on the computer screen, I could clearly see the photos in the background and their features within the cells of the fishnet coverage. Each cell in the "fishnet" was a vector-based polygon, and as such had a set of attributes associated with it which could be modified. Once I had displayed the photo and the "fishnet", I selected each of the

1508 plots. In each of the plots, I estimated the cover type in 1939 and 1993 through aerial photo interpretation, and modified each plot's attributes accordingly.

I manually designated cover type as one of 14 cover classes: bare ground/open, pasture/meadow, shrub, hardwood tree, small mixed, medium mixed, large mixed, very large mixed, small conifer, medium conifer, large conifer, very large conifer, water, or road. If a plot contained greater than 70 percent of a particular cover type, it received that cover type designation. Designating between alder trees and some shrub species was relatively straightforward; alder trees may attain heights of 9 meters (30 ft) by age 5, 16 meters by age 10, and 24 meters by age 20 (Harrington 1990), so it is likely that only very young alder trees would be included in the shrub category. The difference between tree and shrub was readily apparent during photo interpretation, given the grain size of the photos. Mixed plots contained less than 70 percent but greater than zero percent conifer or broadleaf, and, like the conifer classes, were designated as small/medium/large/very large on the basis of conifer crown sizes present. A conifer crown was considered to be very large, and the cover type designated accordingly, if a single crown filled greater than 25 percent of the plot (greater than 100 square meters; crown diameter greater than 10 meters); large if a single crown filled between 6.25 percent and 25 percent of the plot (25 to 100 square meters; crown diameter between 5 and 10 meters); medium if a single crown filled between 1.56 percent and 6.25 percent of the plot (6.25 to 25 square meters; crown diameter between 2.5 and 5 meters); and small if a single crown filled less than 1.56 percent of the plot (less than 6.25 square meters; crown diameter less than 2.5 meters). These size classes are in rough accordance with classes used in the Coastal Landscape Analysis and Modeling Study

(CLAMS), of which this work is a part. They were also readily measurable in each 20 meter plot. Where a mixture of crown sizes was present in the plot, the crown size occupying the greatest area was chosen for class designation. If necessary, I could zoom in to the 1.5-1.7 meter maximum photo image resolution for cover type designation. However, I customarily displayed several cells around each plot on the screen at once in order to provide contrasting tones, textures, shapes, and colors, all of which assisted me in the determination of cover type within the plot. I tended to settle on a particular resolution (usually nine to 25 cells of interest in view) to display on the screen for all analyses, and then if I required further information, I panned across the scene or zoomed in or out, accordingly. For a subset of the area, I visited sites to confirm cover type classifications, in order to assure accuracy in aerial photo interpretation. All plots selected for cover type designation were used in an analysis of landcover change, a study which will not be described here.

I used the same 1508 plots on both the 1939 and 1993 aerial photo sets to obtain an unbiased representation of cover types on the landscape. Any plots having hardwood as the cover type in 1939 were considered as a potential hardwood patch initiation cell for a 1939 patch. Similarly, any plot having hardwood as the cover type in 1993 was considered as a potential hardwood patch initiation plot for a 1993 patch. Some of the 1508 plots had hardwood as the cover type at both dates, and in this case patches were delineated at both dates accordingly. In this way, those plots having hardwood as the cover type in 1939 and/or 1993 were selected as initiation plots for the hardwood patches examined in this study.

Patch Delineation Procedure

Based on preliminary aerial photo analyses and field reconnaisance, and given the dominance of the coniferous forest type in the Pacific Northwest, I had considered that hardwood patches in the Coast Range would be occurring primarily as somewhat isolated, identifiable patches within a conifer matrix (Haeussler 1990). Given this precondition, then, I needed to delineate two sets of patches from this conifer matrix: one set for 1939, and the other for 1993.

Once I had classified the cover type for all the plots, on the aerial photos I re-examined those plots having a cover type of hardwood in 1939, and delineated patches from these initiation plots (Figure 7). I examined those plots having a cover type of hardwood in 1993 and delineated patches from these initiation plots. If the initiation plot contained hardwoods, a patch would be delineated around that plot for the date that hardwoods were present in the plot, and that patch would be added to the population of patches considered in 1939 and/or 1993. I designated hardwood patches using the hardwood patch initiation plots as the origination points for patches, with the polygon strips and background 1939 aerial photos displayed in ARCEDIT. If any adjacent cell in the "fishnet" contained hardwoods, I selected that cell and designated it as hardwood. I included diagonals, cells adjoining only at their corners, as adjacent cells in order to minimize patch contiguity loss from this kind of square-cell-based analysis. I had observed that many hardwood patches, especially along riparian corridors and in areas of variable disturbance, may be either narrow or filamentous, and I wanted to accommodate these patch types in the selection process. I continued selecting cells and designating cover types in this manner until there were no more

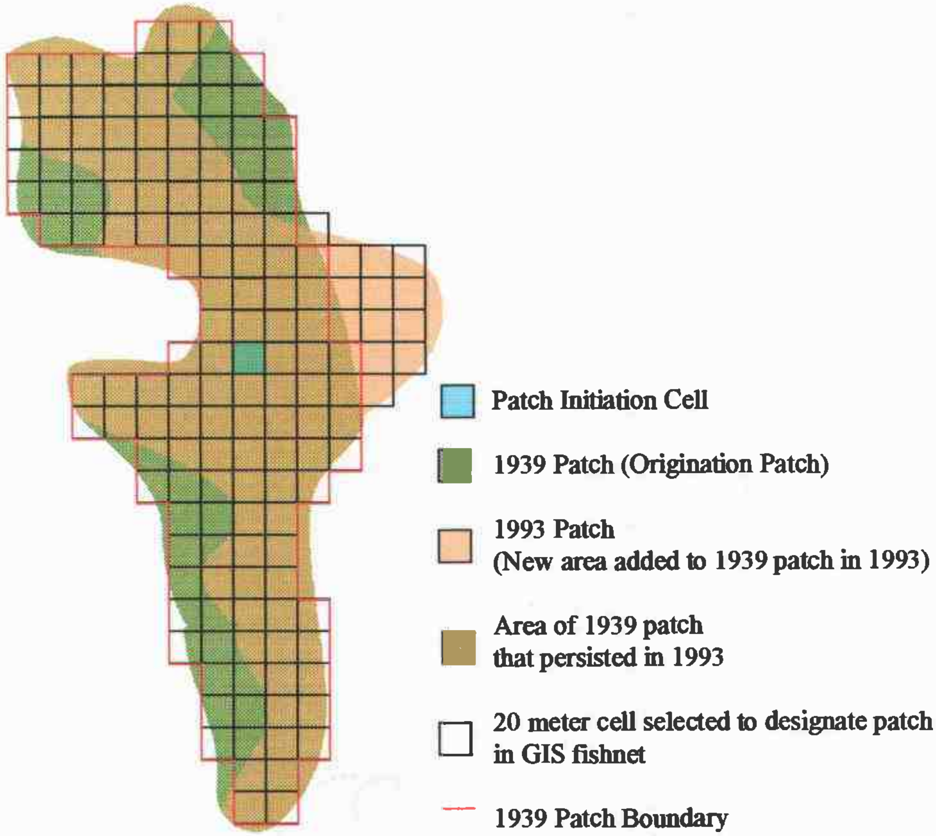

Figure 7. Schematic of patch designation method for patches persisting from 1939 to 1993. Green is 1939 patch area. Yellow is 1993 patch area. Shaded green-yellow is area of 1939 patch that persisted to 1993. "Fishnet" of 20 meter cells overlain on these areas represents the total area occupied by the patch over both years. Blue cell (patch initiation cell) was randomly selected and designated as hardwood based on interpretation of 1939 aerial photo. All other cells were analyzed for inclusion in the 1939 and/or 1993 patch according to the following method. A cell was assigned the 1939 patch designation when it contained greater than 70% hardwood cover, or was surrounded by cells contiguous with the initiation cell containing greater than 70% hardwood. A cell was assigned the 1993 patch designation by first considering all 1939 patch cells as potential initiation cells for 1993 patch, to allow for patch fragmentation. Cells still containing hardwood cover were assigned the 1993 patch designation. Cells were also assigned the 1993 patch designation if they were contiguous with a cell persistent from 1939 and contained hardwood or were surrounded by persistent-contiguous cells containing hardwood. Land cover type (conifer, shrub, hardwood etc.) was then assigned to all patch cells.

contiguous hardwood cells available for selection. Some non-hardwood cells were surrounded by hardwood cells using this patch designation method. I designated the cover type for these non-hardwood cells, and, because they were surrounded by the contiguous patch, considered them to be a component of the patch.

At times, I declined to use the plot in the patch delineation or dropped a patch from consideration; this occurred if aerial photos were blurry, if the patch ran off the edge of the photo set, or if more than one plot occurred in a given patch. These conditions occurred sporadically throughout the study area, but without apparent pattern and at low frequencies. If a patch extended beyond the east or west bounds of the multi-polygon strip, I deleted the patch from consideration. This situation rarely occurred, as the multi-polygon strip was at least an order of magnitude wider than the typical patch, expanding across the entire study area in narrow bands. If a patch extended beyond a single polygon strip's north or south boundary, I displayed each subsequent strip and continued selecting polygons and labelling attributes until the entire patch was designated . I repeated this process for those cells that I had classsified as hardwood in 1993, but not hardwood in 1939. This decreased the likelihood of a polygon landing redundantly in a 1939 patch. In this way, I obtained an unbiased distribution of patches at each date. I assigned an identification number to each patch. If a patch occurred at both dates, it received the same patch identification number at both dates. If a previously-designated patch contained subsequent patch initiation plots, this was also noted.

The patches delineated on the basis of the 1939 photos were utilized for the analysis of patch fates, such as fragmentation, disappearance, increase in size, etc., and for the association of these fates with environmental and other variables. For patch fate information, I followed the patches that I delineated on the 1939 photos over time, and located them in 1993. For all the patch frequency distribution information, such as the distribution of patch shapes, sizes, within-patch heterogeneity, and area measures in 1939 and 1993, I examined all patches from 1939 and all patches from 1993 derived from the hardwood cover typed plots. I obtained the sum of area information for all patches at each date and distributed this information along environmental gradients to I determine area-environment and area-ownership relationships.

Once I had designated patches that were associated with cells that were hardwood only in 1939 or 1993, I returned to those patches whose origination cells I had designated as hardwood both in 1939 and in 1993 and delineated them (Figures 8 and 9). Many patches were present at both photo dates, and I delineated these patches based on interpretation of the photos from both dates. First, I displayed the relevant polygon strip with the 1993 photos as background, highlighting the polygons for each 1939 patch. I considered all the polygons that I had classified as hardwood in 1939 within these patches as potential "origination" (no change) polygons for any number of patches in 1993. I then selected cells based on the patch contiguity rules previously described until no further contiguous hardwood cells were available. All 1993 patches originating from a single 1939 patch received the same patch number as the single 1939 patch. This guaranteed a 1:1 correspondence of patches. All patches designated in 1939 and all patches designated in 1993, except for one very large patch, were included in size, shape (excepting fragmentation/ coalescence and size increase/decrease), and composition change analyses. This insured that I would be able not only to track

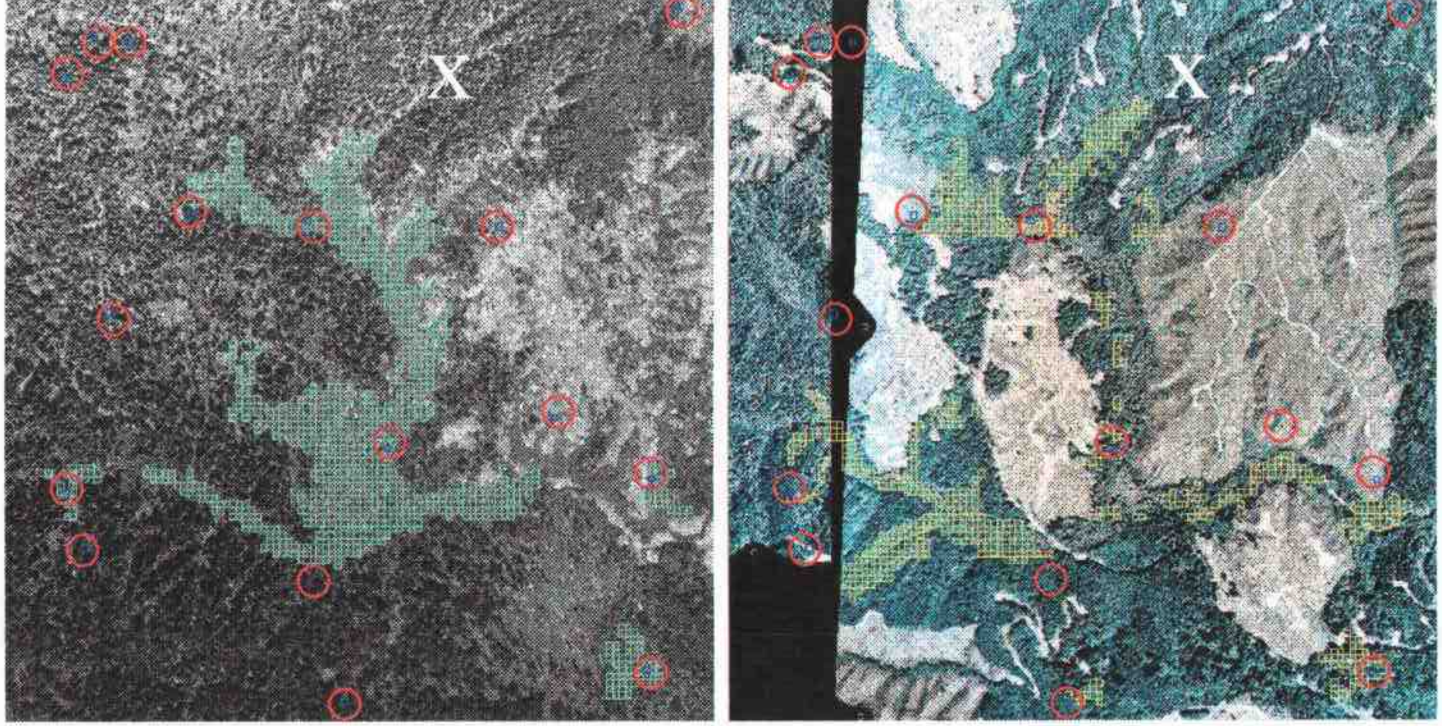

Figure 8. Change in patch number 177. Photos have been registered. Photo on left is from 1939. Photo duo on right is from 1993. White X marks same location on both photos. Green cells indicate 1939 patch designation. Yellow cells indicate 1993 patch designation. Red rings surround blue 20 m plots. For plot and patch areas falling on edge of any 1993 photo, adjacent photo was used to determine cover types. Note fragmentation at patch center and expansion along stream at top of patch. Also note new patch that appears in 1993 at center bottom of photo, large clear-cut at right of 1993 photo, and riparian strip central to both photos.

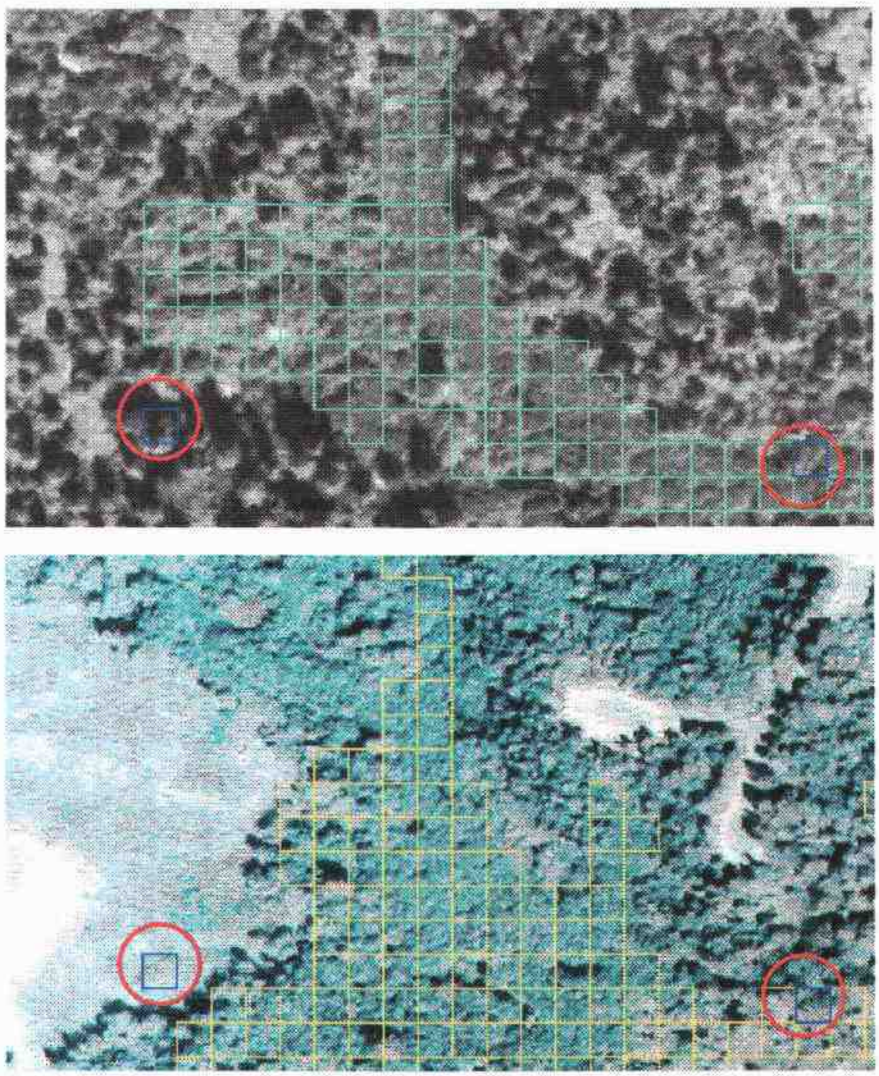

Figure 9. Detail of Figure 8 (upper left arm of patch 177) showing cover types and cells selected from fishnet coverage for patch designation. Top photo is from 1939. Bottom photo is from 1993. Green cells were included in 1939 patch. Yellow cells were included in 1993 patch. Red rings surround blue patch initiation plots. If hardwoods were the primary (>70%) cover type at either photo date in a blue plot, a patch consisting of all hardwood cells contiguous with this plot was delineated. Note prominence of large conifers at patch periphery in 1939, and their relative absence in 1993.

changes in patches present on the landscape in 1939, but also to examine and compare the population distributions of patches present at both dates.

Although it was possible that on the 1993 images I preferentially selected only new patches that were at an earlier stage of development than the random selection of 1939 patches, this did not occur, as many patches persisted from 1939 to 1993. Given the registration constraints of the photos, it was possible for a one-pixel shift to occur between photo dates and that patches selected in 1939 on the basis of single 20 meter cell origination points also occurred in the 1939 landscape. The registration constraint would show a greater effect with very small patches (just a few pixels in size; circa 400-1600 m^2 in area, for example), and would decrease in effect as patch size increased. Because I was not concerned with the spatial dimension within patches, a one-pixel shift in patch location throughout the patch would be acceptable. It was also possible that hardwood patches present in 1939 might have shown some shift in their geographic area of coverage as new hardwood trees arose along a disturbed edge of an already present hardwood patch, and these patches also had the potential to be selected using the aforedescribed method. Further, given the age of patch senescence as between 80-120 years, the 54 year timespan between aerial photos provided ample time for a wide variety of patch ages to be sampled in 1993, even if some of these patches had not been present in 1939.

I obtained cover type information in 1939 and 1993 for 1508 randomly selected 20 m cells. Of these cells, 336 (22.3 percent) were hardwood in 1939, and 294 (19.5 percent) were hardwood in 1993. 105 cells (6 percent of all cells sampled; 31 percent of 1939 hardwood cells; 35 percent of 1993 hardwood cells) were hardwood at both dates under scrutiny. From these cells, I sampled 269 patches in 1939 and 245 patches in 1993; 268 and 244 patches, respectively, were considered in further analyses (Figure 10). One patch was omitted from all analyses for both dates because it was both extremely large (much larger than the next largest patch) and represented the matrix in its local area (along the Alsea River near the Ocean); as a result, realistic mean values for environmental variables were not available for this patch.

Measures for Patch Shape Features

To obtain single-patch shape, fragmentation, and edge-core information, I used the FRAGSTATS patch metrics program (McGarigal and Marks 1995). I used the vector version of FRAGSTATS so that I could sort the output by patch number. I set the core distance at 20 meters to provide a 20 meter edge zone around each patch. FRAGSTATS provided patch measures for area, core area, perimeter, and two shape indices, "shape", and "fractal dimension". I had included diagonal cells when I delineated patches. FRAGSTATS does not consider diagonals to be contiguous, and provides unique output values for each part, or block, of the patch. However, this information was useful in determining patch fragmentation and coalescence values. I considered fragmented patches as those patches that consisted of more blocks in 1993 than in 1939. Conversely, I considered coalesced patches as those patches that consisted of fewer blocks in 1993 than in 1939. Coalescence can occur either with a decrease or increase in patch size; patches that had been separate in 1939, with only one part of the 1993 "patch" measured in 1939 because of the contiguity rules utilized in patch delineation, may have joined as a result of a few hardwood trees bridging the gap between the two 1939 patches; likewise, patches that were of a filamentous nature in

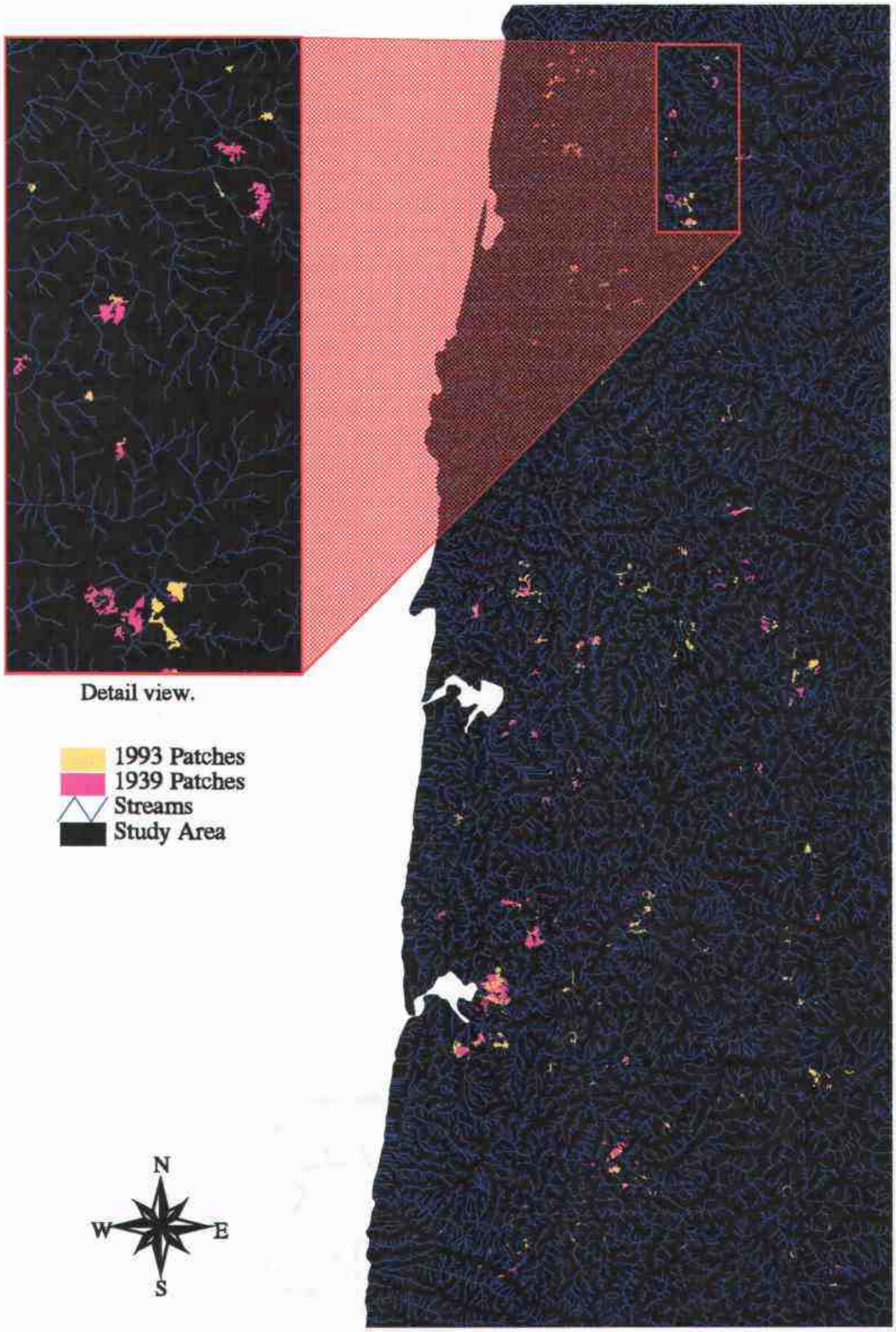

Figure 10. Hardwood patches delineated by interpretation of 1939 and 1993 aerial photos. In all, 269 patches were delineated in 1939. 245 patches were delineated in 1993. Patches were created by merging 20 meter fishnet cells having similar year and patch number assignment combinations. Patches overlap in areas where hardwoods were present at both dates.

1939 but were large, such as a narrow patch occurring along a stream channel that may have consisted of several blocks, may have become more restricted in size, with a congruent reduction in the number of blocks in the patch. Patches considered as unchanged in fragmentation exhibited no change in the number of patch blocks during the study period.

Because I knew that the diagonal cells, and the resultant multiple blocks, were an artifact of my designation method and were important to include as a single patch unit to maintain patch contiguity for patches I considered to be singular, I modified the FRAGSTATS output for perimeter and area, and recalculated the two shape indices accordingly for those patches FRAGSTATS had separated. The vector version of FRAGSTATS calculates shape indices using a circle as the reference point, and provided me with output accordingly. I wanted to account for the effects of using a square cell type in the shape metrics I obtained using the vector version of FRAGSTATS, so I modified output for the two shape indices according to the equation given in the raster, or square-referenced-shape version, of FRAGSTATS. The equation I used for "shape" was: *shape = 0.25(perimeter)/sqrt(area)*; the equation used for "fractal dimension" was: *fractal dimension = 2(ln(perimeter))/ln(area).* For patches with multiple sub-units, I summed areas and perimeters of the sub-units, and then calculated the square version of the shape metrics. For patches without sub-units, I converted from the circle-referenced output to the square form directly, using the equations.

I used the FREQUENCY command in ARC (ESRI 1992) to determine the frequencies of the 14 cover types for each patch, for use in the within-patch heterogeneity analysis. I obtained size information for each patch by creating two patch-level coverages from the raw coverage of all cells I had selected and labeled with a patch number during the patch selection process; these coverages provided area as one of the patch attributes. To obtain relative frequencies for patch general, size, shape, composition, and riparian characteristics, I divided the number of a particular type of patch occurring at a particular level of the variable in question by the number of all patches of that type at all levels of the variable in question. For example, if I wanted to know what proportion of fragmented patches occurred at elevations ranging from 25-100 m, I divided the number of fragmented patches at that elevation level by the number of fragmented patches at all elevation levels. This allowed me to compare frequencies of different types of patches even if there were different number of patches between groups. Because I also computed these frequencies for all subgroups combined, I could also compare subgroup distributions to the distribution of all patches and determine whether the particular patch type occurred more frequently than would be expected given an initial, expected distribution, across a particular gradient or site feature class range.

Because of aerial photo interpretation constraints, I did not designate disturbance types other than logging, and this designation was not used in the analysis because of designation constraints. As a consequence, any differences in patch disturbance type, and the varying effect of such differences in patch form, would be reflected indirectly in the results. The effects of heterotrophs such as beavers, and tree and shrub propagule availability to the patches, were reflected in other measurements of change in patch shape, size, and composition.

Additional Processing of Patch Characteristics Prior to Analysis

Many patch features were obtained in a form that required additional processing prior to analysis. These features included patch size, patch size change classifications, patch core and edge designations, and within-patch cover-type determinations. For patch size, because patches were sampled based on a random sample of plots, I was more likely to select a large patch than a small patch, because a large patch covers more area than a small patch. This likelihood is proportional to the size of the patch. All measures of patch size distribution were therefore weighted by the inverse of patch area so that large patches would not skew size distribution results. Thus, patches of all sizes could be considered with equal weight in the frequency distributions. To develop patch size change categories, the patches that were delineated on the 1939 photos were utilized. The fates of these patches were determined by comparing the 1939 size with the 1993 size for each patch. Patches were classified as having either increased, decreased, or not changed in size, or as having disappeared. For core and edge area measures, preliminary measures were obtained from the FRAGSTATS analysis. It was determined that core area measures for each subpatch analyzed using FRAGSTATS could be pooled to provide an overall core area measure; the same was true for edge area measures. The edge of a patch was designated as the first 20 meters in from the patch periphery (Hibbs, personal communication), applied uniformly around the entire patch periphery. Core areas were designated as all those areas within the patch that were not within this 20 meter buffer. For the within-patch cover type designations, I chose to pool the many large conifer classes to form an aggregate class prior to analyzing the within-patch conifer component. It was considered that while a large or very large conifer crown may not fill an entire cell, the large and very large mixed conifer classes had a prominent large conifer component that should be recognized as such. Therefore, the cover type classes of large mixed, very large mixed, large conifer, and very large conifer were joined, resulting in 1063 cells in 1939 and 313 cells in 1993 having the revised, "large conifer" cover type. Very few cells found in hardwood patches (1939, n=39; 1993, n=0) during either date were purely large or very large conifer cells.

It is not possible to compare overall *percentage*-based frequency distributions between any two groups to see whether the distributions are significantly different (Huso, personal communication); *individual counts* at intervals along the range of an explanatory variable, such as numbers of patches in 1939 and 1993 along an elevational gradient, must be utilized for this kind of comparison. To determine whether there is a significant difference between two frequency distributions, the p-value from the chi-square test can be used. In addition, comparing the *percent* of a given group (e.g., 1939 patches) at a particular level of an environmental variable (e.g. elevations of 100-200 m) to other members of a set of groups (e.g., 1993 patches) allows for the determination of a percentage-based difference between groups at a particular level of an explanatory variable. In order to compare the numbers of patches between a given set of groups at any point along an environmental gradient, then, it was necessary to calculate the percentage of each class occurring at each level of the the gradient. This allowed me to account for differences between groups in the number of patches considered. For some comparisons between groups, such as for the comparison between the distribution of the study area and the distributions of patches sampled in 1939 and 1993 along environmental gradients, individual counts were not available for all groups. In this case, individual counts for the study area distribution were not available for comparison. Prior to comparison at individual levels of a particular environmental gradient, then, the percentage of each group present at each level of the environmental variable was calculated.

Independent Variables

I then gathered information about the physical environment, ecoregion, and ownership type in the form of ARC coverages or grids of the area. I obtained mean values for each patch/variable combination. Independent variables used in the analysis included ownership, ecoregion, distance to the coast, elevation, slope, slope position, curvature, distance to nearest stream, radiation, and riparian class; and for those patches with part or all of the patch falling within the riparian zone, stream order class, and flat valley bottom class. Ownership and ecoregion information, in the form of GIS coverages (Figure 6, a and b), and distance to the ocean information, in the form of an ARC grid (Figure 6 c), were obtained from the CLAMS library at the Corvallis Forestry Sciences Laboratory, USDA Forest Service, 3200 SW Jefferson Way, Corvallis, Oregon. The ownership coverage had been obtained by CLAMS from, collectively, Atterbury Consultants, Inc., the U.S. Forest Service, and the Oregon Wilderness Society. Land allocation by ownership class was considered to be unchanged throughout the study period, and was based on ownership classes effective in 1993. A 10-meter resolution digital elevation model (DEM), 1 kilometer larger on all sides than the study area, was made by clipping (GRIDCLIP; ESRI 1992) three DEMs which included parts of the study area, and then joining (MOSAIC in GRID; ESRI 1992) the resultant three parts to form the final 10-meter DEM. The partial DEMs were obtained from the GIS Fish Laboratory at the Corvallis Forestry Sciences Laboratory. The final DEM was the source for other environmental variables (Figure 5). I generated slope information from the 10-meter DEM by running the SLOPE function in GRID (ESRI 1992). I generated slope position information from the 10-meter DEM using an Arc Macro Language (AML) available from the Corvallis Forestry Sciences Laboratory AML database, with sink fill and peak fill limits of 90 cells, and valley accumulation and ridge accumulation minimums of 1350 cells. Slope positions were very evenly distributed in the study area (Figure 11), an artifact of slope position having been measured by dividing the slope into equal intervals from valley bottom to ridgetop without regard to elevational differences across slope position transects. I determined topographic curvature using the CURVATURE function in GRID (ESRI 1992). Annual solar radiation was obtained using the SolarImg program (Harmon and Marks 1995), with inputs of elevation, aspect, and slope derived from the 10-meter DEM, and latitude. Monthly climatic data required for SolarImg were obtained from the irregular network of weather stations in the study area. The monthly total radiation data provided as output from SolarImg were summarized and a grid depicting annual radiation was created. Each of these four resultant grids (slope, slope position, curvature, and radiation) had a cell size of 10 meters. Independent variables showed a variety of distributions in the study area (Figures 11 and 12).

Streams and Stream-Related Information

I generated a GIS coverage of streams using the MAKESTREAMS AML from the GIS fish laboratory, setting the threshold for filling topographic depressions to three

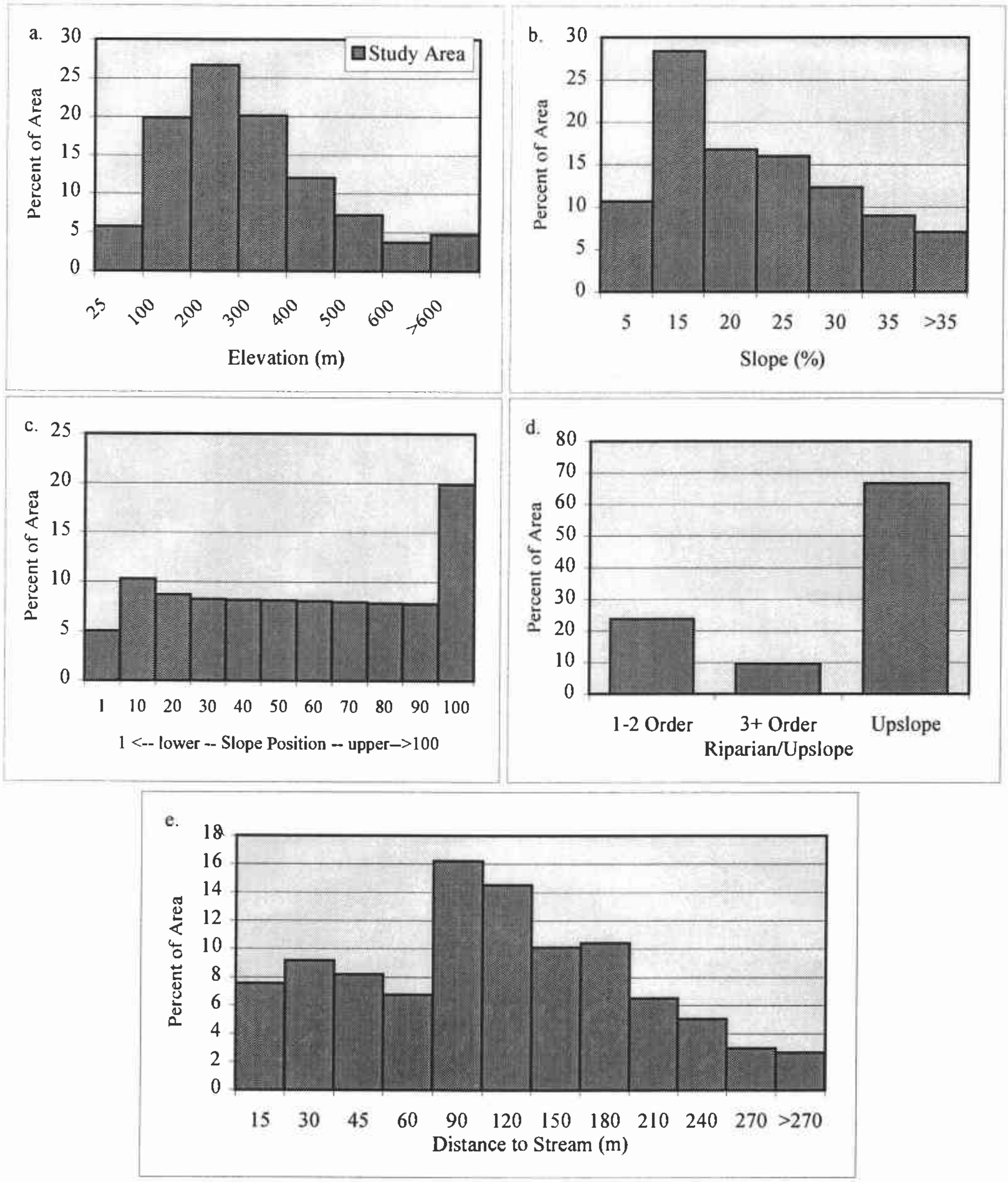

Figure 11. Distribution within study area of environmental variables. Distributions were obtained by taking GIS grid cell counts for classes of each environmental variable and dividing by the total number of cells in the area. a. elevation; b. slope; c. slope position; d. riparian/upslope condition; e. distance to stream. Legend for all figures is in figure a.

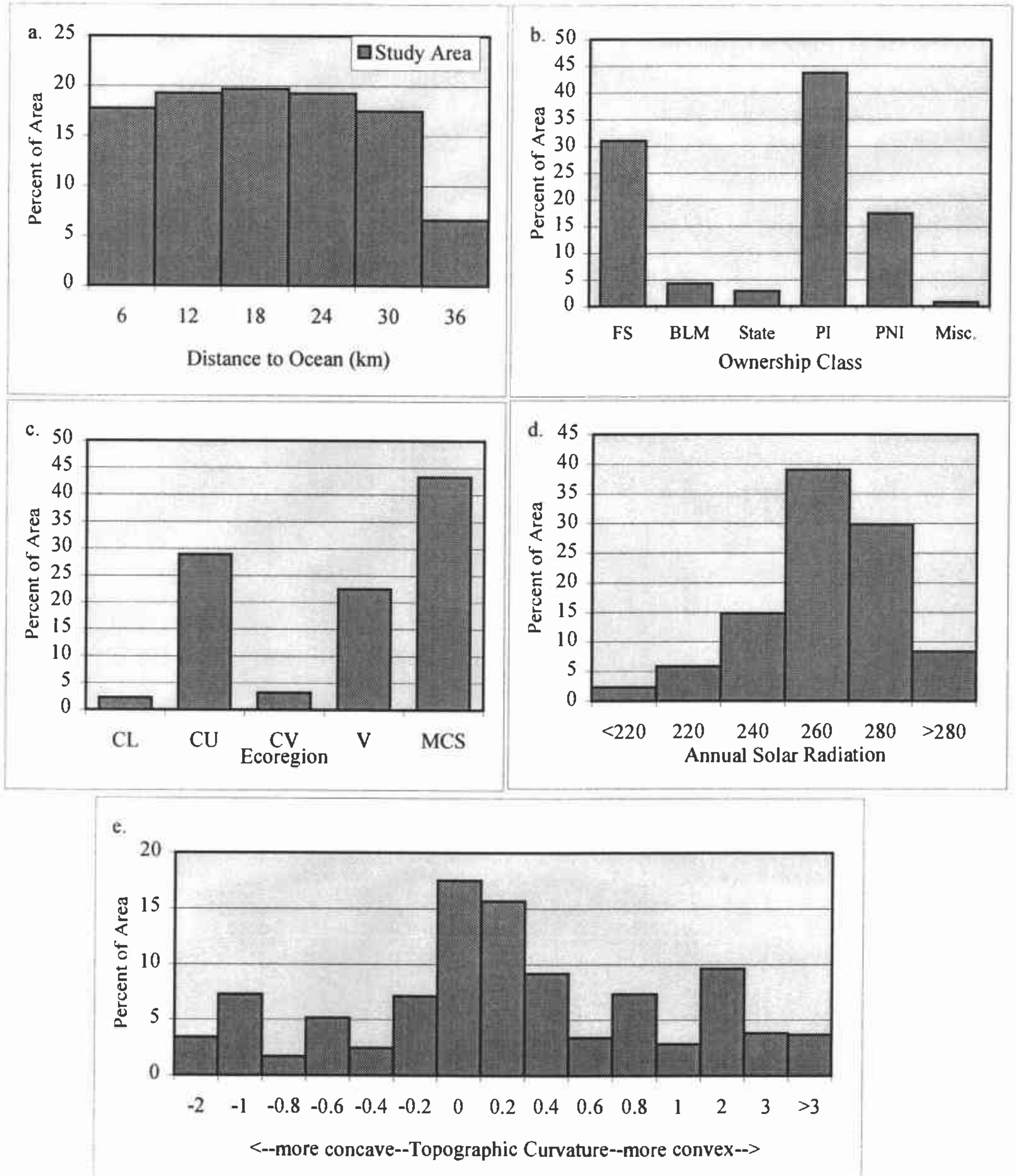

Figure 12. Distribution within study area of environmental variables, distance to ocean, ownership, and ecoregion. Distributions were obtained by taking GIS grid cell counts for classes of each variable and dividing by the total number of cells in the area. a. distance to ocean; b. ownership; c. ecoregion; d. annual solar radiation; e. topographic curvature. Ecoregion classes: CL=Coastal Lowlands; CU=Coastal Uplands; CV=Coastal Volcanics; V=Volcanics; MCS=Mid-Coast Sedimentary. Legend for all figures is in figure a.

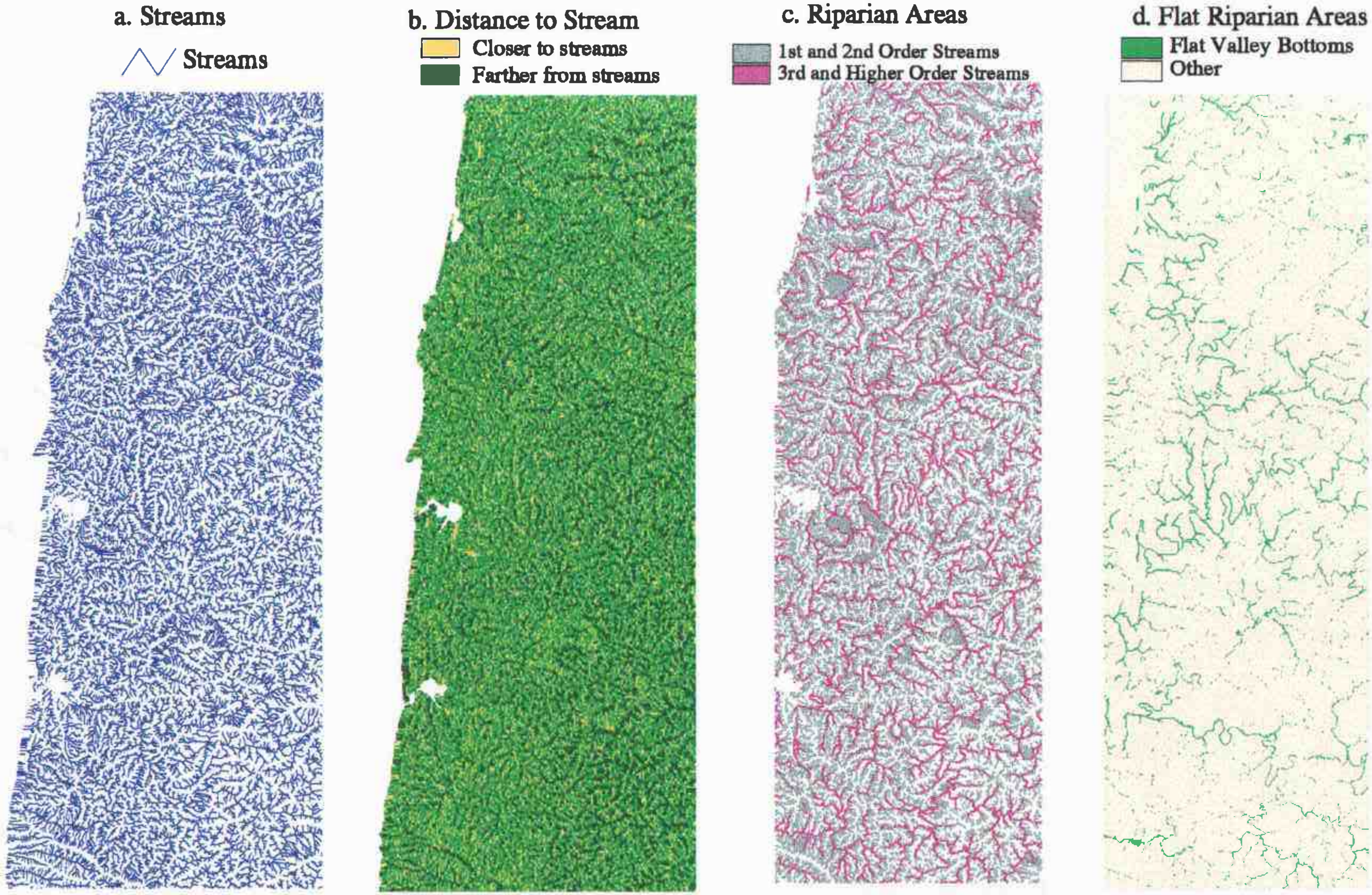

Figure 13. Streams and Stream-Related Coverages.

hectares (Figure 13, a). I utilized this coverage to create all other stream-related coverages (Figure 13). The stream coverage may not perfectly reflect the locations and densities of actual streams in the Coast Range landscape. However, the streams generated via this procedure are very similar in density and location, to streams in a GIS coverage known as the "densified streams coverage"developed by the Alsea Ranger District of the Siuslaw National Forest for an in-depth, single watershed analysis. This "densified" coverage had been formed as a compilation of an existing Siuslaw National Forest streams coverage that was taken into the field in the central Coast Range and ground-truthed. Existing streams not present on the coverage were added, thereby producing the "densified streams coverage." Because measures utilized in the patch analysis that were derived from the DEM-generated streams coverage consisted of distance from streams and some general riparian characteristics, accurate stream density and approximate location are more important than proximity to a particular stream. The 10-meter DEM-generated stream coverage was also compared to the TM Satellite Imagery-derived CLAMS vegetation classification layer and was found to align well with features on that GRID (Moses, personal communication).

I calculated distance from streams from the streams coverage using the LINEDISTANCE function in GRID (ESRI 1992), with an output cell size of 20 meters and a search distance from streams of 1000 meters (Figure 13, b). Stream order was generated as a by-product of the MAKESTREAMS AML. Stream orders were reclassified into two groups: first and second order streams, and all other stream orders. Studies of vegetation patterns in unmanaged riparian forests in the coastal mountains of Oregon showed the greatest difference in vegetation types between these two stream order groups (Pabst and Spies, in press). It may be that fluvial and depositional processes differ along streams of higher order. Within this group of higher stream orders, it was of interest to determine whether patch characteristics differed according to whether the patch was associated with a wide, flat valley bottom or a hillslope. To this end, I created a grid of valleys from a change in slope grid that was generated as part of the CURVATURE process. Change in slope was calculated as the average difference in slope between a single cell and all adjacent cells. I reclassified the cells having values from 1-10 as flat, based on comparison of output with ground data for valleys (Lienkaemper and Grant, personal communication). I then determined a riparian area of interest and removed all valley areas outside this riparian zone from the grid (210, d). The riparian area was set as 60 meters from all stream classes (Figure 13, c.), a measure roughly equivalent to one dominant canopy tree height. This limit was set in accordance with a riparian buffer designation currently in use by the Alsea Ranger District in an extensive riparian study. They set this limit in an attempt to balance micro- and macro-scale influences on riparian features. Setting the riparian area as 60 meters also straddles the differences in legislated riparian zone differences between State and Federal regulations and fish-bearing and non-fishbearing streams, and allows for a single buffer width to be utilized throughout the area; it is also the minimum buffer width required on Federal lands for intermittent streams. Since it was not known which streams in the study area may have been fish-bearing, a broad, conservative estimate for riparian zone seemed appropriate. Federal regulations indicate that on fish-bearing streams, a distance equivalent to two dominant canopy tree heights should be removed from harvest planning. The current State of Oregon expected Riparian Management

Area width for first, second, and third order fish bearing streams and fourth order (perennial) streams is 150 feet (45.5 meters); for fifth order (perennial) streams 210 feet (63.6 meters), and for sixth and higher order (perennial) streams 240 feet (72.7 meters) (Oregon Department of Forestry 1997). These measures, and the 60 meter buffer I developed, are for a single side of the stream. The overall buffer width along any stream, then, would be 120 meters, with the stream lying centrally within the buffer.

RESULTS

The Amount of Area Encompassed by Hardwood Patches and the Distribution of Hardwood Area and the Study Area along Environmental Gradients

The patches I selected covered a total of 9,840,000 m^2 (984 ha) in 1939 and 5,847,200 m^2 (585 ha) in 1993. This random sample of patches declined by 59 percent in overall area from 1939 to 1993. The amount of decline in hardwood area encompassed by these patches differed from the decline in hardwood area derived from the random sample of plots (the patch decline in area was greater). A discrepancy can be expected, because any single sample of points, or of patches, may not adequately represent the amount of hardwood cover present on the landscape. To more accurately quantify the amount of hardwood cover in the entire landscape, it would be necessary to obtain several independent samples of plots and/or patches, and then to derive the mean and standard error for this collection of samples so as to account for the variability between the sets of samples. The randomly sampled plots from which hardwood patches in this study were delineated showed a decline from 22.3 percent hardwood to 19.5 percent hardwood during the study period. These two percentages of hardwood cover from the randomly sampled plots are both greater than the mean amount of hardwood cover (10.8 percent) found by Ripple et al. (in press) in their estimation of percentages of forest types prior to logging in the central portion of the Oregon Coast Range (Ripple et al. in press).

The geographic area encompassed by hardwood patches sampled for this study differed in its distribution along environmental gradients from the overall study area distribution along these gradients (Figures 14 and 15). Hardwoods were more

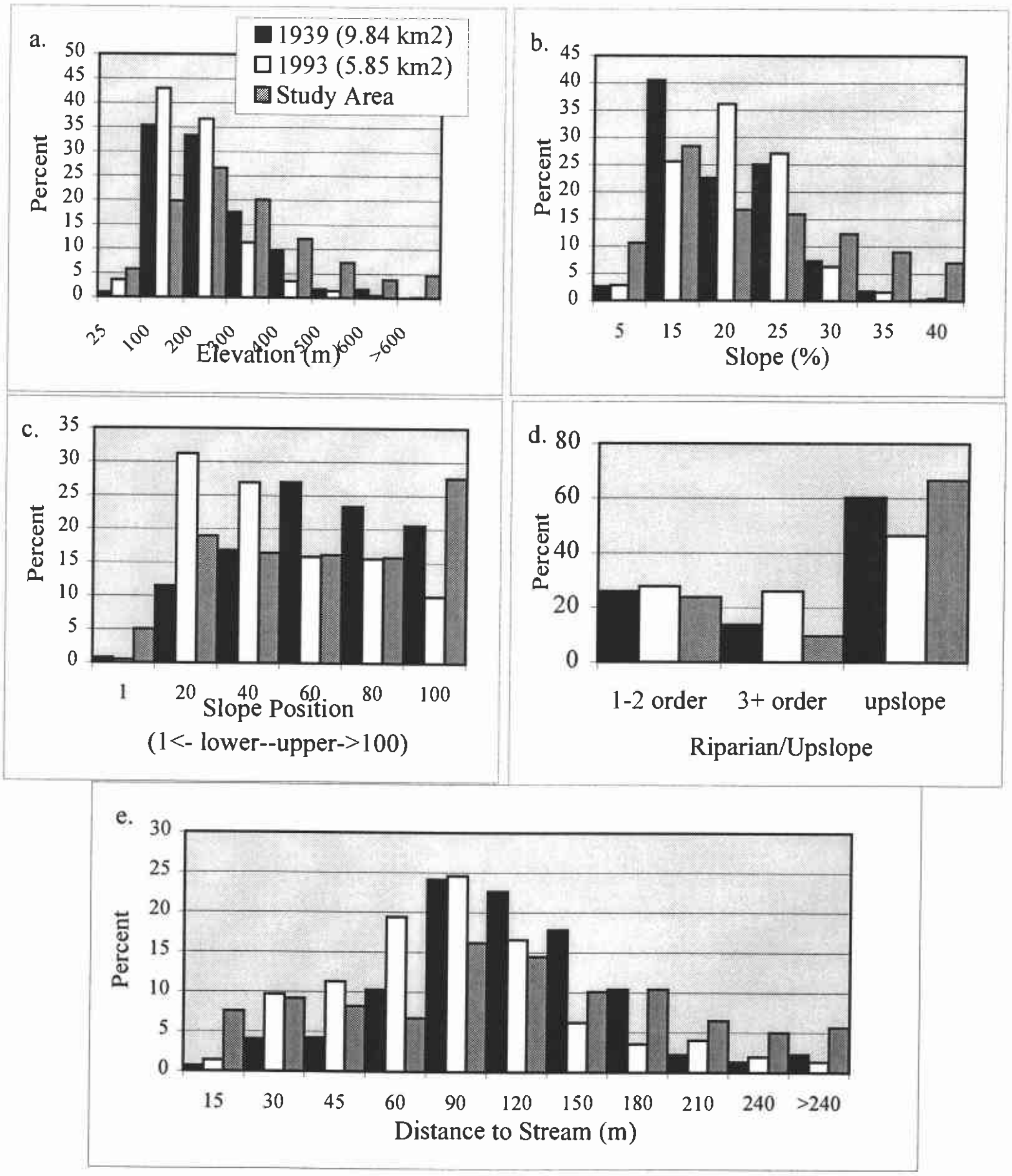

Figure 14. Distribution of total hardwood area in 1939 and 1993 patches and distribution of study area along environmental gradients. a. elevation; b. slope; c. slope position; d. riparian location; e. distance to stream. Legend for all figures is in figure a.

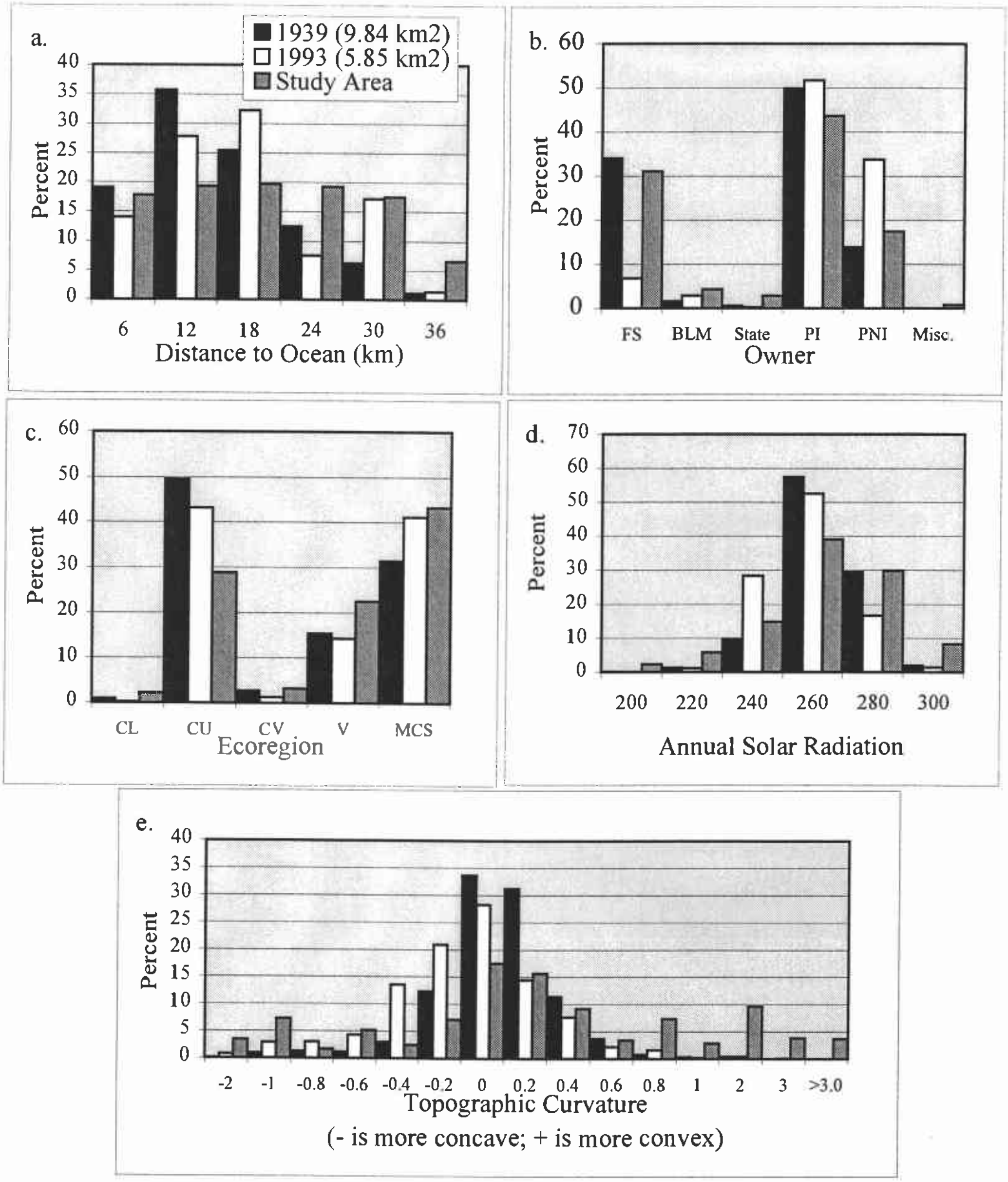

Figure 15. Distribution of total hardwood area in 1939 and 1993 patches and distribution of study area according to environmental gradients, distance to ocean, ownership, and ecoregions. a. distance to ocean; b. ownership; c. ecoregion; d. annual solar radiation; e. topographic curvature. Ecoregion classes: CL=Coastal Lowlands; CU=Coastal Uplands; CV=Coastal Volcanics; V=Volcanics; MCS=Mid-Coast Sedimentary. Legend for all figures is in figure a.

frequently found on very moderate slopes, at low elevations, and along the higher order streams than was the study area as a whole (Figure 14). Hardwood area was found at short distances from the ocean, in the coastal uplands ecoregion, and at sites with moderate concavity or convexity, and low levels of annual solar radiation more frequently than was the study area (Figure 15). Hardwoods were less frequently found in upland (non-riparian) areas than the study area.

There were some differences between dates in the distribution of hardwood area: in 1939, hardwood area was higher on more convex sites and at higher slope positions than in 1993 (Figures 14 and 15). Overall, hardwood area distributions reflected the distribution of ownerships in the study area. However, from 1939 to 1993, hardwood area showed a drastic decline on Forest Service lands, plummeting from 34 to 8 percent of the total hardwood area sampled. Hardwood area also showed a dramatic increase on private non-industrial lands during this time, jumping from 14 to 34 percent of the total hardwood area sampled. These 1993 percentages are far less and far greater, respectively, than the percentages of the study area possessed by these landowners (Figure 15, b).

The Geographic Distribution of Hardwood Patches

The geographic distributions of hardwood patches in 1939 and 1993 differed significantly according to ownership (p=0.001), slope position (p=0.03), proportion of patch in riparian buffer (p=0.04), and distance to stream (p=0.04) (Figures 16 and 17). In 1939, patches were most often found along the ridgetops, while in 1993 hardwood patches were most commonly restricted to the lower slopes. Patches more frequently occurred entirely outside the riparian buffer in 1939, but entirely inside the riparian

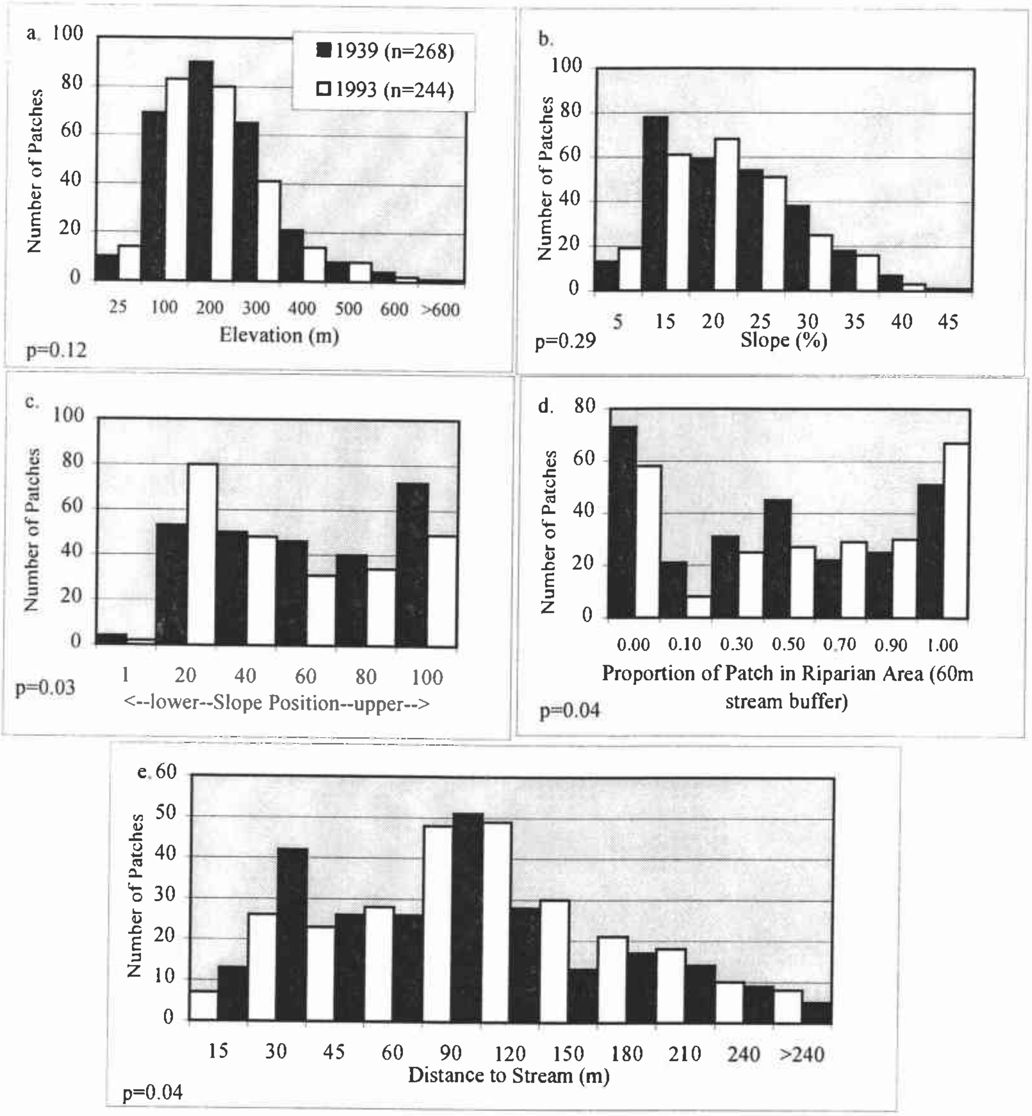

Figure 16. Frequency distribution of patches along environmental gradients for patches selected in 1939 and 1993. Bars indicate mean patch values for: a. elevation; b. slope; c. slope position; d. proportion of patch in riparian area; e. distance to stream. P-values are from a chi-square test. Legend for all figures is in figure a.

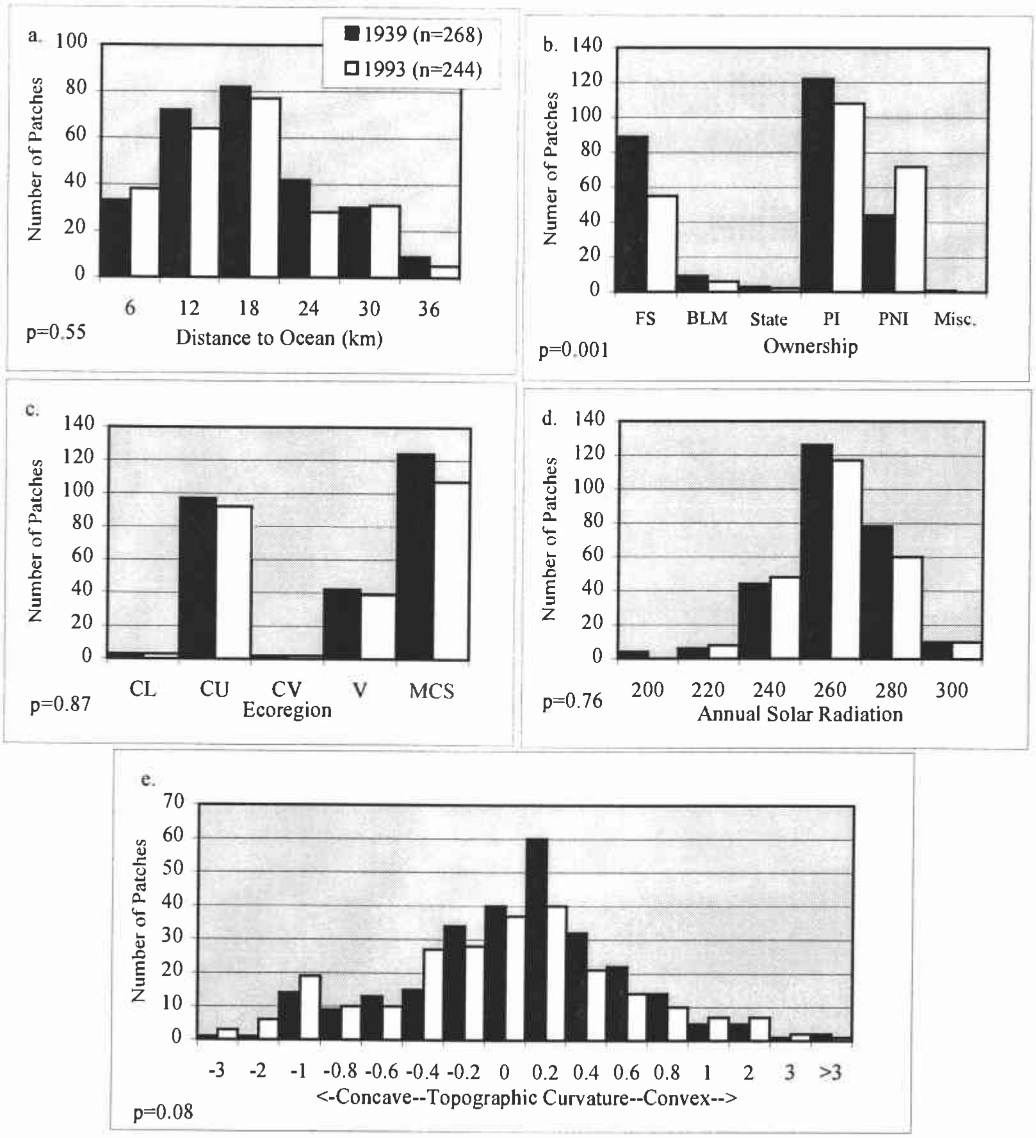

Figure 17. Frequency distribution of patches according to environmental gradients, distance to ocean, ownership, and ecoregion, for patches selected in 1939 and 1993. Bars indicate mean patch values for: a. distance to ocean; b. ownership; c. ecoregion; d. annual solar radiation; e. topographic curvature. Ecoregion classes: CL=Coastal Lowlands; CU=Coastal Uplands; CV=Coastal Volcanics; V=Volcanics; MCS=Mid-Coast Sedimentary. P-values are from a chi-square test. Legend for all figures is in figure a.

buffer in 1993. Similarly, in 1939, patches were found farther from streams than in 1993 (Figure 18). Patches were more often located on Forest Service lands in 1939 than in 1993 and were less often located on private non-industrial lands in 1939 than in 1993 (Figure 19). All other distributions along environmental gradients were not significantly different between dates.

Patch frequencies at both dates were sometimes at their highest levels under environmental conditions that were found less commonly throughout the study area. For example, patches were found more frequently on gentle slopes than these slopes occurred in the study area as a whole (Figures 18 and 11). Patches were also found less often on the highest and the lowest slope positions than these slope positions occurred in the study area as a whole. Patches at both dates were found at higher frequencies at shorter distances to the ocean than the distribution of ocean distances in the study area as a whole; while over 70 percent of hardwood patches were located within 18 km of the ocean, only 55 percent of the study area fell within this distance to the ocean (Figures 12 and 19). Hardwood patches also occurred less frequently in convex topographic positions than occurred in the study area as a whole (Figures 12 and 19).

Differences between Hardwood Area and Hardwood Patch Geographic Distributions

One difference between the distribution of hardwood patches and hardwood area involves the amount of hardwoods fully outside the riparian area. While between 40 and 60 percent of all hardwood area was located in areas outside the riparian zone at either date considered, only between 23 and 27 percent of all hardwood patches were

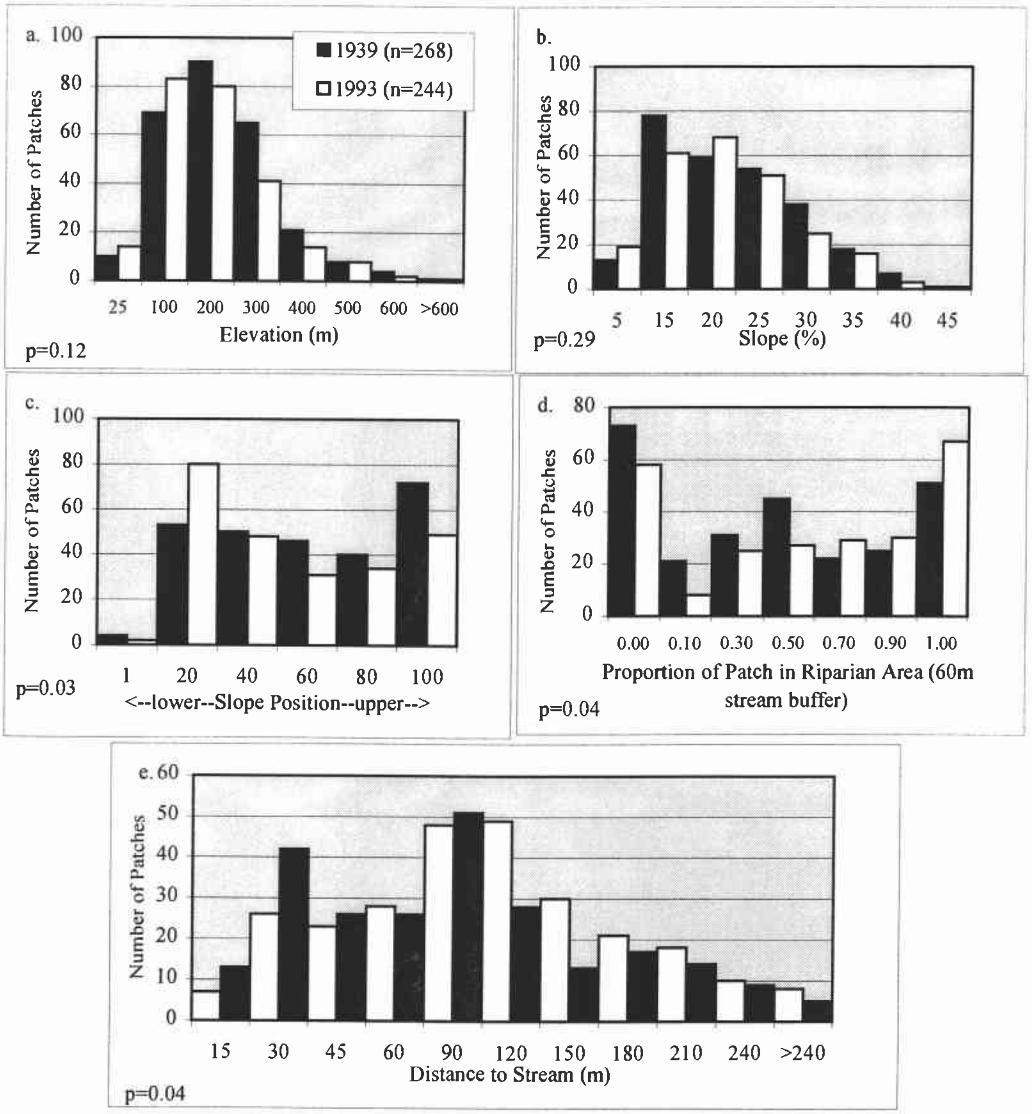

Figure 16. Frequency distribution of patches along environmental gradients for patches selected in 1939 and 1993. Bars indicate mean patch values for: a. elevation; b. slope; c. slope position; d. proportion of patch in riparian area; e. distance to stream. P-values are from a chi-square test. Legend for all figures is in figure a.

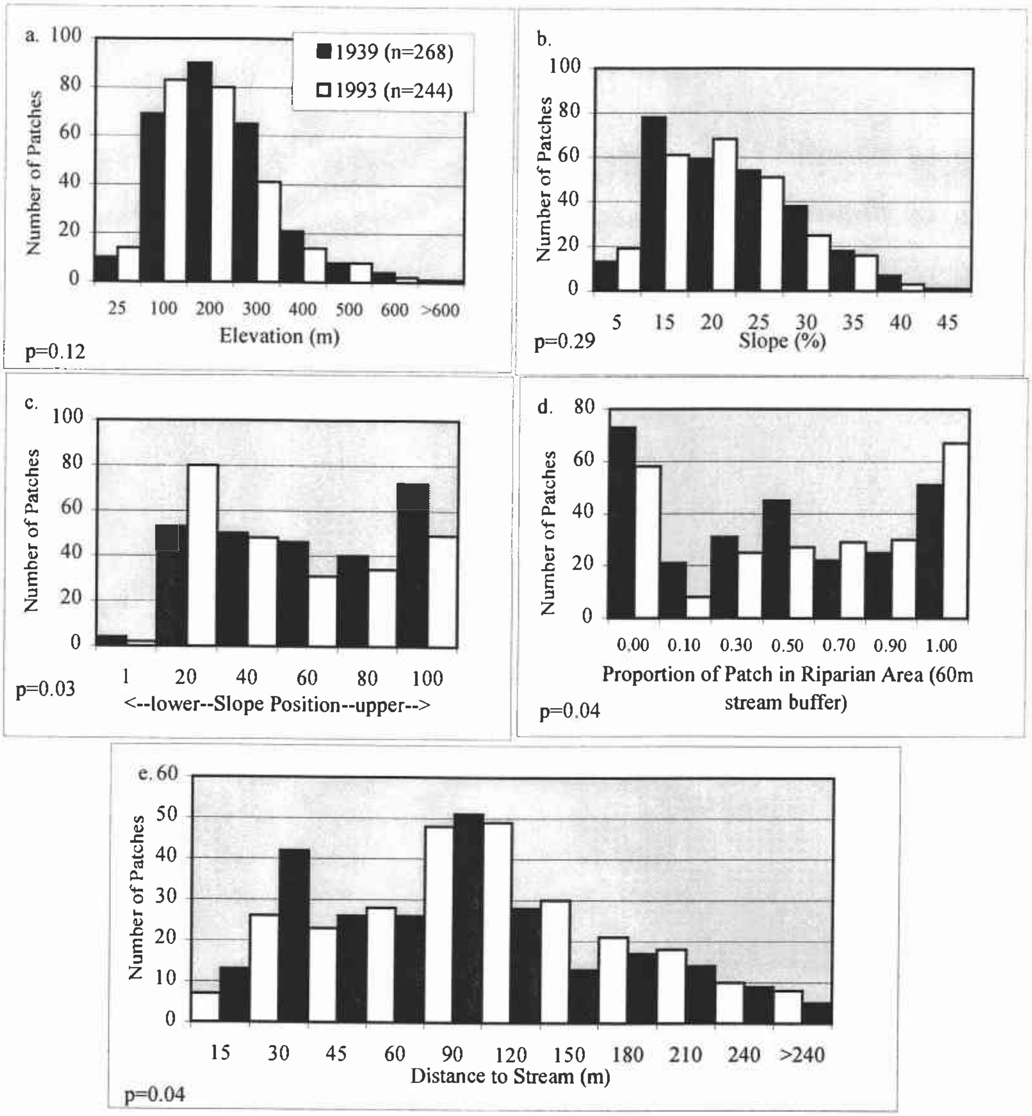

Figure 16. Frequency distribution of patches along environmental gradients for patches selected in 1939 and 1993. Bars indicate mean patch values for: a. elevation; b. slope; c. slope position; d. proportion of patch in riparian area; e. distance to stream. P-values are from a chi-square test. Legend for all figures is in figure a.

located fully outside the riparian zone, with no part of the patch falling within the riparian zone (Figure 14, d; Figure 18, d). This indicates that patches in these upslope areas were larger than the average patch: fewer patches encompassed more of the overall hardwood area on these upslope sites. In 1939, the percent of patches declined at distances greater than 18 km from the ocean, but overall hardwood area declined at lower distances from the ocean, at distances greater than 12 km from the ocean. This indicates that in 1939, the larger patches occurred nearer the ocean. Selected patches occurring on coastal upland sites showed an increase in number but a decrease in overall area from 1939 to 1993, such that the percent of patch numbers occurring here more closely resembled the percent of overall hardwood area in 1993 than in 1939; patch number on mid-coastal sedimentary sites decreased similarly (Figure 19, c; Figure 15, c).

The various ownership classes in the study area also exhibited differences between hardwood patch and hardwood area percentage distributions. In 1993, the percent of patches occurring on private industrial lands was lower than the percent of overall patch area occurring on these lands. This indicates that patches were slightly larger than average on these lands. Lands under this ownership actually exhibited a slight decline in the percentage of patches from 1939 to 1993, but a slight increase in the percentage of overall hardwood area occurring here. On Forest Service lands, the number of patches declined by approximately 10 percent, but the overall area encompassed by these patches declined by nearly 20 percent. This indicates that, while the Forest Service may be maintaining moderate levels of hardwood patches on their lands, these patches were much smaller on average in 1993 than the patches that were present in 1939 (Figure 19, b; Figure 15, b).

Patch Size Characteristics

The weighted mean patch size declined during the study period for all patches delineated in 1939 and 1993, and many patches that had been present in 1939 disappeared by 1993. The weighted mean size of patches decreased by 16%, from 3,675 m^2 to 3,082m^2 during the study period (Table 1; Figure 20); a T-test indicated that this difference between 1939 and 1993 in weighted mean patch area is significantly different from zero ($p=0.00001$). The distribution of patch sizes between dates, however, was not significant ($p=0.42$ from a chi-square test). With a large sample size, the t-test for difference between means has greater power than the chi-square test. Most of the patches delineated at either date occurred in the very small, small, and medium size classes (Figure 20; Table 1). The median patch size decreased from 11,600 to 9,200 m^2.

For patches that were delineated in 1939 and tracked through the study period, the size of the patch was related to its fate – either increasing or decreasing in size, or disappearing. Small patches disappeared more often than large patches, while large patches tended to decline in area rather than to disappear (Figure 21). This is not surprising, given that the areal extent of disturbance required to cause a large patch to disappear is far greater than that for a small patch. Medium-sized patches showed the highest frequency of size increase in relation to the initial frequency of that patch size group (Figure 23, a).

Table 1. Weighted mean area and mean area values for all patches, by size class. For weighted means, each patch area value was multiplied by 1/patch area) so that large patches would not carry more weight than small patches in the calculation of mean area for all patches. Size classes: VS=very small; S=small; M=medium; ML=medium -large; L=large; VL=very large. N is the number of patches present in that size class for the given date.

1939

Size Class (m^2)	n	weighted mean area (m^2)	s.e.	mean area (m^2)	s.e.
ALL PATCHES	268	3674.74	674.37	36716.42	4677.98
VS (400-5000)	80	1312.89	123.46	2230.00	155.37
S (5000-10000)	50	6949.53	216.50	7280.00	226.27
M (10000-20000)	40	14710.75	433.65	15250.00	440.32
ML (20000-40000)	34	27579.12	1034.20	28858.82	1064.77
L (40000-80000)	33	51783.64	1414.59	53600.00	1853.09
VL (>80000)	31	1411496.80	15362.45	191535.48	26416.27

1993

Size Class (m^2)	n	weighted mean area (m^2)	s.e.	mean area (m^2)	s.e.
ALL PATCHES	244	3082.08	538.79	26062.04	3271.36
VS (400-5000)	85	1241.15	125.70	2310.59	157.63
S (5000-10000)	45	7067.79	223.15	7377.78	226.90
M (10000-20000)	41	14002.90	455.33	14595.12	466.25
ML (20000-40000)	30	27374.65	944.39	28386.67	1027.35
L (40000-80000)	27	54978.23	2131.59	57125.93	2222.09
VL (>80000)	17	134659.70	16879.61	168494.12	26746.97

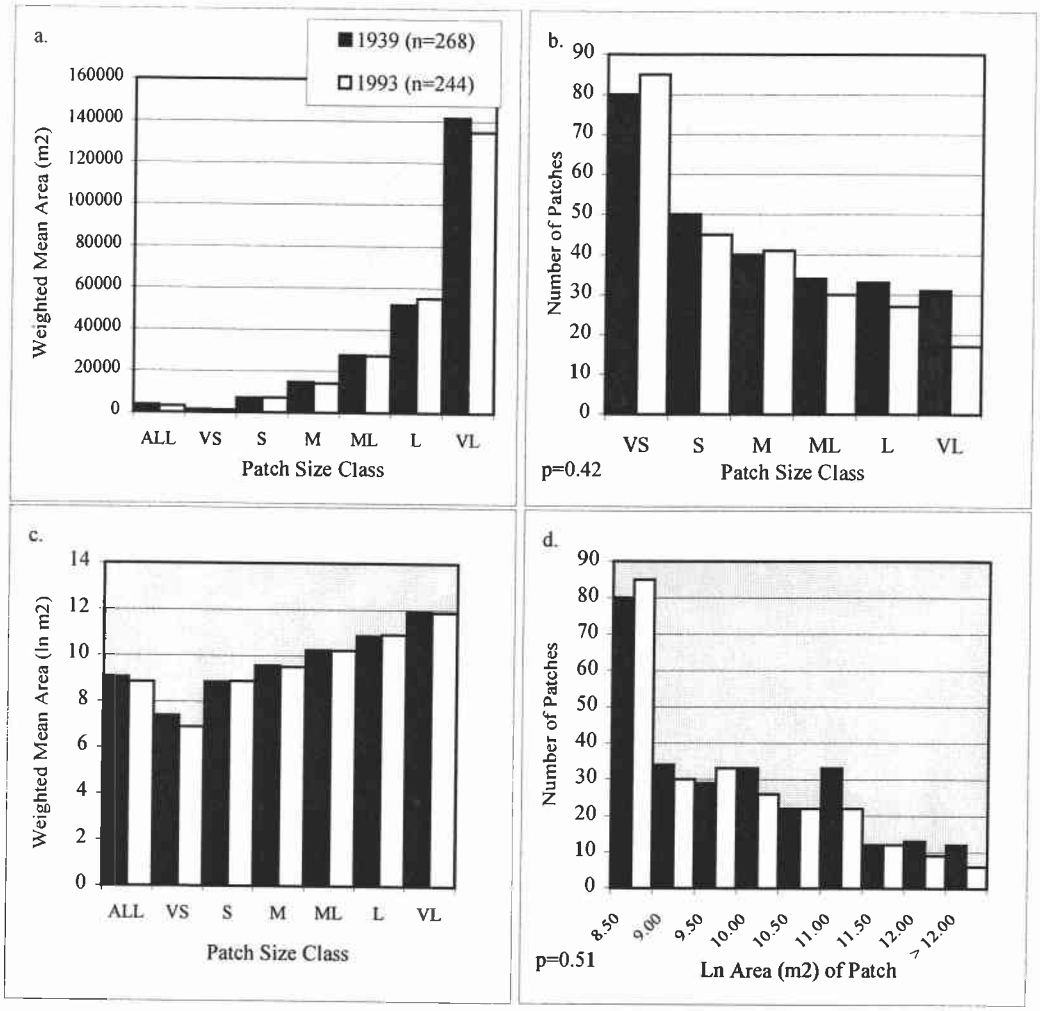

Figure 20. Patch size distributions. a. patch size distribution by weighted mean area; b. number of patches in each size class; c. ln patch size distribution by weighted mean area; d. number of patches by ln patch area. For a., c. and d., all patches were weighted by (1/patch size) so that large patches would not carry more weight in the frequency distribution than small patches. Patch size classes: ALL: all patches combined; VS=400-5000m2; S=5000-10000m2; M=10000-20000m2; ML=20000-40000m2; L=40000-80000m2; VL= >80000m2. P-values are from a chi-square test. Legend for all figures is in figure a.

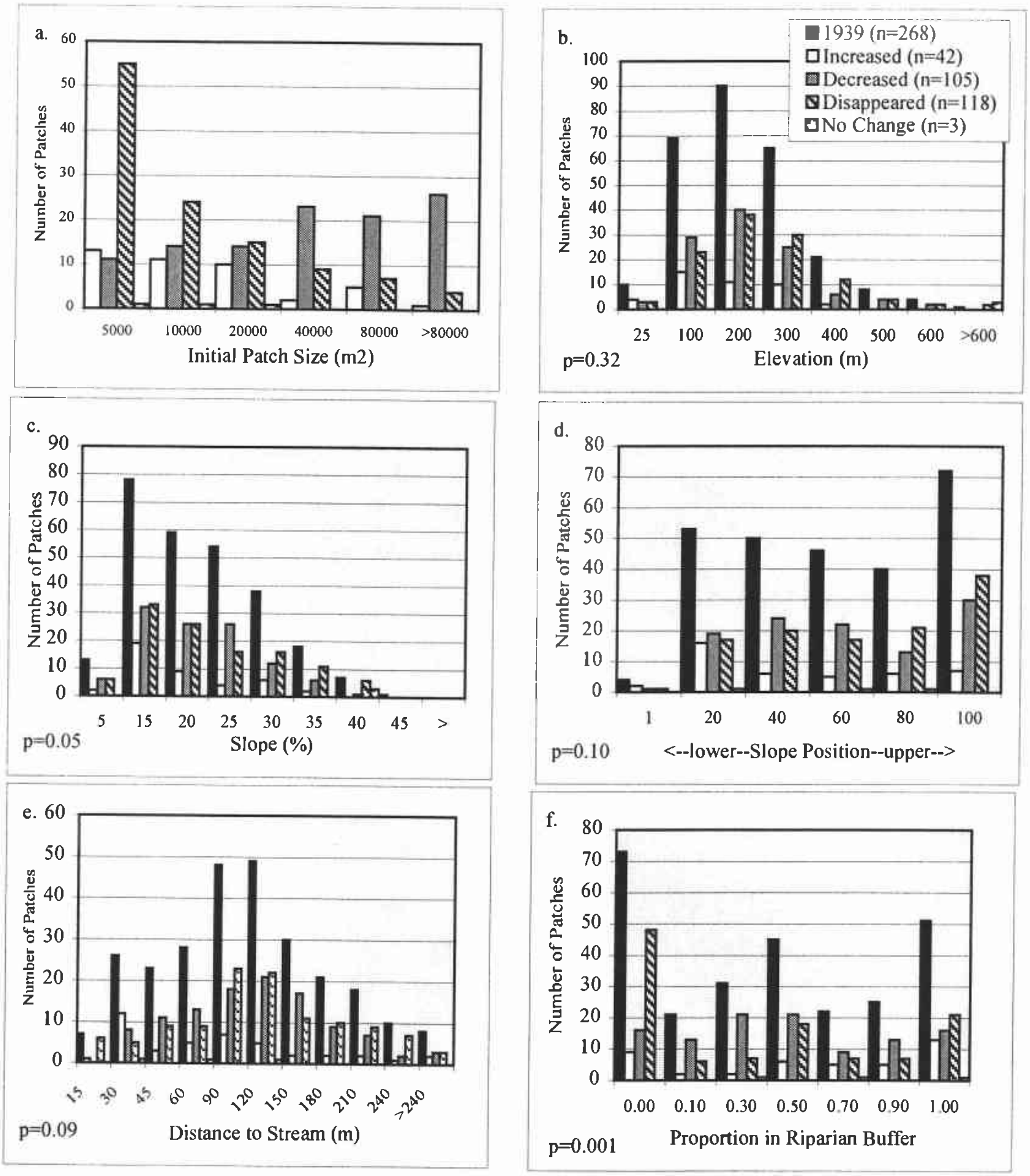

Figure 21. Patch size change frequency distributions in relation to initial patch size and along environmental gradients for size change classes: increased, decreased, disappeared, no change. Patch size change measures were obtained by comparing cell counts in 1939 and 1993 for patches that originated in 1939. Figures: a. initial patch size; b. elevation; c. slope; d. slope position; e. distance to stream; f. proportion in riparian buffer. P-values are from a chi-square test. Legend for all figures is in figure b.

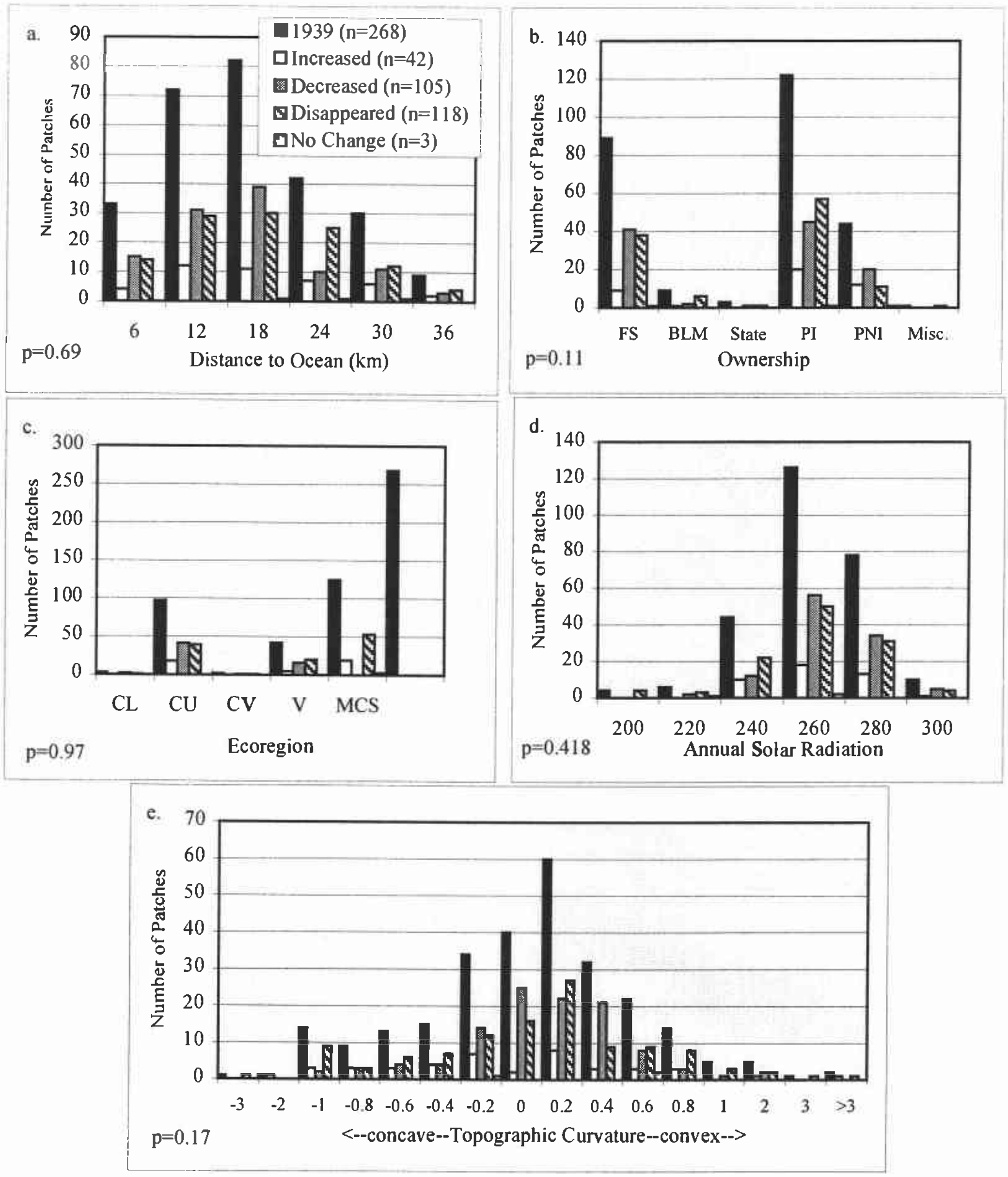

Figure 22. Patch size change frequency distributions according to environmental gradients and other variables for size change classes: increased, decreased, disappeared, no change. Patch size change measures were obtained by comparing cell counts in 1939 and 1993 for patches that originated in 1939. Figures: a. distance to ocean; b. ownership; c. ecoregion; d. annual solar radiation; e. topographic curvature. Ecoregion classes: CL=Coastal Lowlands; CU=Coastal Uplands; CV=Coastal Volcanics; V=Volcanics; MCS=Mid-Coast Sedimentary. P-values are from a chi-square test. Legend for all figures is in figure a.

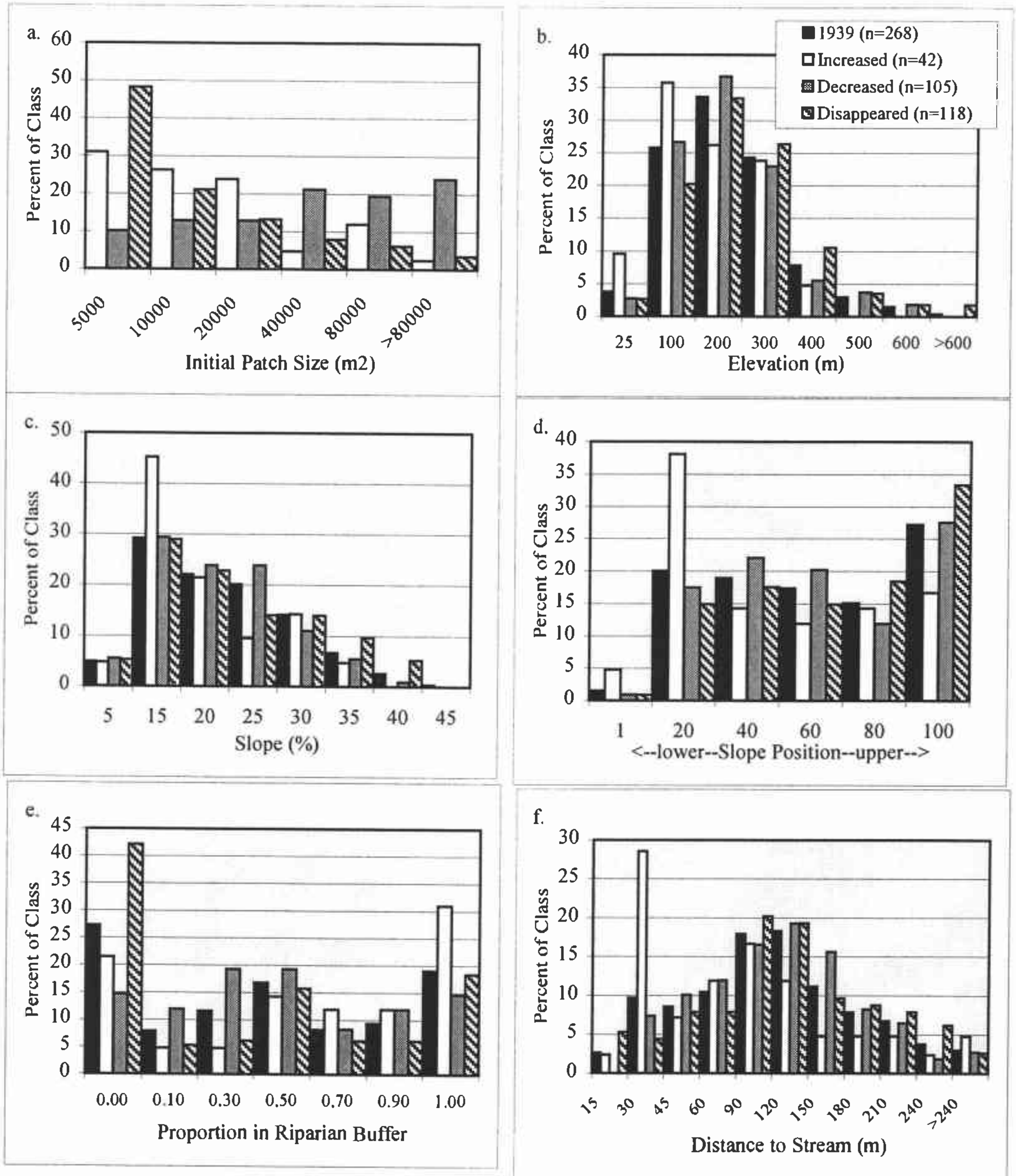

Figure 23. Patch size change distributions, by percent of class, in relation to initial patch size and along environmental gradients for size change classes: increased, decreased, disappeared, no change. Patch size change measures were obtained by comparing cell counts in 1939 and 1993 for patches that originated in 1939. Figures: a. initial patch size; b. elevation; c. slope; d. slope position; e. distance to stream; f. proportion in riparian buffer. Legend for all figures is in figure b.

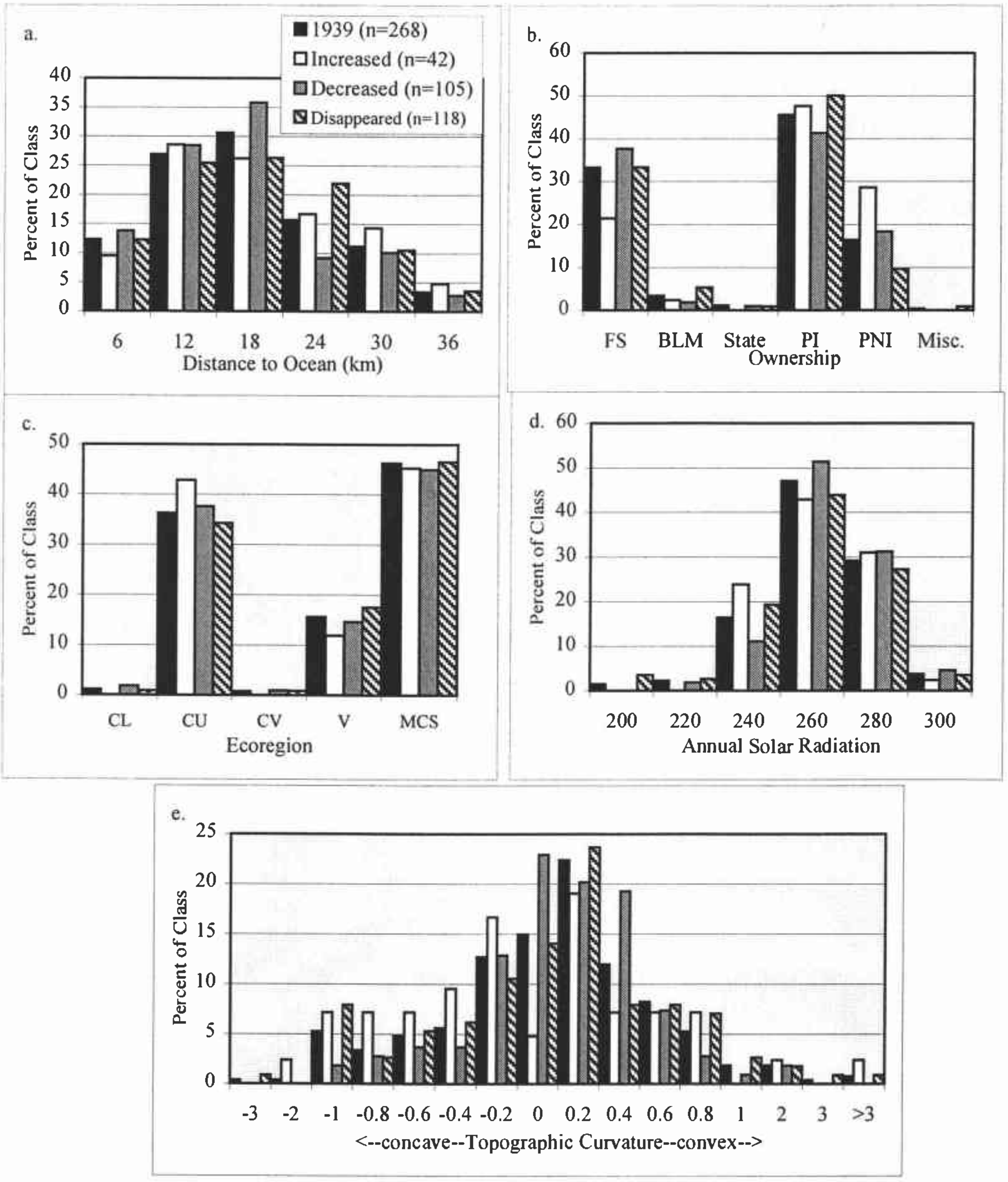

Figure 24. Patch size change distributions, by percent of class, according to environmental gradients, distance to ocean, ownership, and ecoregion for size change classes: increased, decreased, disappeared, no change. Patch size change measures were obtained by comparing cell counts in 1939 and 1993 for patches that originated in 1939. Figures: a. distance to ocean; b. ownership; c. ecoregion; d. annual solar radiation; e. topographic curvature. Ecoregion classes: CL=Coastal Lowlands; CU=Coastal Uplands; CV=Coastal Volcanics; V=Volcanics; MCS=Mid-Coast Sedimentary. Legend for all figures is in figure a.

Patch changes in size (increased, decreased, or disappeared) and the 1939 initial condition of these patches had significantly different distributions in relation to slope (p=0.05) and to whether the patch occurred within the riparian buffer (p=0.001) (Figure 21). All other distributions of these four classes along environmental gradients were not significantly different (Figures 21 and 22). Patches that increased in size occurred more often than the initial 1939 patches at low elevations, very gentle slopes, very close to streams, at lower slope positions, at moderate radiation levels, or on coastal upland sites (Figures 23 and 24). Twenty-nine percent of patches that increased in size during the study period were found on private non-industrial lands, although only 16 percent of the hardwood patches were found here in 1939 (Figure 24). Patches disappeared most often when they fell just outside the 60 m riparian buffer. These patch disappearances occurred at much higher frequencies than the frequency of 1939 patches in non-riparian areas (Figures 23, e and f). Patches decreased in size on slightly convex sites much more frequently than the availability of 1939 patches on these sites (Figure 24). For other landscape features, patches that decreased in area were found in approximate proportion to patch availability in 1939.

Patch Shape Characteristics

Patch shapes in both 1939 and 1993 were predominately intermediate in complexity, neither entirely square nor highly irregular (Figure 25). The mean shape value for all patches was 1.85 in 1939 and 1.96 in 1993; the mean fractal dimension value was 1.14 in 1939 and 1.16 in 1993 (Table 2). Patches in 1993 were more irregular in shape than patches in 1939 (Figure 25, b). Shape frequency distributions for 1939 and 1993 patches were significantly different (p=0.001), and mean patch shape

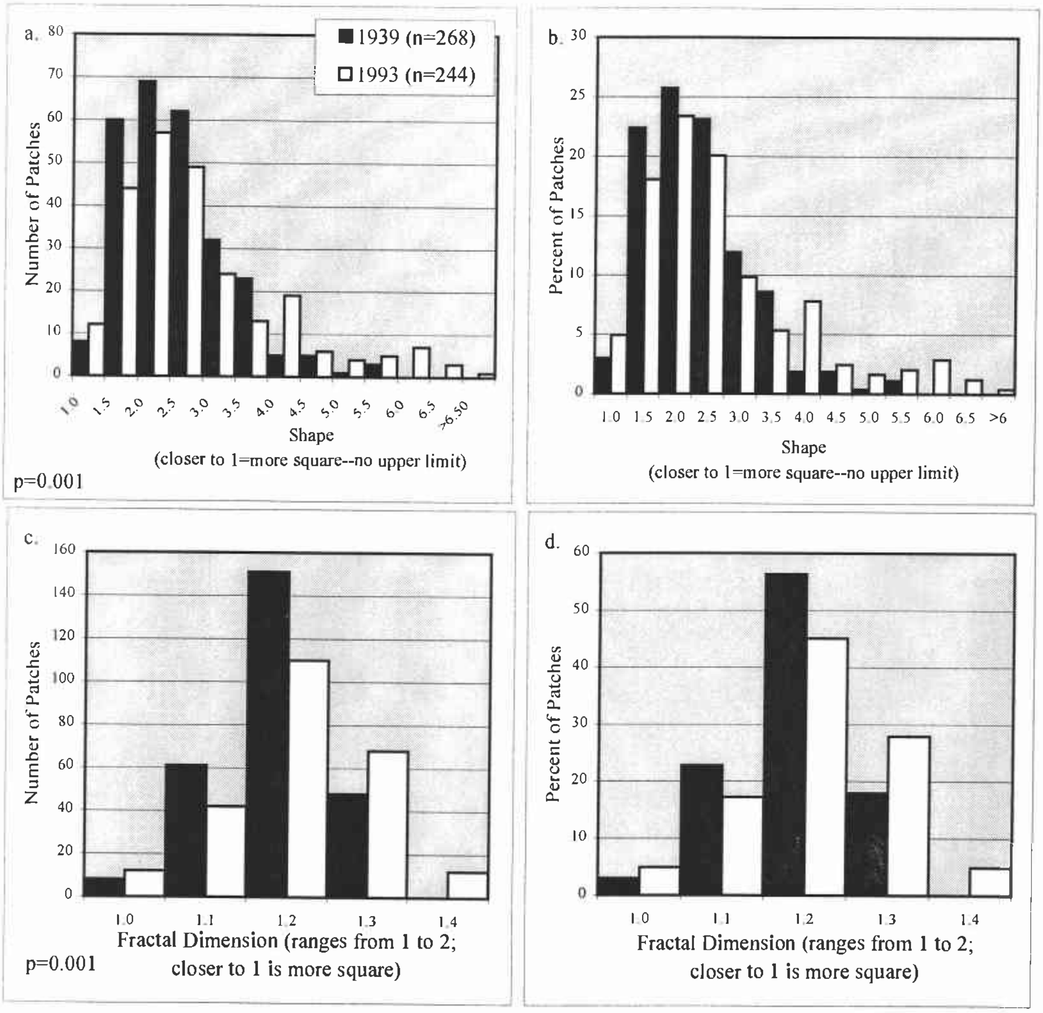

Figure 25. Frequency distributions for patches according to patch shape. a. number of patches and patch shape; b. percent of patches and patch shape; c. number of patches and fractal dimension; d. percent of patches and fractal dimension. P-values are from a chi-square test. Legend for all figures is in figure a.

Table 2. Mean 1939 and 1993 shape and fractal dimension values for patches delineated in 1939. For patch class designations, please see figure 26. N is number of patches that occurred in each class. Shape and fractal dimension are measured such that values closer to one are more square, or regular. Fractal dimension has the upper bound of two; shape is limitless.

1939

Patch Class	n	Mean Shape	s.e.	Mean Fractal Dimension	s.e.
All 1939 patches	268	1.85	0.04	1.13	0.04
1939 patches that fragmented	90	2.09	0.08	1.15	0.08
1939 patches that coalesced	28	2.38	0.13	1.19	0.13
1939 patches that did not change	32	1.82	0.09	1.13	0.09
1939 patches - All non-fragmented	60	2.05	0.08	1.16	0.08
1939 patches that disappeared	118	1.62	0.06	1.11	0.06

1993

Patch Class	n	Mean Shape	s.e.	Mean Fractal Dimension	s.e.
All 1939 patches	268	1.96	0.06	1.15	0.01
1939 patches that fragmented	90	2.82	0.12	1.22	0.01
1939 patches that coalesced	28	1.73	0.13	1.13	0.01
1939 patches that did not change	32	1.54	0.10	1.11	0.01
1939 patches - All non-fragmented	60	1.64	0.08	1.12	0.01
1939 patches that disappeared	118	.	.	.	.

differed significantly between the two dates (p=0.0001, for both shape and fractal dimension) (Figure 25).

Of the patches sampled in 1939, 44 percent disappeared, 34 percent fragmented, 12 percent persisted and neither fragmented nor coalesced, and 10 percent coalesced. Patches could have disappeared if they were harvested or if they shifted into another patch type through succession or natural disturbance. Mean shape varied between dates for all patches (Figure 26). Patches that fragmented showed an increase in shape complexity, while patches that coalesced or did not change in the number of sub-patch units present showed a decrease in shape complexity from 1939 to 1993 (Figure 26). Of the patches that fragmented, coalesced, did not change, or disappeared, patches that coalesced by 1993 showed the highest mean shape complexity in 1939, and patches that fragmented by 1993 showed the highest mean shape complexity in 1993. Non-fragmented patches in 1939 were much more irregular in shape than they were in 1993. Patches that coalesced showed even higher differences in mean shape between the two dates. In contrast, patches that neither fragmented nor coalesced showed much more similar mean shape values for the two dates (Table 2). General trends in shape distribution were similar regardless of whether fractal dimension or shape was the shape measure considered. 1939 patches, and patches that fragmented, coalesced, disappeared, or did not change in sub-patch units had distributions along environmental gradients that were not significantly different (Figures 27 and 28), save for one condition: the proportion of the patch found in the riparian buffer differed significantly between these shape change groups (p=0.001). This could be because a high proportion of patches that disappeared fell entirely outside the riparian zone (Figure 29, d).

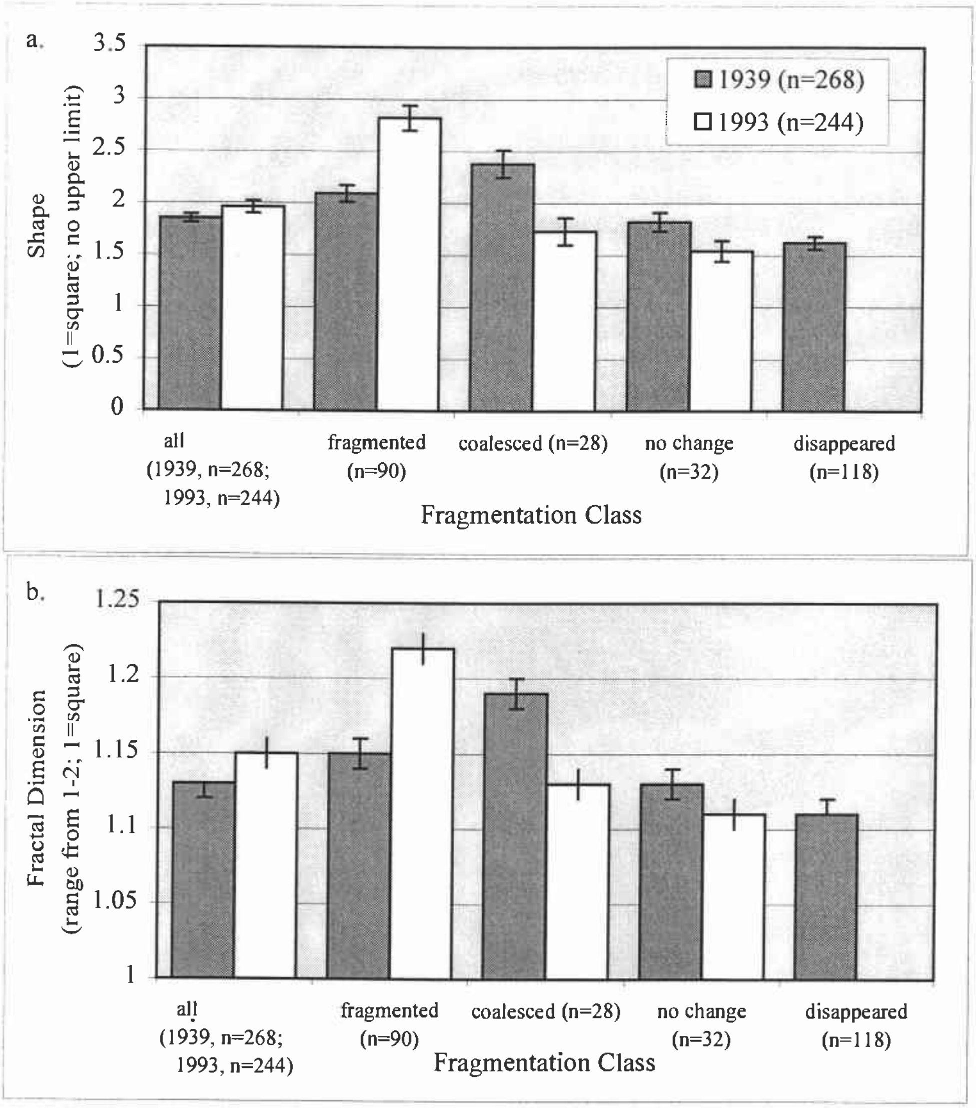

Figure 26. Change in mean patch shape and fractal dimension, by fragmentation class. Patches were broken into sub-patch units if all cells with identical patch numbers were not contiguous with nearest-neighbor cells (N-S-E-W). Fragmentation class was determined by examining the difference in number of sub-patch units from 1939 to 1993 for patches that originated in 1939, because diagonal cells were not recognized by FRAGSTATS program as contiguous but were considered to be so. Patches that fragmented exhibited an increase in sub-patch units; patches that coalesced exhibited a decrease; all non-fragmented patches includes those patches that either coalesced or did not change in number of sub-patch units. Figures: a. change in mean patch shape; b. change in mean patch fractal dimension. Legend for both figures is in figure a.

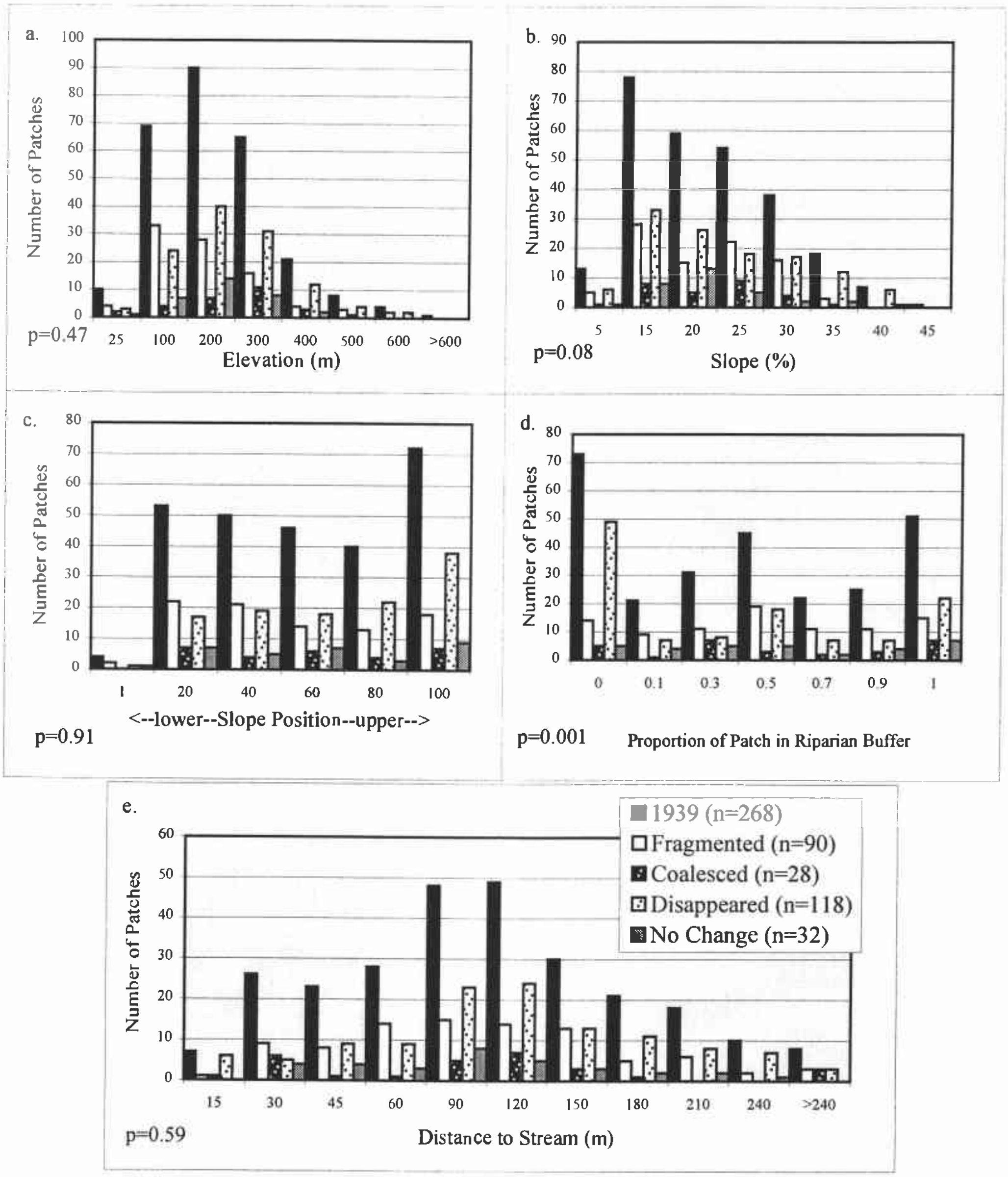

Figure 27. Frequency distribution of patch shape change classes along environmental gradients. For description of classes, please see figure 26. a. elevation; b. slope; c. slope position; d. proportion of patch in riparian buffer; d. distance to stream. P-values are from chi-square test. Legend for all figures is in figure e.

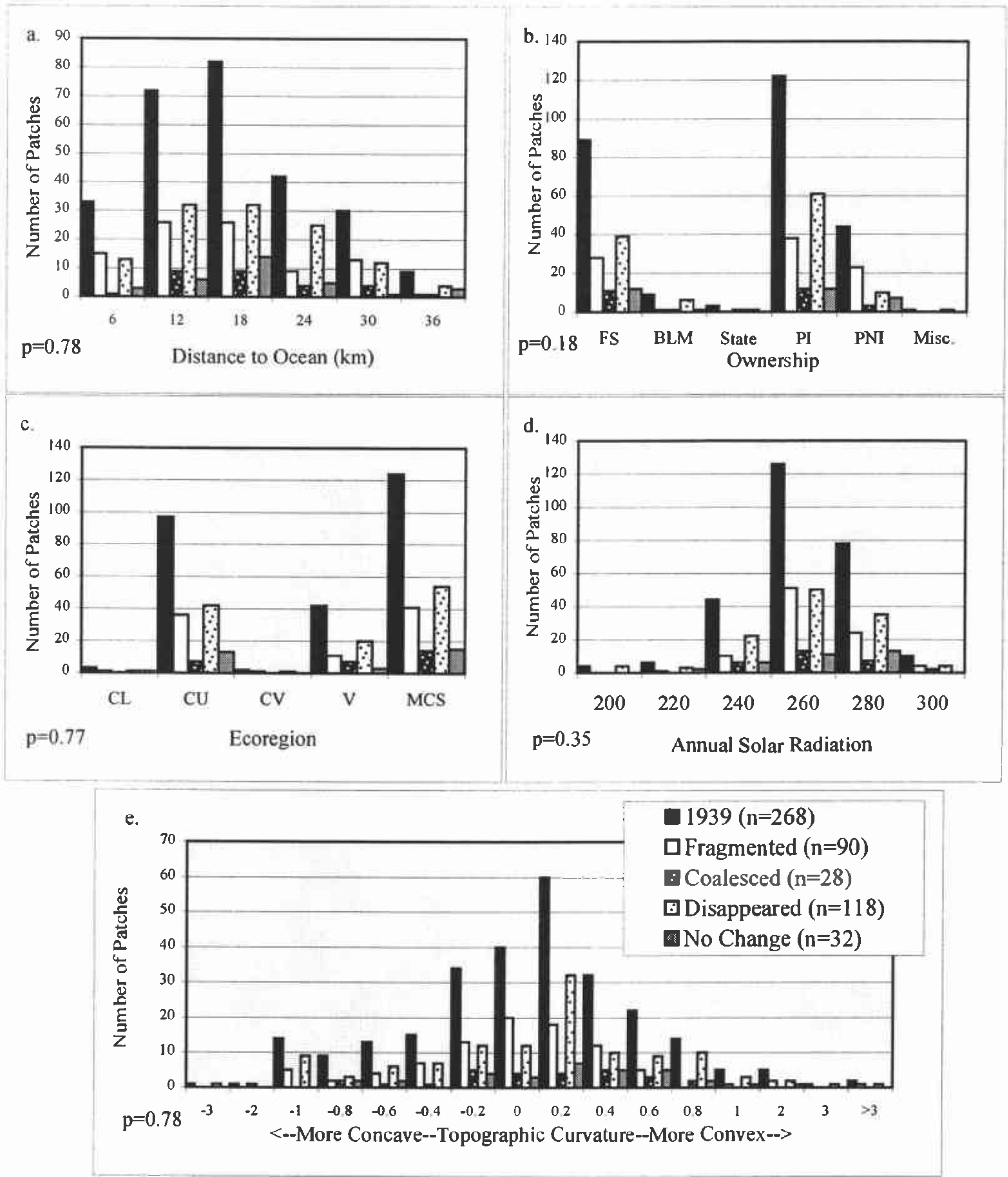

Figure 28. Frequency distribution of patch shape change classes according to environmental gradients, distance to ocean, ownership, and ecoregion. For description of classes, please see figure 26. a. distance to ocean; b. ownership; c. ecoregion; d. annual solar radiation; e. topographic curvature. P-values are from a chi-square test. Legend for all figures is in figure e.

Patches that neither fragmented nor coalesced ("no change"), and patches that coalesced, occurred at higher frequencies on moderate slopes or at moderate elevations than the 1939 distribution of patches (Figure 29). Patches that did not change also occurred more frequently at middle distances to the ocean and on sites receiving higher annual radiation levels than the 1939 distribution of patches (Figure 30). Patches that coalesced occurred less frequently on coastal uplands, and more frequently on volcanic ecoregions, than the 1939 distribution of patches (Figure 30, c). Patches that fragmented into more sub-patch units occurred with fairly similar frequencies as the distribution of 1939 patches.

Mean core area and edge area values declined for all patches from 1939 to 1993 (Figure 31). Coalesced patches, patches that exhibited no change in fragmentation, and all non-fragmented patches showed higher mean edge values in 1939 than in 1993 (Figure 31; Table 3). This result is consistent with the overall decline in patch area observed from 1939 to 1993; as the area of a region goes down, the proportion of the region in the edge area of the region increases more rapidly than the proportion in the interior. Patch core area- and edge area-affecting disturbance can occur along the patch periphery, especially if clear-cut units fringe the patch borders. These disturbances can punctuate the edge irregularly, increasing the perimeter distance around the patch and hence increasing edge values. Core values, on the other hand, did not change significantly during the study period. This combination of events can occur in cases where there is a small decrease in patch size, as was observed. These differences in mean edge areas and core areas led those patches that were first sampled in 1939 to have a much lower core area: edge area ratio in 1993 than in 1939. This trend was

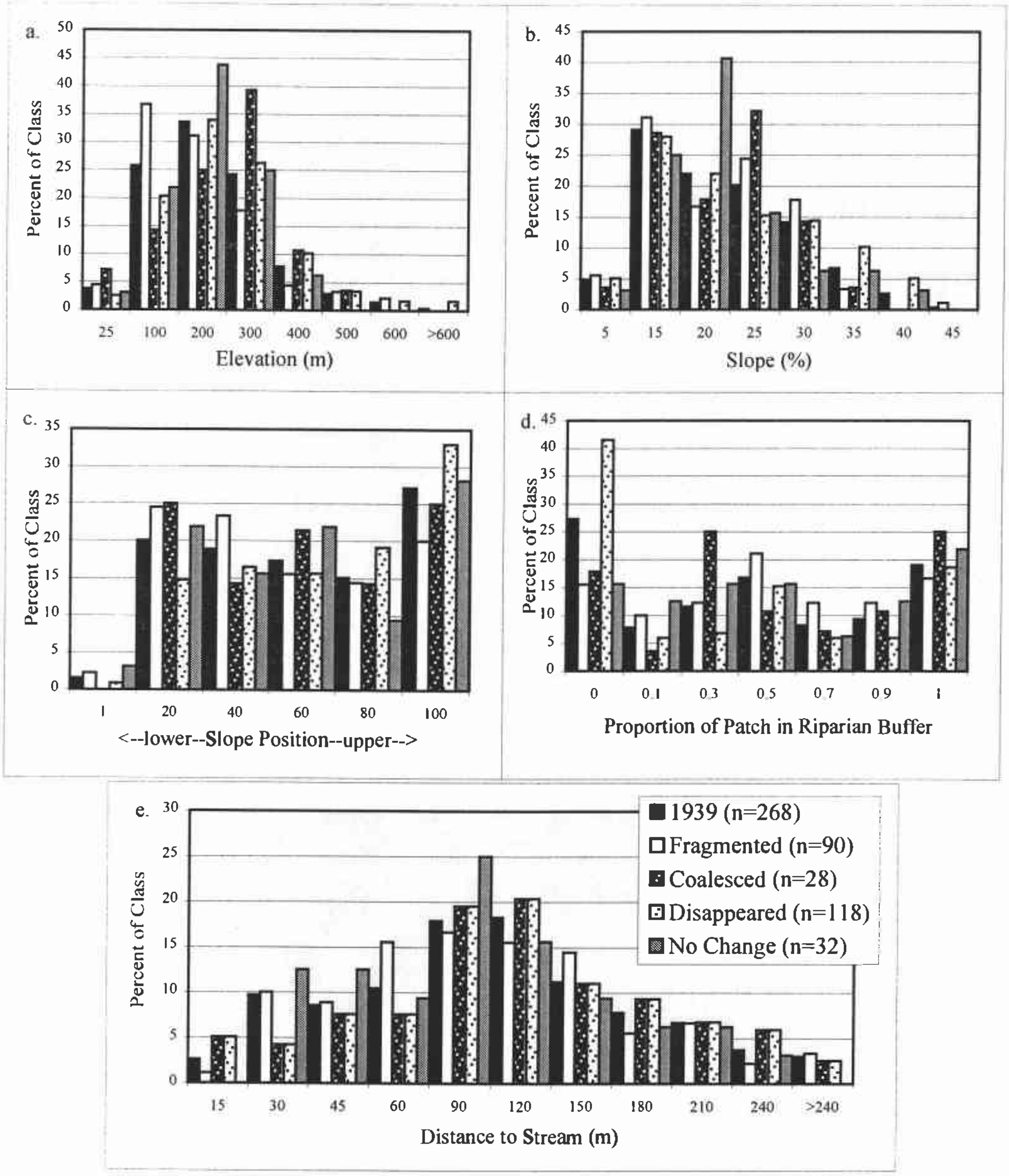

Figure 29. Percent of class distributions for all patch shape change classes along environmental gradients. For description of classes, please see figure 26. a. elevation; b. slope; c. slope position; d. proportion of patch in riparian buffer; d. distance to stream. Legend for all figures is in figure e.

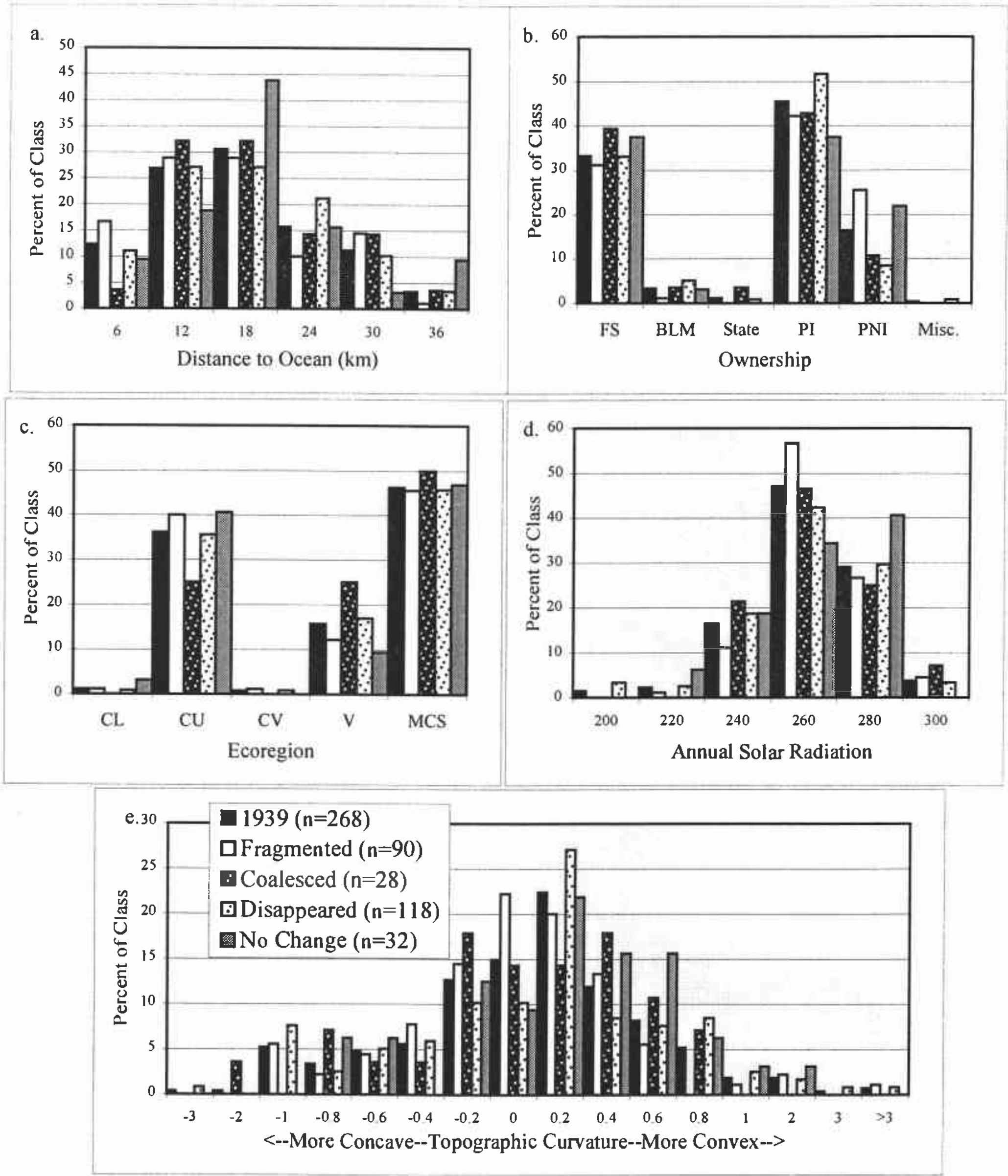

Figure 30. Percent of class distributions for all patch shape change classes according to environmental gradients, distance to ocean, ownership, and ecoregion. For description of classes, please see figure 26. a. distance to ocean; b. ownership; c. ecoregion; d. annual solar radiation; e. topographic curvature. Legend for all figures is in figure e.

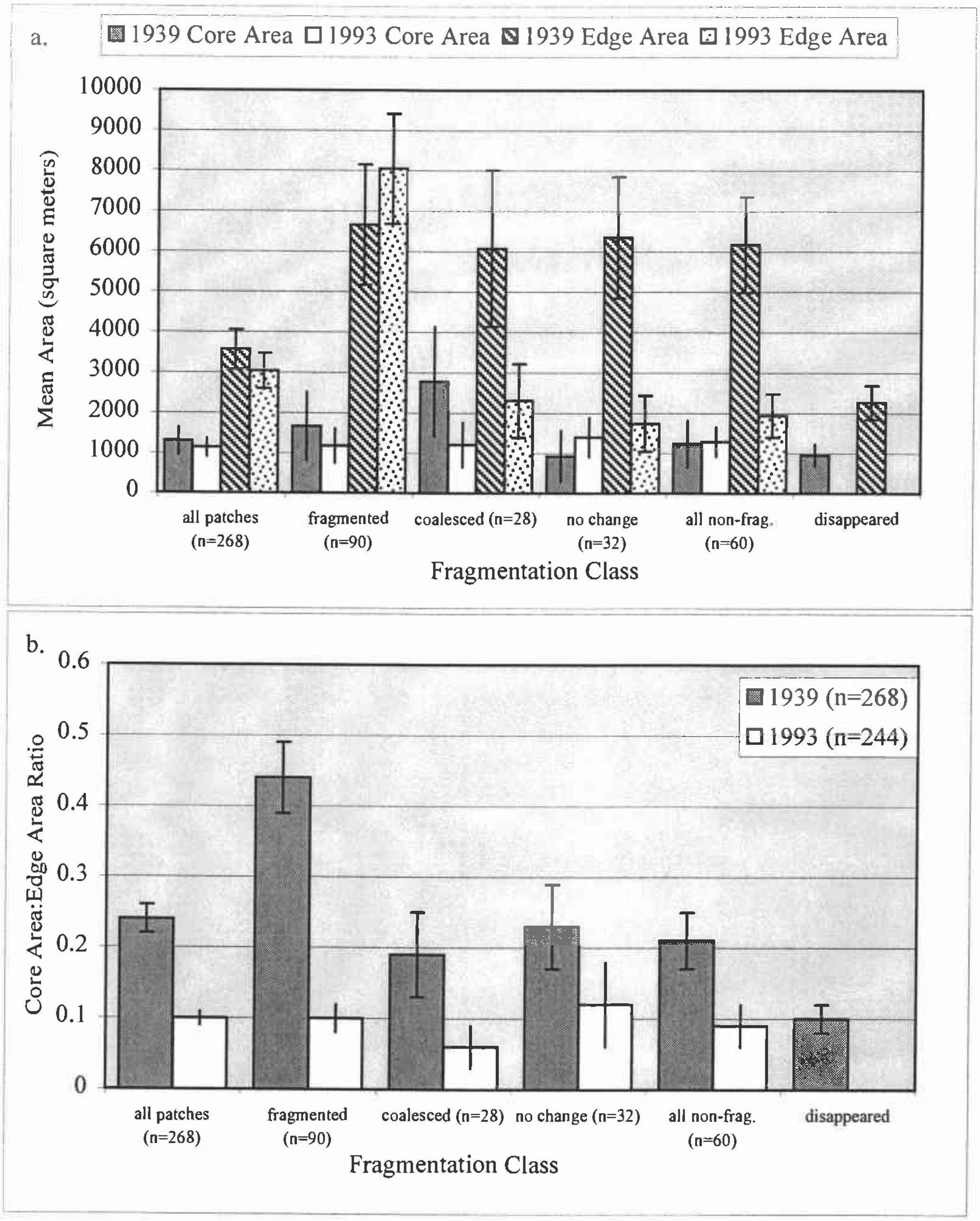

Figure 31. Patch values for core area and edge area. Patch edge was considered as the first 20 meters into the patch interior from the periphery of the patch. Patch core was any patch area inside this zone. Figures: a. Mean core area and edge area values, by fragmentation class; b. Mean core area:edge area ratios, by fragmentation class. For description of fragmentation classes, please see Figure 26.

Table 3. Mean patch core area and edge area values, and standard errors for the means. Edge was considered to be the outside row of 20 meter cells of the patch, such that the width of the patch edge was 20 meters around the circumference of the patch. Core was any area of the patch that fell inside this edge zone. For more information about core and edge designations, please see Figure 31. For a description of fragmentation classes, please see Figure 26.

1939

Fragmentation Class	core area (m^2)	s.e.	edge area (m^2)	s.e.
all patches	1298.65	350.44	3565.4	491.27
fragmented	1664.22	854.1	6659.5	1488.14
coalesced	2776.57	1370.29	6069.73	1934.1
no change	930.06	643.64	6349.89	1503.93
all non-fragmented	1241.13	587.26	6172.56	1184.07
disappeared	959.28	277.43	2269.24	420.55

1993

all patches	1139.83	225.38	3040.73	443.84
fragmented	1179.86	428.76	8049.01	1369.67
coalesced	1210.24	560.61	2306.16	916.63
no change	1398.35	489.98	1736.67	687.95
all non-fragmented	1294.59	370.19	1935.67	542.17

Table 4. Core area : edge area ratios for core area and edge area means. A higher core area : edge area ratio indicates a higher proportion of core, or interior, in the patch.

	1939		*1993*	
Fragmentation Class	corearea : edge area	s.e.	core area : edge area	s.e.
all patches	0.24	0.02	0.10	0.01
fragmented	0.44	0.05	0.10	0.02
coalesced	0.19	0.06	0.06	0.03
no change	0.23	0.06	0.12	0.06
all non-fragmented	0.21	0.04	0.09	0.03
disappeared	0.10	0.02	.	.

consistent for all patch fragmentation types, including those patches that fragmented during the study period (Figure 31; Table 4).

Patch Composition

The frequency of non-hardwood cover types within hardwood patches varied widely, with most cover types appearing within hardwood patches at both dates (Table 5). Large mixed conifers had the highest frequency in both 1939 (n=891) and 1993 (n=289), but the number of cells, and the proportion of this cover type among all cells, was much lower in 1993 (Table 5). For patches that persisted from 1939 to 1993, medium mixed conifer cells had the highest frequency of occurrence (n=68) of all cover types observed in 1993. Patches that persisted from 1939 had a high frequency of shrub occurrence in 1939. There were 20 cells having the shrub cover type in the patches that persisted from 1939 (n=145). There were only 29 shrub cells in all the hardwood patches sampled in 1993 (n=243).

Patch Composition and Distance to Streams

Several significant differences in distance to streams occurred for patches having inholdings of non-hardwood cover types. Patches with inclusions of large and very large mixed conifer cells were farther from streams in 1939 than in 1993. Patches that persisted from 1939 to 1993 that had pasture or meadow within their borders in 1939 were located farther from streams than persisting patches that had pasture or meadow within their borders in 1993. This could indicate a filling in of upland meadow sites for these persisting patches as grazing levels declined in the study area. 1993 patches that had shrubs within them were found farther from streams than 1993 patches

Table 5. Occurrence of cover types within hardwood patches for 1939 and 1993. In 1939 or 1993, the number of patches is given. Mean distance to stream is the mean patch distance to stream for all patches having the indicated cover type within their

Attributes of Patches	Cover Types within Hardwood Patch Boundaries													
All 1939 Patches	open/ bare	pasture/ meadow	shrub	hardwood	small mixed	medium mixed	large mixed	very large mixed	small conifer	medium conifer	large conifer	very large conifer	water	road
Number of Patches	2	37	2	268	0	28	109	36	0	0	2	5	1	1
Total number of 20m cells occupied by this cover type	5	416	4	22860	0	170	891	133	0	0	22	17	4	2
Mean distance to stream of patches having this cover type (m)	113	109	91	102	0	112	105	105	0	0	69	65	39	136
Standard error for mean distance to stream	1	10	71	4	0	11	5	10	0	0	7	15	0	0

Patches that were present in both 1939 and 1993	open/ bare	pasture/ meadow	shrub	hardwood	small mixed	medium mixed	large mixed	very large mixed	small conifer	medium conifer	large conifer	very large conifer	water	road
Number of patches occupied by this cover type in 1939	1	29	2	229	0	21	97	34	0	0	2	5	1	1
Number of patches occupied by this cover type in 1993	6	6	15	145	9	31	16	2	10	5	1	0	0	3
Total number of 20m cells occupied by this cover type in 1939	1	391	4	20857	0	153	832	142	0	0	22	18	4	2
Total number of 20m cells occupied by this cover type in 1993	6	7	20	3268	10	68	35	5	12	5	3	0	0	3
Mean distance to stream of patches having this cover type in 1939 (m)	114	113	91	93		115	105	103			69	63	39	136
Standard error for 1939 mean distance to stream	0.00	11.75	70.74	4.07	0.00	13.15	5.58	10.64	0.00	0.00	6.76	16.79	0.00	0.00
Mean distance to stream of patches having this cover type in 1993 (m)	135	63	89	89	89	84	120	47	129	79	102	0	0	114
Standard error for 1993 mean distance to stream	20.04	15.40	15.94	5.53	25.59	9.01	21.17	24.20	32.80	23.53	0.00	0.00	0.00	31.46

All 1993 Patches	open/ bare	pasture/ meadow	shrub	hardwood	small mixed	medium mixed	large mixed	very large mixed	small conifer	medium conifer	large conifer	very large conifer	water	road
Number of Patches	1	2	2	243	0	20	25	5	0	1	0	0	0	0
Total number of 20m cells occupied by this cover type	2	4	29	14046	0	126	289	24	0	9	0	0	0	0
Mean distance to stream of patches having this cover type (m)	172	100	151	86	0	110	82	54	0	54	0	0	0	0
Standard error for mean distance to stream	0.00	40.69	32.80	4.19	0.00	14.37	10.54	8.85	0.00	0.00	0.00	0.00	0.00	0.00

that had large or very large conifers present (Figure 32). This could be the case if conifers are persisting in riparian reserves, and the shrubs are occurring in upland areas from which conifers have been removed and the hardwoods and shrubs have established after disturbance. Patches that persisted from 1939 to 1993 with inclusions of medium mixed conifer cells were located closer to streams than patches with mixed conifer cells in 1939. Patches that persisted from 1939 to 1993 with open areas as inclusions in 1993 were located farther from streams than patches that persisted that had pasture or meadow as inclusions in 1993. On the other hand, patches that persisted from 1939 to 1993 that had pasture or meadow as inclusions in 1939 were located farther from streams than patches that persisted and had large or very large conifers as inclusions in 1939 (Figure 32).

Heterogeneity of Hardwood Patch Composition

Patch heterogeneity, measured as the proportion of all non-hardwood cells (20 x 20 m) within a patch relative to the total number of cells occupied by the patch, declined steeply from 1939 to 1993. The number of patches containing non-hardwood cells declined, from 230 to 63. In 1939, 85 percent of all patches showed some non-hardwood component in the patch. In 1993, only 20 percent of all patches contained any non-hardwood cells. This change came about largely because of loss of large conifers. Because large and very large conifers (in conifer and mixed cells) had provided most of the patch heterogeneity in 1939, it is not surprising that heterogeneity has decreased as large conifers are removed from the Coast Range landscape. Fifty-seven percent of all patches had some large conifers (conifer or mixed) in 1939, compared to only 13 percent in 1993 (Table 6). The average percent of patch area in

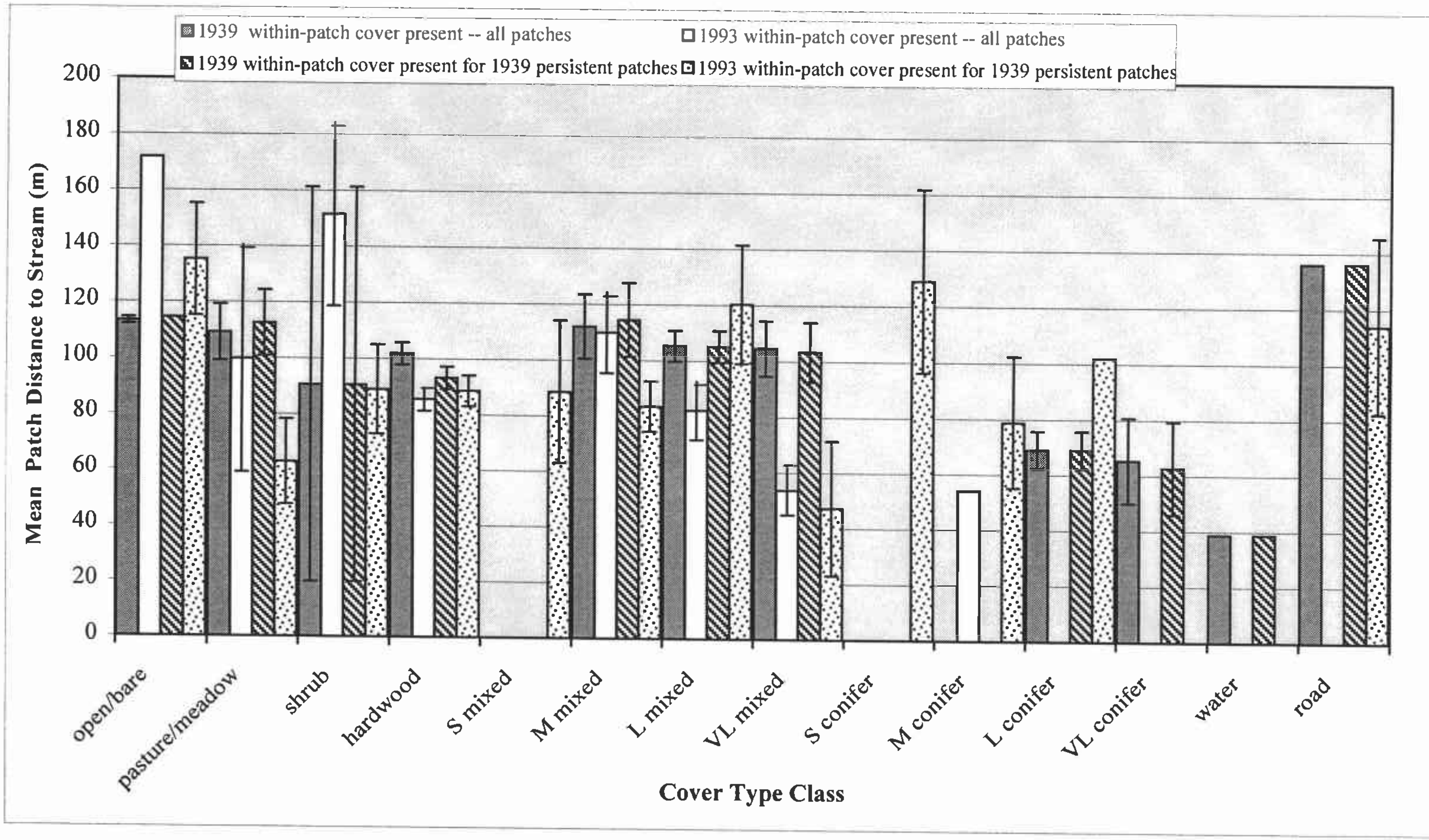

Figure 32. Mean distance to stream for patches and cover types present within these patches. For more information on means and counts of cover type cells and number of patches having each cover type within, please see Table 5. Lack of standard error bars indicates that only one patch contained this cover type.

Table 6. Heterogeneity of hardwood patches in 1939 and 1993. Number of patches is number of patches considered in the analysis. Number with non-hardwoods is the number of patches having non-hardwood cells within the patch boundary. Number with large conifers is the number of patches with either large mixed, very large mixed, large conifer, or very large conifer within the patch boundary. Percent of patches considered is the percent of the total number of patches that exhibited some within-patch heterogeneity. Mean percent of area is the mean amount of within-patch area, for heterogeneous patches, occupied by non-hardwood cover types.

	Number of Patches	Number with Non-Hardwoods	Percent of Patches Considered	Mean Percent of Area	s.e.
1939	268	230	85.82	5.93	0.79
1993	242	63	20.60	7.05	1.74

	Number of Patches	Number with Large Conifers	Percent of Patches Considered	Mean Percent of Area	s.e.
1939	268	152	56.72	6.83	1.00
1993	242	31	12.81	4.88	1.06

large conifer also declined for patches with a large conifer component, from 7 in 1939 to 5 in 1993.

Shape and Patch Heterogeneity

For the 1939 dataset, there was a very significant but weak relationship between the level of heterogeneity in the patch and patch shape (F Statistic = 9.13; p = 0.0028; R-Square = 0.033). Heterogeneity explained only 3 percent of the variation in patch shape. For 1939, fractal dimension conformed to the following equation: *fractal dimension = 1.13 (s.e. 0.004) + 0.096 (s.e. 0.03) (percent not hardwood).* For the 1993 dataset, there was no significant relationship between patch shape and heterogeneity.

Patches Within Riparian Areas

Approximately 34 percent of the study area fell within 60 meters of the streams (Figure 11, d). Of this, 24 percent was associated with first and second order streams, and 10 percent was associated with third and higher order streams. Hardwoods occurred only between 20 and 30 percent of the time completely in upslope areas (Figure 18, d). In 1939, more hardwood patches, and more hardwood area, occurred fully outside the riparian area than fully within; the converse was true in 1993 for both patches and area. A far higher proportion of the number of patches occurred entirely within the riparian area in 1993 than in 1939 (Figure 18, d). In both 1939 and 1993, patches occurrring partially within the riparian zone had fairly even distributions of the proportion of the patch within the riparian zone (Figure 18, d).

Riparian and Upslope Areas

For the riparian and upslope patch analysis, a patch was considered to be a riparian patch if any part of the patch fell within the riparian zone. The riparian zone was 60 m for all stream orders.

Patch Size

There was a significant difference between the size distributions of riparian patches in 1939, riparian patches in 1993, upslope patches in 1939, and upslope patches in 1993 ($p=0.001$). The dominant patch size in the riparian area was very small (less than 5000 m2) in both 1939 and 1993 (Figures 33 and 34). The proportion of very small patches in riparian zones increased from 1939 to 1993, while the proportion of large and very large classes decreased during this period.

Patch Shape

Riparian shape distributions were significantly different from upslope shape distributions from 1939 to 1993 ($p=0.001$ for both shape measures), with more complex-shaped patches occurring in 1993 riparian zones. In 1939, upslope patches tended to have more square shapes (Figure 33, c) than upslope patches in 1993. Riparian patches in 1939 had a higher frequency than did their 1993 counterparts at the moderate fractal dimensions (Figure 33, d). "Shape" captured the variation in irregular patches more effectively than did fractal dimension. 1993 riparian patches showed much higher frequencies of complex-shaped patches than did their 1939 counterparts (Figure 33, c), using this measure for patch shape. In a chi-square test, patch

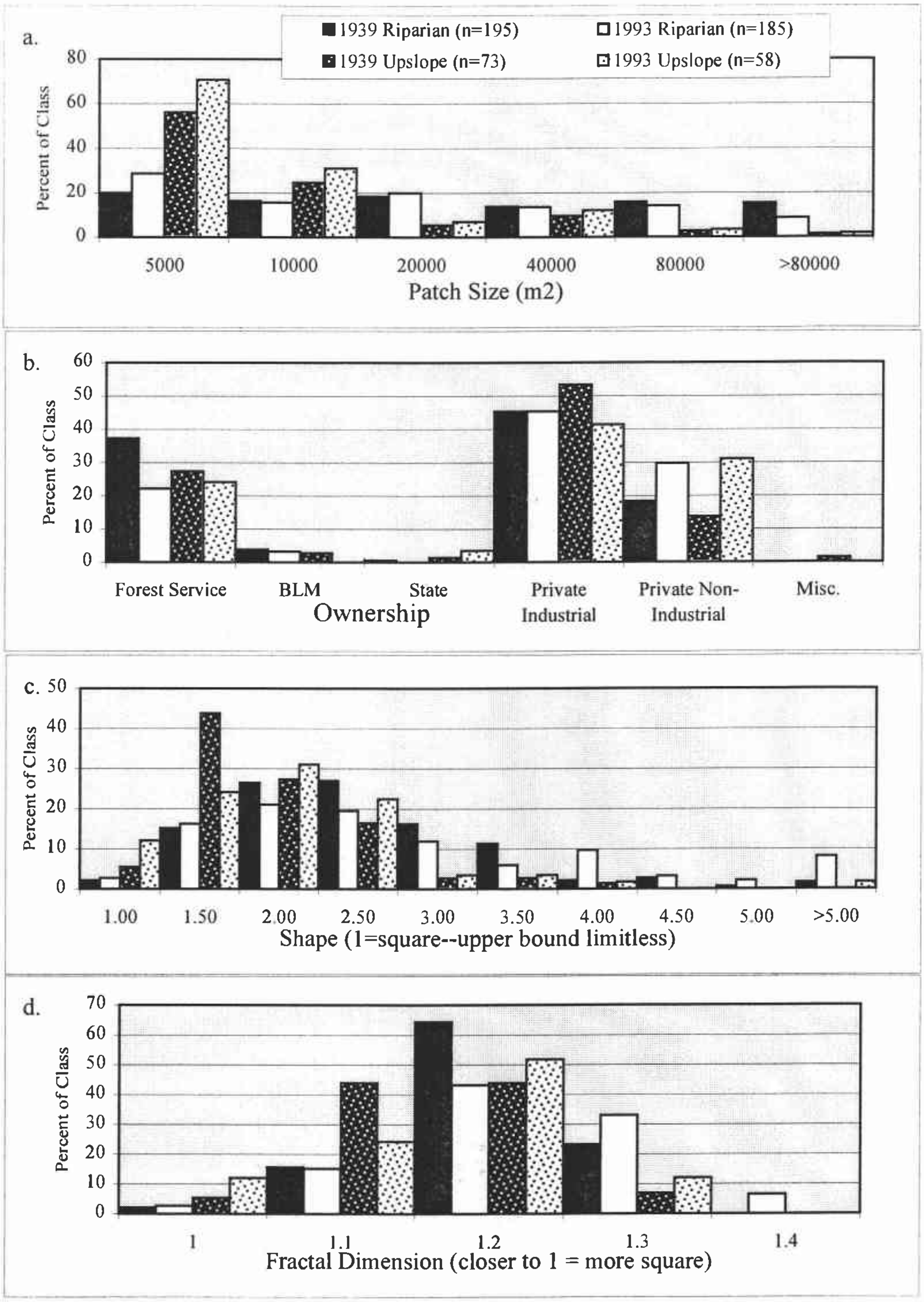

Figure 33. Percent of patches in riparian and upslope areas by patch size, ownership, and shape measures, by percent of class. Figures: a. patch size; b. ownership; c. shape; d. fractal dimension. Legend for all graphs is at top of page.

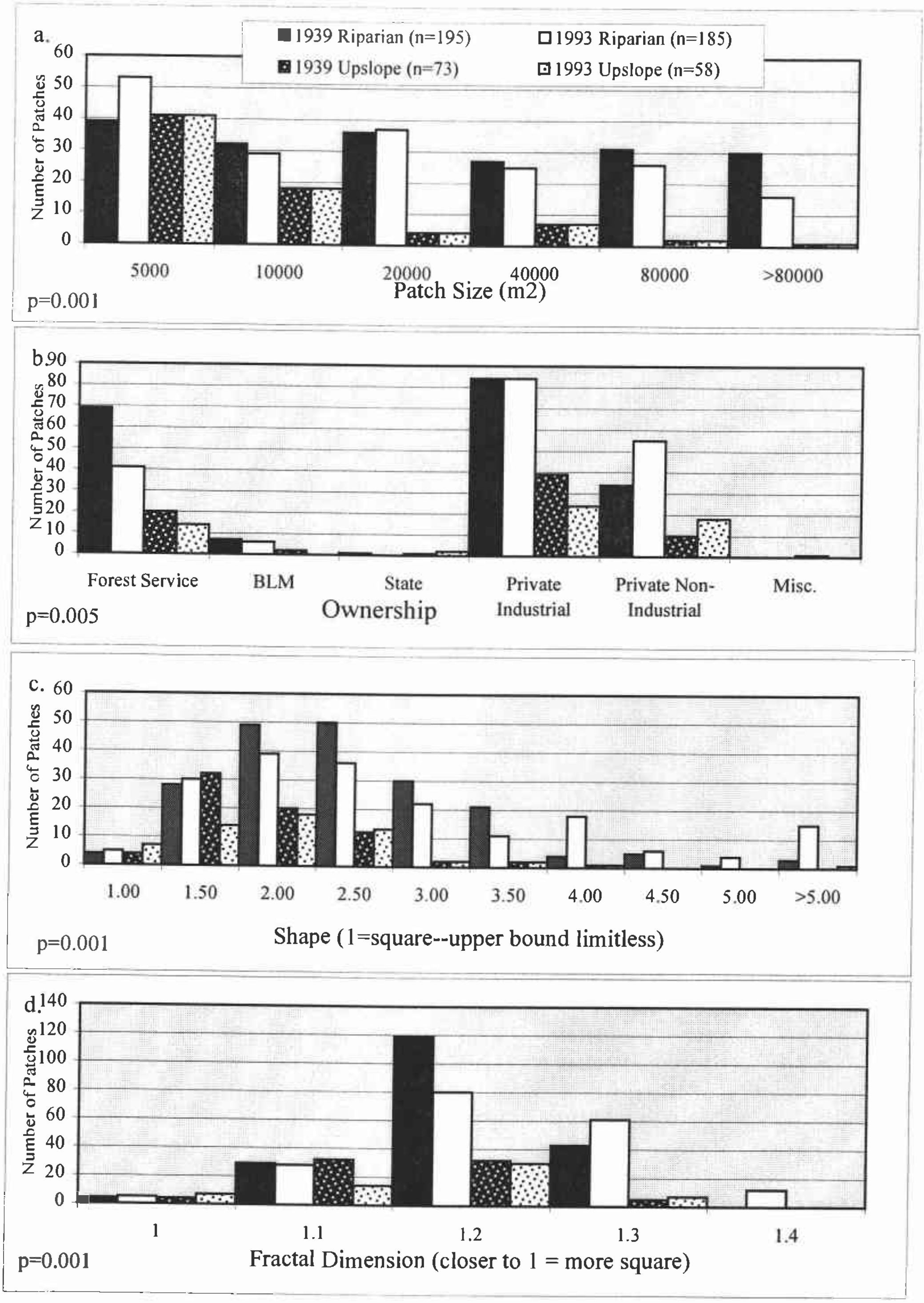

Figure 34. Frequency distributions of riparian and upslope patches by patch size, ownership, and shape measures. Figures: a. patch size; b. ownership; c. shape; d. fractal dimension. P-values are from a chi-square test. Legend for all graphs is at top of page.

heterogeneity was not significantly different for either riparian vs upslope patches in 1939 ($p=0.51$), or for riparian vs upslope patches in 1993 ($p=0.34$).

Patch Ownership

Riparian patch ownership reflected ownership patterns in the study area, with a few interesting differences. Riparian and upslope distributions across ownerships at the two dates were significantly different ($p=0.005$). A higher proportion of both riparian and upslope patches occurred on private non-industrial lands in 1993 than in 1939 (Figure 33, b). The Forest Service owned a much lower proportion of riparian patches in 1993 than in 1939, concommitant with the dramatic decrease in their ownership of hardwood area overall. Private industrial landowners owned the highest numbers of patches, riparian and upslope alike, of any landowner group (Figure 34, b). The private industrial landowners had the highest proportion of upslope patches in 1939, but in 1993 their proportional ownership of upslope patches dropped. While they remained the largest landowner of upslope patches, they owned a higher proportion of riparian patches in 1993 than they owned upslope patches.

Stream Order Differences Among Riparian Patches

Patch Size

Patch size did not change dramatically for third and higher order streams between 1939 and 1993. First and second order streams showed a general decrease in patch size from 1939 to 1993, having a mean patch size of 49,126 m^2 in 1939 and 23744 m^2 in 1993 (Table 7). Patch size distributions did not differ significantly between first and second, and third and higher order streams during the study period

Table 7. Summary table of mean values, for groups of patches examined in hardwood patch study, for area and environmental variables. Area is patch area. Environmental Variables: distance to coast (coast); elevation; slope; slope position (slpos); annual solar radiation (rad); distance to nearest stream (stream); percent in 60 m riparian buffer (rip); and topographic curvature (curv). 1993 area is given for patches sampled in 1939 that were considered in size change and shape change analyses.

Group of Patches		**Area** (m^2)	**coast** (km)	**elevation** (m)	**slope** (%)	**slpos** (1-100)	**rad**	**stream** (m)	**rip** (%)	**curv** (-/+)	**1993 Area** (m^2)
All 1939 Patches		36716.42	15.01	176.83	18.79	52.53	252.62	101.79	0.41	-0.01	n/a
(n=268)	s.e.	4677.98	0.46	7.16	0.53	1.96	1.07	3.92	0.02	0.04	n/a
All 1993 Patches	**mean**	23963.93	14.44	151.43	18.16	42.98	251.92	85.35	0.51	-0.19	n/a
(n=244)	s.e.	2520.24	0.49	7.54	0.51	2.10	1.05	4.18	0.03	0.07	n/a
1939 Patches that	**mean**	14983.05	15.35	200.95	19.17	59.07	250.86	109.12	0.35	-0.03	0.00
Disappeared (n=118)	s.e.	2411.04	0.73	11.72	0.90	2.96	1.90	6.35	0.04	0.08	0.00
1939 Patches that	**mean**	69702.75	14.22	166.22	18.23	52.02	254.97	102.81	0.41	0.02	18300.92
Decreased in Size (n=105)	s.e.	10452.84	0.69	10.56	0.73	2.97	1.43	5.54	0.03	0.04	3503.55
1939 Patches that	**mean**	16285.71	15.63	138.61	18.81	39.10	251.88	82.31	0.55	-0.09	47895.24
Increased in Size (n=42)	s.e.	3281.29	1.23	15.19	1.38	5.07	2.30	10.47	0.06	0.14	7251.53
1939 Patches that had	**mean**	7066.67	21.67	180.90	24.82	40.75	244.07	59.21	0.63	0.22	7066.67
No Change in Size (n=3)	s.e.	2924.23	2.41	89.85	1.75	16.27	12.63	21.15	0.22	0.28	2924.23
1939 Patches that	**mean**	69728.89	13.98	147.26	18.43	45.42	254.18	96.77	0.45	-0.04	35480.00
Fragmented (n=90)	s.e.	12160.20	0.78	12.07	0.88	3.26	1.50	6.36	0.04	0.07	5197.62
1939 Patches that had	**mean**	27062.50	16.04	164.81	18.07	50.43	252.78	90.68	0.11	0.12	13125.00
No Change in Shape (n=32)	s.e.	9465.82	1.32	15.74	1.37	5.73	3.09	9.88	0.04	0.09	3207.72
1939 Patches that	**mean**	33228.57	16.22	198.23	19.05	50.02	252.88	96.22	0.49	-0.08	14785.71
Coalesced (n=28)	s.e.	8542.70	1.40	19.79	1.34	6.26	2.98	13.64	0.07	0.11	4681.59

Table 7, cont'd. Summary table of mean values, for groups of patches examined in stream portion of hardwood patch study, for area, patch shape, and environmental variables. Area is patch area. Environmental variables: distance to coast (coast); elevation; slope; slope position (slpos); annual solar radiation (rad); distance to nearest stream (stream); percent in 60 m riparian buffer (rip); and topographic curvature (curv). Shape variables: patch shape (shape); and fractal dimension (frac).

Group of Patches		Area (m^2)	coast (km)	elevation (m)	slope (%)	slpos (1-100)	rad	stream (m)	rip (%)	curv (-/+)	shape	frac
All 1939 Riparian Patches	mean	46008.21	14807.09	159.40	18.40	44.11	252.15	76.17	0.56	-0.11	2.30	1.15
(n=195)	s.e.	6214.55	533.96	7.56	0.59	2.14	1.08	3.21	0.02	0.04	0.06	0.00
All 1993 Riparian Patches	mean	29008.60	14212.65	139.03	18.25	33.22	250.33	58.88	0.67	-0.24	2.63	1.17
(n=186)	s.e.	3189.59	547.24	7.85	0.58	2.01	1.14	2.95	0.02	0.08	0.10	0.01
All 1939 Upslope Patches	mean	9638.36	15534.93	223.39	19.83	75.21	253.86	170.22	0.00	0.23	1.65	1.10
(n=73)	s.e.	1904.53	914.63	15.66	1.14	3.10	2.68	6.77	0.00	0.10	0.07	0.01
All 1993 Upslope Patches	mean	7786.21	15174.37	191.18	17.86	74.28	257.01	170.24	0.00	-0.03	1.83	1.12
(n=58)	s.e.	1414.85	1048.30	18.52	1.08	3.84	2.39	7.52	0.00	0.13	0.10	0.01
All 1939 1-2 Stream Order	mean	49126.15	14756.54	180.69	18.84	53.02	253.44	83.09	0.51	-0.09	2.22	1.15
Riparian Patches (n=130)	s.e.	8407.26	671.01	9.10	0.65	2.43	1.31	3.88	0.03	0.05	0.07	0.01
All 1993 1-2 Stream Order	mean	23743.59	13437.44	164.15	19.14	43.61	252.35	66.22	0.60	-0.12	2.54	1.17
Riparian Patches (n=117)	s.e.	3252.09	682.14	10.61	0.71	2.48	1.52	3.77	0.03	0.12	0.12	0.01
All 1939 3+ Stream Order	mean	39772.31	14908.18	116.82	17.53	26.42	249.56	62.34	0.66	-0.14	2.45	1.17
Riparian Patches (n=65)	s.e.	8084.41	881.71	11.97	1.20	3.20	1.90	5.34	0.04	0.09	0.11	0.01
All 1993 3+ Stream Order	mean	37936.23	15527.15	96.43	16.74	15.61	246.91	46.43	0.78	-0.44	2.79	1.18
Riparian Patches (n=69)	s.e.	6492.62	899.94	9.13	0.99	2.12	1.57	4.36	0.03	0.08	0.17	0.01
All 1939 3+ Stream Order	mean	67926.67	15011.06	102.07	14.84	25.01	249.63	59.61	0.70	-0.23	2.60	1.17
Flat Riparian Patches (n=60)	s.e.	16484.03	972.47	10.28	1.10	3.25	1.60	5.34	0.04	0.06	0.12	0.01
All 1993 3+ Stream Order	mean	47868.57	14560.08	92.71	14.98	16.59	246.48	45.24	0.79	-0.46	3.22	1.21
Flat Riparian Patches (n=70)	s.e.	6800.10	866.14	8.04	0.83	2.21	1.20	4.11	0.03	0.06	0.17	0.01
All 1939 3+ Stream Order	mean	42448.00	13247.67	170.40	23.96	42.16	252.48	86.93	0.48	0.15	2.25	1.16
Sloping Riparian Patches (n=25)	s.e.	13040.82	1250.46	22.24	1.62	5.21	3.69	8.30	0.06	0.19	0.14	0.01
All 1939 3+ Stream Order	mean	23254.55	14236.97	160.63	23.96	33.73	250.45	74.66	0.51	-0.07	2.32	1.14
Sloping Riparian Patches (n=22)	s.e.	7822.15	1508.28	26.65	1.55	4.87	4.76	8.29	0.08	0.14	0.31	0.02

(p=0.53; Figure 36, a). Very small first and second order riparian patches increased by almost 10 percent during the study period (Figure 35, a). Third and higher order streams increased in the frequency of patches of sizes 20,000 to 40,000 m^2 from 1939 to 1993, while these medium large patches declined along the lower-order streams. A higher proportion of the patches greater than 80,000 m2 in size were located in the riparian buffers of third and higher order streams in 1939 than in 1993 (Figure 35, a).

Patch Shape

Patch shape and fractal dimension frequency distributions differed between stream groups and dates (p = 0.01; p=0.002; Figure 36). Patches along the larger streams had more complex shapes, on average, than those occurring along first and second order streams (Table 7) in both 1939 and 1993. Third and higher order streams had more complex shapes, on average, in 1993 than in 1939 (Table 7).

Patch Ownership

The distribution of riparian patches across ownerships and stream orders differed significantly through the study period (p=0.01; Figure 36, b). Private non-industrial owners owned a much higher percentage of riparian patches in 1993 than in 1939 for both stream order classes (Figure 36, a). Conversely, the Forest Service owned a much lower proportion of riparian patches in 1993 than in 1939. Patterns of private industrial stream order-based patch ownership were relatively similar through the study period, with very little difference either between the study dates or the stream order group.

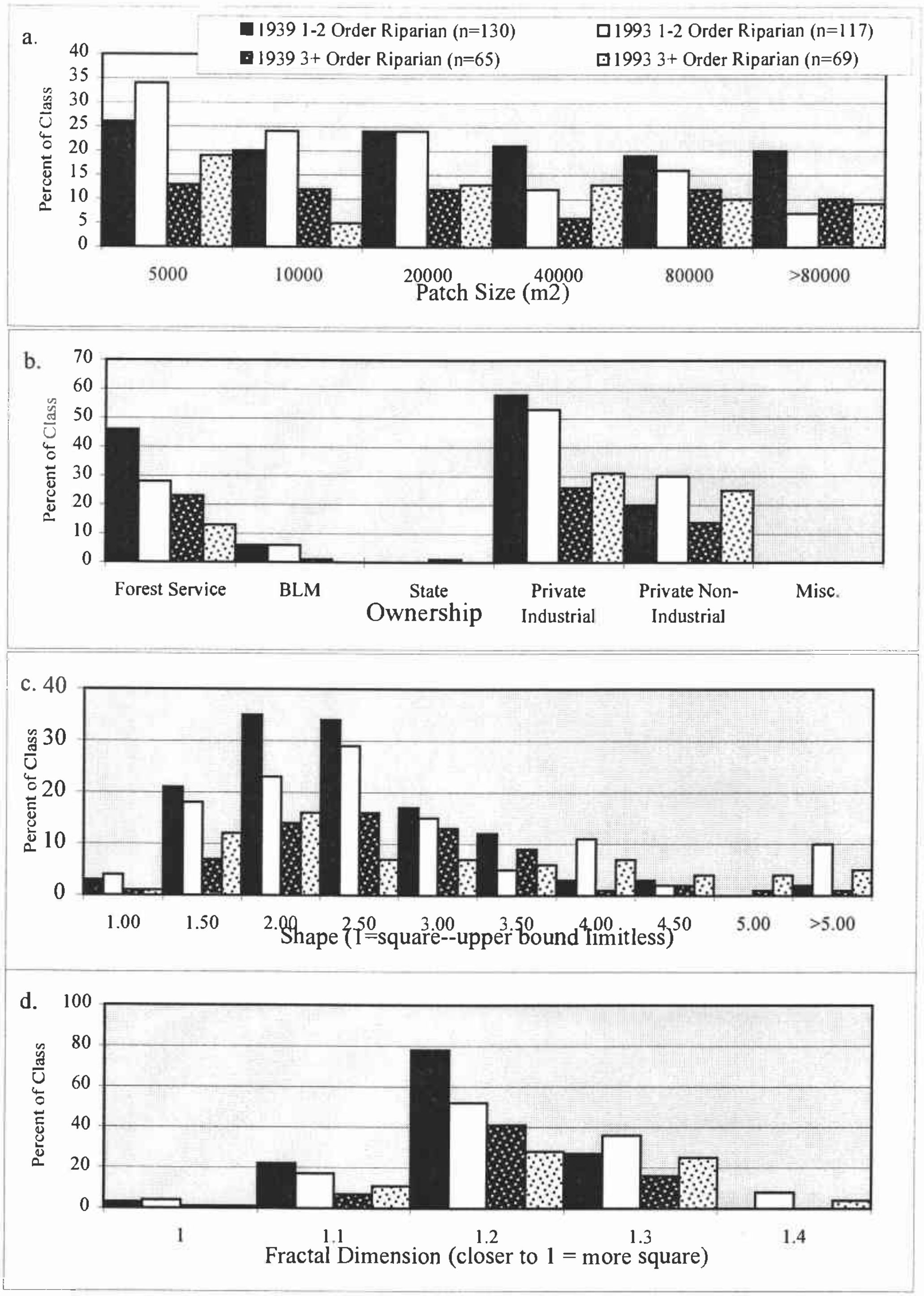

Figure 35. Percent of patches along first and second, and third and higher streams, by patch size, ownership, and shape measures, by percent of class. Figures: a. patch size; b. ownership; c. shape; d. fractal dimension. Legend for all graphs is at top of page.

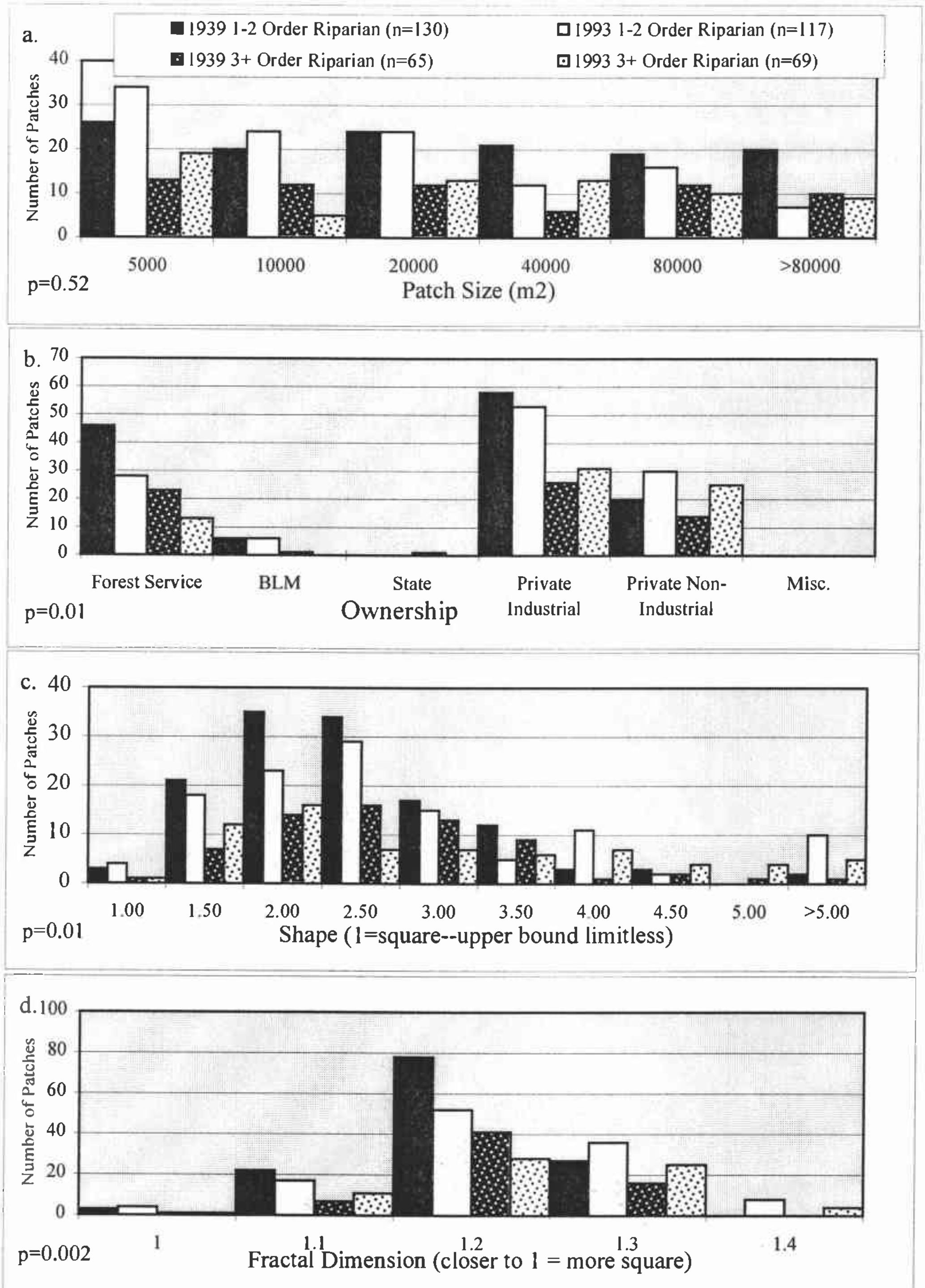

Figure 36. Frequency distributions of patches along first and second, and third and higher order streams, by patch size, ownership, and shape measures. Figures: a. patch size; b. ownership; c. shape; d. fractal dimension. P-values are from a chi-square test. Legend for all graphs is at top of page.

Patches Along Valley Bottoms

Patch Shape

Fractal dimension and shape distributions of hardwood patches differed between slope classes within the riparian areas of higher order streams (p=0.009 and p=0.003, respectively; Figure 37, b and c). Patches in flat areas had more irregular shapes, on average, than patches that occurred in sloping areas (Table 7; Figure 38).

Patch Ownership

The distribution of ownerships among riparian patches occurring on flat and sloping terrain along the higher order streams did not differ significantly through the study period (p=0.08; Figure 37, a). The Forest Service, in both 1939 and 1993, owned a higher percentage of riparian patches on sloping terrain than on flat terrain (Figure 38, a). Private industrial owners owned the majority of patches occurring on both flat and sloping terrain in both 1939 and 1993. Private non-industrial landowners possessed a higher proportion of riparian patches occurring on flat terrain than on sloping terrain at both study dates. The proportion of private non-industrial ownership of riparian patches along these higher-order streams increased through the study period.

Comparison of Managed and Unmanaged Landscapes

The Drift Creek Wilderness, which lies in the southern portion of the study area, has one of the largest unmanaged areas of mature forest remaining in the Oregon Coast Range, and the disturbance history of the Wilderness Area differs from the rest of the study area. Twenty-two hardwood patches were sampled within the Wilderness Area boundary in 1939, and 15 patches were sampled there in 1993. The Drift Creek

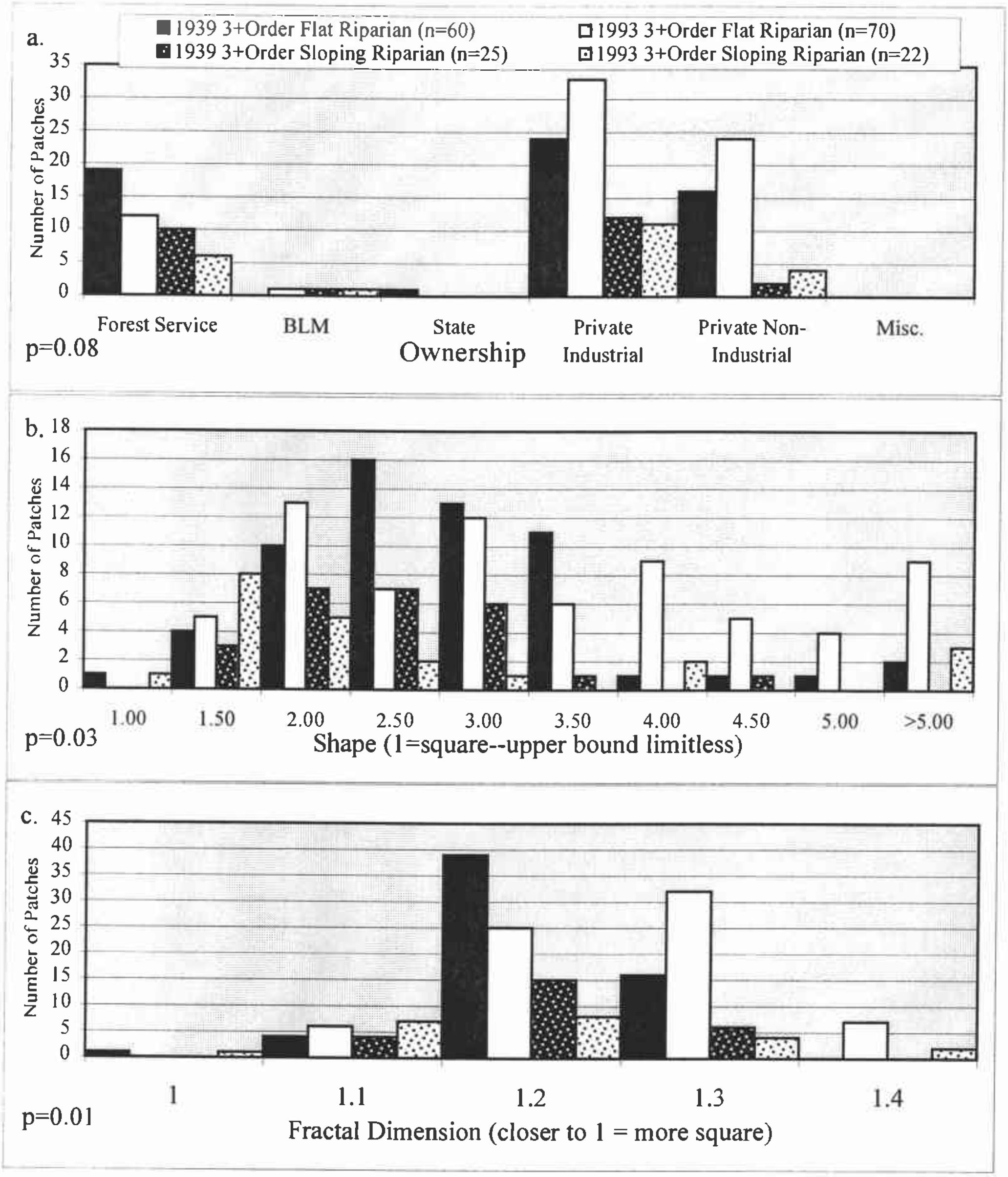

Figure 37. Frequency distributions of patches occurring along third and higher order streams in flat and sloping areas, by patch ownership and shape measures. Figures: a. ownership; b. shape; c. fractal dimension. P-values are from a chi-square test. Legend for all graphs is at top of page.

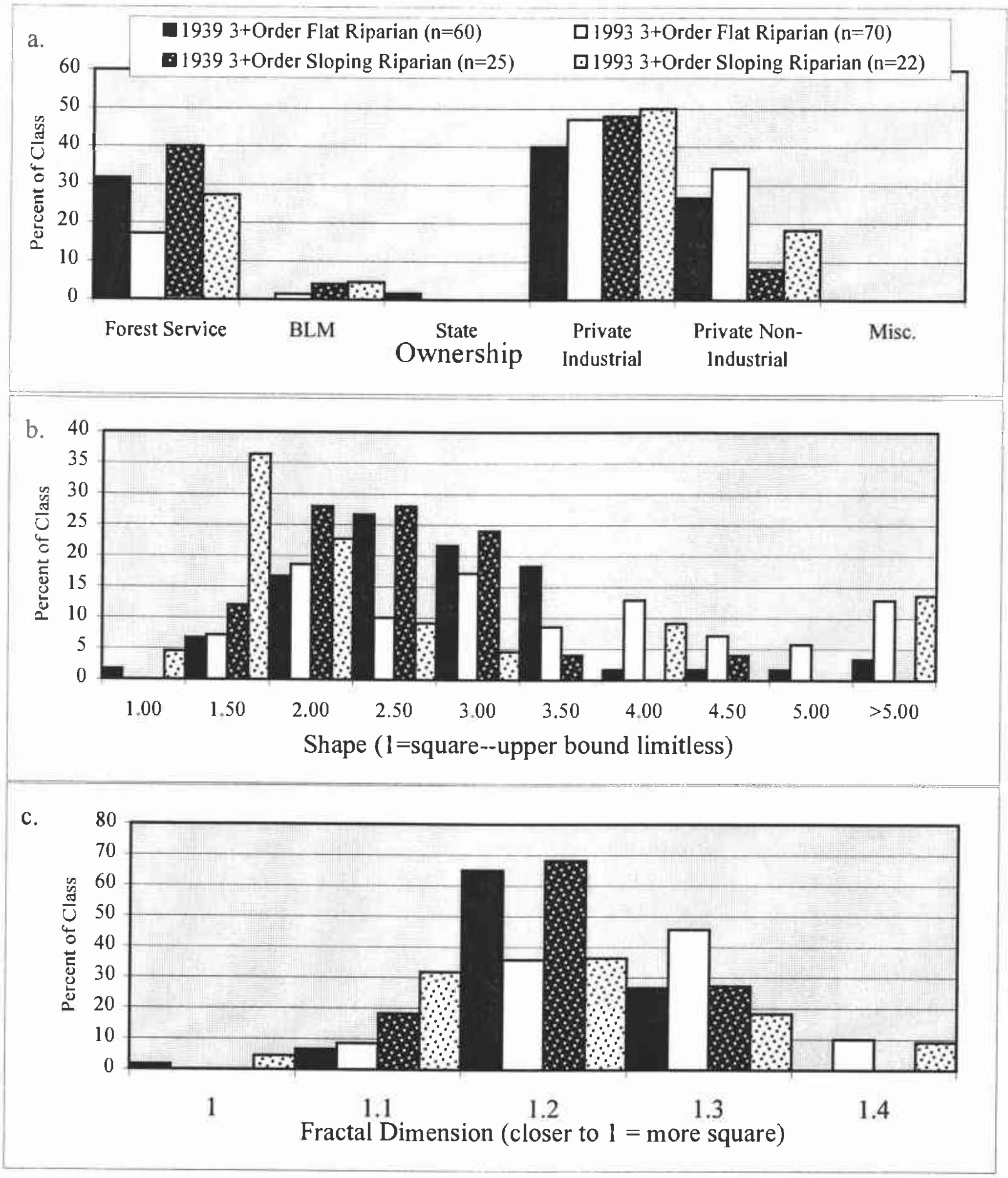

Figure 38. Percent of patches occurring along third and higher order streams in flat and sloping areas by ownership and shape measures, by percent of class. Figures: a. ownership; b. shape; c. fractal dimension. Legend for all graphs is at top of page.

Wilderness patch size, shape, and fractal dimension distributions were not significantly different from the distributions of those patches outside the Wilderness boundary in either 1939 or 1993 (for all p-values and all chi-square values for the hardwood patch study, please see Table 8). Likewise, the distribution of hardwood patches occurring in Drift Creek did not differ significantly according to size, shape, or fractal dimension between 1939 and 1993. However, while patches occurring outside the Drift Creek Wilderness did not show a significant difference in area distributions between dates, they did show a significant difference in shape and fractal dimension distributions ($p=0.01$ and $p=0.001$, respectively). The shape distributions for the population of hardwood patches within the Wilderness boundary were more similar from 1939 to 1993 than the shape distributions for the population of patches that occurred outside the Wilderness Area.

Table 8. Summary table of Chi-squares and p-values for all frequency distributions provided in results section. A p-value of <= 0.05 was considered as evidence of a significant difference between groups compared in the frequency distributions. Compared groups are listed in on the left in the order of their occurrence within the results section. Category indicates the gradient or variable across which the groups were compared (i.e., elevation).

Groups Compared in Frequency Distribution	Category of Comparison	Chi-Square	p-value
1939 patches vs 1993 patches	elevation	8.71	0.12
	slope	7.36	0.29
	slope position	11.06	0.03
	proportion in riparian buffer	11.77	0.04
	distance to stream	18.94	0.04
	distance to ocean	4.02	0.55
	ownership	15.78	0.001
	ecoregion	0.29	0.87
	annual solar radiation	1.89	0.76
	topographic curvature	16.67	0.08
1939 patches vs 1993 patches	patch size class	4.95	0.42
	ln area (m2) of patch	7.21	0.51
1939 patches vs 1939 patches that increased in size vs 1939 patches that decreased in size vs 1939 patches that disappeared vs 1939 patches that had no change in size	elevation	13.78	0.32
	slope	16.85	0.05
	slope position	18.62	0.1
	proportion in riparian buffer	40.67	0.09
	distance to stream	22.72	0.001
	distance to ocean	9.12	0.69
	ownership	10.40	0.11
	ecoregion	1.37	0.97
	annual solar radiation	6.04	0.48
	topographic curvature	23.66	0.17
1939 patches vs 1993 patches	shape	27.71	0.001
	fractal dimension	24.62	0.001
1939 patches vs 1939 patches that fragmented vs 1939 patches that coalesced vs 1939 patches that disappeared vs 1939 patches that had no change in frag.	elevation	15.76	0.47
	slope	19.51	0.08
	slope position	9.08	0.91
	proportion in riparian buffer	32.16	0.001
	distance to stream	17.89	0.59
	distance to ocean	11.48	0.78
	ownership	11.40	0.18
	ecoregion	4.83	0.77
	annual solar radiation	8.89	0.35
	topographic curvature	18.45	0.78

Table 8, cont'd. Summary table of Chi-squares and p-values for all frequency distributions provided in results section. A p-value of <= 0.05 was considered as evidence of a significant difference between groups compared in the frequency distributions. Compared groups are listed on the left in the order of their occurrence within the results section. Category indicates the gradient or variable across which the groups were compared (i.e., elevation).

Groups Compared in Frequency Distribution	Category of Comparison	Chi-Square	p-value
1939 riparian patches vs	patch size	82.06	0.001
1993 riparian patches vs	ownership	18.46	0.005
1939 upslope patches vs	shape	100.50	0.001
1993 upslope patches	fractal dimension	86.04	0.001
1939 riparian patches vs 1939 upslope patches	heterogeneity	2.29	0.51
1993 riparian patches vs 1993 upslope patches	heterogeneity	2.16	0.34
1939 1-2 order stream riparian vs	patch size	9.07	0.53
1993 1-2 order stream riparian vs	ownership	12.87	0.01
1939 3+ order stream riparian vs	shape	30.98	0.01
1993 3+ order stream riparian	fractal dimension	24.21	0.002
1939 3+ order stream riparian flat vs	ownership	8.42	0.08
1993 3+ order stream riparian flat vs	shape	35.75	0.03
1939 3+ order stream riparian sloping vs	fractal dimension	20.25	0.01
1993 3+ order stream riparian sloping			
Drift Creek patches 1939 vs	patch size	1.87	0.87
Drift Creek patches 1993	shape	9.31	0.41
	fractal dimension	5.95	0.20
Non-Drift Creek patches 1939 vs	patch size	4.61	0.46
Non-Drift Creek patches 1993	shape	26.26	0.01
	fractal dimension	22.01	0.001
Drift Creek patches 1939 vs	patch size	2.79	0.73
Non-Drift Creek patches 1939	shape	6.92	0.65
	fractal dimension	1.91	0.59
Drift Creek patches 1993 vs	patch size	6.45	0.27
Non-Drift Creek patches 1993	shape	11.83	0.46
	fractal dimension	1.96	0.74

DISCUSSION

Implications for Landscape Ecology of Hardwood Patches

I found a change in the areal extent and the geographic distribution of patch occurrence of hardwoods during the years of my study. While it is a commonly held notion that expansion of hardwoods has occurred as fire and logging set back the successional stage of stands from conifer to hardwoods since the time of European settlement (Hibbs and Giordano 1996), I did not observe this. This could be because of the fires had occurred prior to the years covered by my study, so the purported expansion of hardwoods could have occurred prior to 1939; and it could be because successional stages of stands have been set back not from large conifer to hardwood, but from large conifer to small conifer, as the result of management activities. I had expected to see an overall gradual decline in hardwood area on the landscape as a result of the conversion of stands to young conifer plantations, and I did witness a decline in both overall hardwood area and the number of patches present. In terms of ownership effects, I had expected that private industrially owned lands would show a decrease as hardwoods were converted to young conifers, and that private non-industrially owned lands would show an increase, but that this increase would be offset by private industrial stand conversions. I was surprised to see that Forest Service-owned lands, instead of exhibiting a moderate decline in hardwood area, showed by far the greatest decrease in hardwood area of any landowner group; this could be the case if they have a relatively limited presence in the riparian areas, or if they more thoroughly planted their lands with conifers following harvest. This sharp decline in hardwood area on Forest Service lands likely contributed to the greater than expected decrease in hardwood areal extent and patch occurrence, and offset any additions made by the private landowner groups.

Hardwood patches and hardwood area were not always distributed along environmental gradients in the manner I expected. I expected to find patches occurring with higher frequencies and larger areas in hardwoods in the higher moisture areas, such as low topographic position, north aspects, and adjacent to streams (Haeussler et al. 1995). While I did see hardwood patches, and hardwood area, occurring on sites that received moderate annual solar radiation levels, neither hardwood patches nor area were present at higher frequencies at the lower radiation levels that would be associated with north-facing, shaded slopes. However, hardwood area and patches were located close to streams, especially in 1993, and at moderate distances to the ocean, where precipitation levels are high. Ripple et al. (in press) also found more prelogging hardwood near streams. The location of hardwood patches in 1993 at the lower slope positions could be a result of a combination of factors, including loss from upper slopes or increases on lower slopes. The previous patches located along ridgetops could have been an result of historic fire patterns, both natural and anthropogenic (Crane 1951; Parry 1985; Hays 1976), and these may not be optimal sites for hardwood species (Harrington 1990), although as highly competitive early successional species they could occupy these sites rapidly following disturbance. Also, these patches could have been removed as these higher elevations were converted from a patchy mosaic of various stand types to predominantly young conifer plantations.

In terms of patch size and shape changes, I observed the overall decrease in patch size throughout the landscape that I had expected. I also observed a higher frequency of patch fragmentation and disappearance than coalescence on private industrial lands, and a higher frequency of coalescence than fragmentation or disappearance on private non-industrial lands, all of which were changes I had anticipated. The size limits to clear-cuts mandated by the Oregon Forest Practices Act, and the resulting decrease in harvest unit size, also could have contributed to the observed fragmentation of patches. Adjacency rules in the Act, which prohibit the clear-cutting of an area adjacent to a clear-cut until the conifers in the first clear-cut have risen above the competing vegetation and are free to grow (circa 2-4 years), also likely increased the fragmentation of patches. While I had expected that patch shapes would simplify with time, I did not observe this, and in fact, shapes became more complex. I attribute this to three factors. First, the decrease in the allowable size of clear-cuts likely played a role. It may have allowed for an increase in the irregularity of the edges of hardwood patches present adjacent to cut areas. The decrease in clearcut size and the concommitant reforestation procedures required in these clear-cut areas may have limited the extent of any hardwoods that established in the area following harvest, thereby producing irregularly shaped patches as hardwood sites were converted to conifers. Second, the adjacency rules could have increased the complexity of patch shapes as disjunct units were harvested, taking small bites out of large patches. The third factor in the increase in complexity of patch shapes is related to the shift in patch locations during the study period. In 1993 more patches were located in riparian than in upslope areas, and more patches occurred at lower slope positions and closer to streams than in 1939. Hardwoods have a competitive advantage over conifers in these near-stream sites because of rapid colonization following flood- and landslide-related disturbances, and because of their tolerance of flooded soils (Harrington 1990; Harrington 1987). The ecological attributes enable the persistence of hardwoods along narrow streamsides, providing more complex shapes than found in upland areas. Management practices in these riparian areas, especially areas that are used for agriculture, could also increase hardwood patch shape complexity. If these lands are neither converted to conifer plantations nor are currently used for agricultural purposes at levels equivalent with earlier use of these areas, then hardwoods could both be maintained in these areas and expand, as meadows are replaced by hardwood stands. This expansion would likely occur in an irregular fashion, which would be reflected either in an increase in shape complexity or in the coalescence of patches.

I also expected to see a downward shift in patch core area:edge area ratios which would be associated with shape simplification. The increase in core area:edge area ratios can be attributed to the observed increase in shape complexity, as the amount of edge area relative to core area increses as patches become more complex in shape and perimeter values increase relative to interior patch area.

Within-patch non-hardwood cover types occurred at levels lower than I had expected. I had expected to see both moderately-sized shrub patches embedded within hardwood patches, and a persistent large conifer component within hardwood patches, as mixed stands of red alder are common throughout the range of that species (Harrington et al. 1994; Newton and Cole 1994). I had expected that shrub fields occurring in open areas within hardwood stands would expand as hardwoods senesced, and as salmonberry expanded (Tappeinter et al. 1991; Newton and Cole 1994). However, I found a low proportion of shrubs in hardwood patches at both dates of the study. Interestingly, patches that persisted through the course of the study had a higher frequency of shrub occurrence in these same patches in 1993 than in 1939 (2 patches in 1939 vs 15 patches in 1993, of all patches that persisted, contained shrub cells); this could be related to the persistence of patches in frequently disturbed near-stream areas, where shrubs also commonly occur. The process of hardwood patches transitioning to shrubs may be occurring but at slower rates than the conversion of patches to conifer in the Coast Range landscape.

I had also expected to see an expansion in the large conifer component within hardwood stands during the study period as hardwoods died and created gaps, but this was not observed. It is likely that large conifers, with their high economic value, were removed from the interior of hardwood patches, much as they have been removed from other areas of the Coast Range landscape. The removal of large conifers would contribute to the decline in conifer within-patch heterogeneity. Lack of expansion of large conifers within hardwood patches could also occur if suppressed conifers either remained under the hardwood canopy or did not reach the larger size classes, or if shade-intolerant conifer densities were initially low (Shainsky 1988). In addition, in riparian areas, sites may be too wet for conifers or may exhibit frequent disturbance effects, such as landslides and floods, which can occur at a finer scale than fire-related disturbance. Conifers may have difficulty persisting under these conditions, while rapidly growing hardwoods do not (Harrington 1987; Minore and Smith 1971; Harrington et al. 1994). Both the tolerance of hardwoods for these conditions and the relative difficulty for conifers to persist under these conditions, may contribute to the presence of more pure hardwood stands, and less within-stand conifer heterogeneity, in these areas. If the spatial distribution of patches shifted to these lower elevation, near-to-stream areas, then the likelihood for diminished conifer composition within these hardwood stands is high.

In terms of overall within-patch heterogeneity, I had expected to see an increase as the various non-hardwood cover types increased (e.g., shrubs and conifers); however, this was not observed. This could be because large conifers made up a large proportion of all within-patch heterogeneity in 1939, and these cover types were present at reduced levels in hardwood patches in 1993. The drop in the heterogeneity of hardwood patches spanned both riparian and upslope areas, without distinction, as would be expected with a systematic removal of large conifers from hardwood stands throughout the landscape. The decrease in within-patch heterogeneity was evidently not sufficient to simplify patch shapes. The increase in patch shape complexity may be occurring at coarser scales than those at which within-patch heterogeneity is observed.

In riparian areas, where elongate patches occur along streams and diverse land use practices might be common, I observed what I had expected: more complex shapes than those found in upslope areas. This was most commonly observed along first and second order and on flat topography along third and higher order streams. Along the higher order streams in flat areas, private non-industrial groups, who in 1993 owned a greater percent of patches in this area than in 1939, may be positively affecting patch shapes.

I had hoped to use the Drift Creek Wilderness portion of the study area to provide a "control" to measure management effects on hardwood patches. I had expected to see a greater shift toward smaller sizes in the frequency distribution of patch sizes in the Drift Creek patches than was observed in the frequency distribution of patch sizes for the rest of the study area. I hypothesized that this would occur as existing hardwood patches succeeded to conifer, and as new large hardwood patches did not arise, because of a lack of large-scale disturbances. However, I saw no difference in the frequency distribution of patch sizes either within or outside of Drift Creek. The distribution of hardwood patch shapes in the Drift Creek area did not change much between 1939 and 1993; however, outside of the Drift Creek area shape distributions were significantly different, and shape complexity increased, between the two dates. Although Drift Creek makes up a relatively small portion of the study area, and the implications of the results may thereby be limited, these results suggest that management activities may have a greater impact on the shape of hardwood patches than on the distribution of their sizes. This may be the case if hardwoods are regenerating in more linear areas of disturbance, such as along the extensive network of roads, and also if upslope hardwood patches, which typically are of more uniform shape than riparian patches, are being replaced by young conifer plantations.

Implications for Spatial Modeling

The results of the study also provide important information for efforts in the spatial modeling of forest dynamics. Spatial models that seek to include hardwood patches in their models must set a minimum size area of resolution that will adequately capture the variation in hardwood patch sizes, and will not omit smaller patches from the list of considered landscape features. Hardwood patches in the Central Coast Range of Oregon in both 1939 and 1993 were found at the highest frequencies at under 5000 m^2 in size. If minimum patch size designated in the modeling efforts exceeds these limits then models and maps will not reflect actual conditions, both in terms of patch size distribution and in the total area of the landscape occupied by hardwoods. In addition, because hardwood patches and the greatest proportion of hardwood area are currently found most frequently at less than 90 meters from streams, any models that block the landscape into units larger than 90 meters on a side may omit a large proportion of the hardwood patches present on the landscape from consideration. To preserve the hardwood-related heterogeneity in the landscape, then, a minimum area size for the spatial resolution of model elements might best be restricted to less than 90 meters.

Successional Dynamics and Stability

The hardwood patch mosaic was not stable during the period from 1939 to 1993. As a landscape element, hardwood patches decreased in numbers, and hardwood area decreased in the landscape. The increase in shape complexity, the decrease in weighted mean patch size, the high levels of fragmentation and disappearance of patches, the decrease in heterogeneity, and the shift in location of hardwood patches to lower slope position areas near streams, all imply that hardwood patches were dynamic between 1939 and 1993. Hardwoods were also not replaced by large shrub fields, an hypothesized stable vegetation state, during the study period. However, some degree of stability was observed in riparian areas, especially along higher order streams. Areas that did not change were associated with private non-industrial landowners. These landowners may have the most diverse management goals of any single landowner group (Lettman, personal communication). These owners may not invest as much as the other landowners in silviculture to grow conifers. With the prevalence of this ownership group in the valley bottom areas where agricultural and pasture lands are relatively common, hardwood stands occurring here may have a higher likelihood of persistence, given the increases in recent years in hardwood patch numbers and overall hardwood area on private non-industrial lands. In the Drift Creek Wilderness, hardwood patches also exhibited stability in patch size and shape frequency distributions. However, on the landscape as a whole, with the prevalent proclivity for timber harvest and conversion to conifer monoculture stands in forests of the Coast Range on both public and private industrial lands, it appears unlikely that most individual hardwood stands will persist for time periods long enough for succession to change hardwood stands into stable, large shrub fields. The potential remains for successionally stable shrub fields to result in areas occupied by hardwood patches, if the landscape is unmodified by frequent and widespread clear-cutting. In this study, any potential stability was lost as a result of clear-cutting and forest conversion, rather than successional change.

Management and Disturbance

Human management of the landscape has had a dramatic effect on hardwood patch size, shape, composition and location in the Oregon Coast Range. Stands in 1939 occurred commonly at higher elevations and slope positions, and on topographically convex sites that might be associated with ridgetops or drier sites; alder may have occupied these areas following the widespread fire disturbances in the late 1800s and early 1900s, with the reduction of grazing in these areas, or after logging occurred on these sites (Impara 1997; Strome 1985; Hays 1976; Crane 1951; Parry 1985). Wildfires, coupled with anthropogenic disturbances in the area such as clear-cutting and road building, resulted in a distribution of hardwood patches in which hardwoods established across a wide variety of site conditions. Interestingly, the environmental gradients associated with hardwood area and hardwood patch occurrence in 1939 tended to reflect more closely the overall distribution of environmental gradients in the landscape than the distribution of patches and hardwood area in 1993. This suggests that hardwood patches occurred fairly widely throughout the landscape under earlier European settlement conditions when fire, grazing, and selective logging were widespread disturbances. More recent management practices, including clear-cut harvest methods, the planting of conifers, and conversion of hardwoods to conifers, and fire suppression practices, are likely increasing hardwood shape fragmentation and complexity, restricting the landscape distribution of hardwood patches.

Potential Constraints and Limitations of the Study

Limits of Aerial Photograph Interpretation

Although aerial photo interpretation was the preferred large-scale analytical technique for the landscape, the use of aerial photos brought constraints to the analysis of hardwood patches, relating to stand age, composition, and management activity levels. Aerial photos allow the viewer to see the canopy, but not the finer scale features of the stands in question. In addition, some measure of error is inherent to aerial photo interpretation, both from aerial photo quality constraints and from interpreter error. While the 1993 photo interpretation could be confirmed by site visits, this was not possible for the 1939 patches. Further, the fine-scale features under examination in this study would not be captured by the coarser-scale historic vegetation cover type maps of the area.

Several studies have shown that aerial photo interpretation error varies more between interpreters than between a single viewer and the medium (e.g., Poso et al. 1968; Haack 1962). In this study, there was a single photo interpreter. In addition, randomly selected patches that were difficult to delineate or for which feature determination was difficult, were dropped from the analysis; this was determined by photo quality and occurred only sporadically in the area. This was common close to photo edges and in areas of film over- or under-exposure, so these areas were avoided. The latter condition was excessively common with the 1939 photo set. Thus, questionable patches were not included in the analysis, and any aerial photo interpreter error should be distributed randomly throughout the sample, thereby not skewing the results.

Patch Age and Composition

Because I used a random sampling method, patches of different ages were selected, thereby allowing me to describe the condition of hardwood patches as a class on the landscape, but not to detail distinctions for patches of different ages. Hardwood stands, especially those comprised of pure red alder, can be relatively tall even at young ages (e.g., 9m at age 5; Harrison 1990), making it possible to distinguish them readily from shrubs in aerial photo-based analysis. Thus there was likely little confusion between young hardwood trees and shrubs in this study. However, young alder stands may have a lower probability of being cut than older stands, as they frequently may occur in recently cut areas, and it is possible that more stands were young in 1993 than in 1939. Young alder stands may be dense and have low understory diversity, while older alder stands may be breaking up, with dying trees being replaced gradually by conifer species that take advantage of openings in the canopy. These two types of stands may occur in different kinds of areas in the Coast Range landscape. These differences could be described only indirectly in this analysis, perhaps via patch composition or fragmentation measures. Thus, no explicit descriptions of changes in average alder stand age on the landscape can be derived from this analysis. Within this constraint, however, opportunities occur for the analysis of hardwood patches across age classes. Patches of different ages were examined, thereby obtaining a complete picture of the long-term change in hardwood patch size, shape, and composition. Because hardwood patches serve important functions in the landscape, such as nitrogen fixation and the production of high quality litter to streams, and these functions can be considered typical of this patch type, an inability to distinguish between ages of hardwood patches may not be a great limitation in this study.

Forest Management Activities and Aerial Photo Interpretation

At the outset of the study, I had hoped to divide the patches into managed and unmanaged stands that persisted throughout the study period in their respective human disturbance-related groups; this proved to be impossible, for two reasons. For one, forest management, primarily in the form of clear-cut harvesting followed by the planting of conifers, is extremely widespread in the Coast Range landscape. It is likely that very few natural stands, unaffected by management in any way, occur in this landscape. In some areas, management activities would likely result in the development of a hardwood stand, perhaps because of the lack of herbicides used on federal lands, or the proximity of fast-growing alder trees which would seed in the site once the site had been cleared. These two features of management effects made it difficult to distinguish stands impacted by management. In addition, unless management activities had taken place relatively near the dates that the aerial photos were taken, it was difficult to see clear boundaries between managed and unmanaged stands because of the rapid regrowth of tree species in the highly productive coastal region. This management delineation difficulty was enhanced by the tendency for multiple harvests to occur at short time intervals in the Coast Range landscape, relative to the 54-year time span of the aerial photos. Further, even if hardwood patches appeared to be somewhat intact within their borders, most often these stands had boundaries that had been altered by adjacent management activities. This resulted in the production of many individual hardwood stands that could be classified, at best, as a mixture of managed and unmanaged areas during the time period of the study. However, the comparison of the Drift Creek Wilderness patches to the rest of the patches in the area allowed for conclusions to be made about the effect of management during the study area period on patch size and shape, with patches affected by management activities showing an increase in shape complexity, and patches unaffected by management showing no change in shape.

CONCLUSIONS

Several conclusions can be drawn from this study of the spatial distribution and patch dynamics of hardwoods. The hardwood patch mosaic was not a stable landscape feature. The variety of management practices in the Central Coast Range has had diverse effects on hardwood patches. The geographic distribution of hardwood patches sampled has been restricted, and patch sizes, shapes, and within-patch compositional heterogeneity have changed. The most important conclusions are as follows:

1. A viable methodology has been developed for the detailed study of the change in a population of vegetation patches across landscapes using digital photo imagery and GIS techniques. The methodology involves scanning and georeferencing aerial photos, obtaining a random sample of plots having the hardwood cover type, delineating hardwood patches using these plots as origination points, and linking patch size, shape, composition, and distribution information to a suite of environmental and other variables. Aerial photo registration was the most time consuming portion of the methods; time of registration could be lessened if aerial photos having more information, such as focal length, were used because other more streamlined registration techniques could be employed.
2. The total geographic area covered by hardwood patches sampled in 1939 and 1993 declined, from 984 ha to 585 ha. The most dramatic drop in hardwood area occurred on Forest Service lands, while the most dramatic increase in hardwood area occurred on private non-industrial lands.
3. The number of hardwood patches randomly sampled declined from 1939 to 1993, from 268 to 244.

4. Weighted mean size of hardwood patches declined from 1939 to 1993 (p=0.001), and most patches that were present in 1939 either disappeared or decreased in size.
5. In 1993, hardwood patches were found closer to streams (p=0.04) and on lower slope positions than in 1939 (p=0.03). This may be associated with historic disturbance patterns prior to 1939 of fire, logging, and grazing that occurred on the upper slopes and allowed for alder establishment on these sites.
6. Hardwood patches became more complex in shape during the study period ($p<0.001$), especially in riparian areas. Core area:edge area ratios increased, as patches became more complex in shape and patch perimeter values increased relative to interior patch area.
7. Hardwood patches were less heterogeneous in within-patch composition than expected, and the low levels of within-patch heterogeneity declined through the study period, with the number of patches with non-hardwoods present within their borders declining from 230 to 63 from 1939 to 1993 (a decline in heterogeneity from 85 percent of all patches to 20 percent of all patches having non-hardwoods present). Large mixed and pure conifers comprised approximately half of the within-patch heterogeneity of cover types.
8. Large shrub fields did not replace hardwood patches. This could in part be because harvesting of hardwood stands was widespread and occurred at rates more rapid than the successional shift to shrub fields would occur.
9. Given the characteristics of the hardwood patches sampled, spatial models should consider that the majority of hardwood patches are less than 5000 m^2 in size. To preserve the hardwood-related heterogeneity of landscape elements in riparian areas,

modelers should understand that hardwoods have complex shapes in these areas and frequently occur within 90 meters from streams.

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APPENDICES

APPENDIX A -- BIOLOGICAL CHARACTERISTICS OF HARDWOOD TREE SPECIES AND SOME OTHER SPECIES INVOLVED IN HARDWOOD PATCH DYNAMICS

Red Alder

General Properties

Red Alder is considered to be a short-lived, pioneer species occurring on disturbed sites where mineral soil has been exposed. It occurs primarily on the soil orders of Inceptisols and Entisols, but is also found on Spodosols, Alfisols, Ultisols, Histosols, and Andisols (Harrington and Courtin 1994). Characteristics of these soils range from well-drained gravels or sands to poorly drained clays and organic soils (Harrington et al. 1994). Historically, red alder was thought to be primarily a riparian species, but human-caused disturbance such as fire and logging has resulted in the expansion of alder to a wide variety of sites (Carlton 1988), indicating the versatility of the species. However, red alder abundance decreases dramatically in the Oregon Coast Range as the distance from the coast increases (Franklin and Dyrness 1988). The range of red alder extends from Southeastern Alaska to Southern California, within 200 km of the Pacific Ocean and at elevations below 750 m (Harrington 1990). It has an average lifespan of from 80-100 years, is intolerant of shade, and typically attains a size of 55-75 cm in diameter and 30-40 m in height (Franklin and Dyrness 1988). It is immune to *Phellinus weirii*, a root-rot fungus of Douglas-fir, and is often planted to prevent the spread of this pathogen. It is host to more epiphytic species than either Douglas-fir or Sitka spruce (Pechanec and Franklin 1968).

Red alder seed is contained in 1-3 cm long cones. Each cone contains from 50 to 100 wingless, nutlike seeds, and while seed is produced annually, abundant cone crops occur every two to five years (Ager et al. 1994). Viability of one seed lot collected from a site in the eastern portion of the Central Coast Range was 95% (Haeussler and Tappeiner 1993). Red alder reaches maturity at an average age of 3-4 years for individual trees and 6-8 years for most dominant trees in a stand (Harrington 1990).

Seed Predation

In a thorough study of several aspects of red alder seedling establishment in the central Coast Range, caged and uncaged plots were established on undisturbed and disturbed forest floors in clearcuts and second-growth forest on south and north aspects in the interior and coastal portions of the area (Haeussler et al. 1995). Seed predation rates were significantly different from zero on all four sites (S coastal, N coastal, S interior, N interior), and predation was significant on both disturbed and undisturbed plots, averaging 74% on disturbed plots and 38% on undisturbed plots. However, even with the higher predation rates, fewer seedlings emerged on undisturbed than disturbed plots. There was no difference in predation rate between clearcut and forest, but 60% of seed on undisturbed seedbeds appeared to have been lost to soil organisms, compared to only 20% of the seeds on disturbed seedbeds (Haeussler et al. 1995). Red alder seed is more subject to predation by invertebrates and pathogens on undisturbed than disturbed seedbeds, but small mammals and birds predate more on seeds on disturbed than undisturbed seedbeds, and more on north than south facing slopes (Haeussler et al. 1995), as estimated by the difference in predation found between caged and uncaged plots. The effects of seed predation on germination rates, then, might be minimized in situations where seed is sown on disturbed sites, with more losses to birds occurring at disturbed sites but more losses to invertebrates occurring at undisturbed sites.

Seed Germination

Red alder seed germinates more effectively under the red light conditions provided by open conditions in clearcuts or under an overstory of evergreen needles, than under the far-red wavelengths found beneath a multi-layer red alder canopy or under large amounts of herbaceous vegetation. Both of these latter conditions appear to reduce the red-far red light ratio too dramatically for germination to occur (Haeussler and Tappeiner 1993). On both undisturbed and disturbed clearcut and second-growth forest plots, 60% of the variation in the percent seedling emergence was explained by the mean March through June soil moisture level, with more seedlings emerging on disturbed than undisturbed seedbeds at any given moisture level (Haeussler et al. 1995). Several authors have speculated that the lack of a significant fleshy seed coat may explain the requirement of red alder seed to encounter moist mineral soil conditions upon germination (e.g. Ager et al. 1994; Haeussler and Tappeiner 1993).

Seedling Survival and Early Growth

Once seeds have germinated, red alder seedlings survive better under high light and surface soil moisture conditions in clearcuts than they do in low light conditions in forests, which are compounded by herbivory, fungi, and smothering by litter and debris (Haeussler et al. 1995). Survival rates were found to be better under the compacted soil conditions of skid trails and landings than in other clearcut areas, potentially due to the increased thermal conductivity and volumentric heat capacity, increased moisture availability in surface soil layers, and lack of symbiosis-prevention microbes in these disturbed and compacted soils (Haeussler et al. 1995). On coastal sites, where the climate is milder and wetter, alder established on all slopes and aspects, but on south-facing slopes established more commonly in areas of some shade (Haeussler et al. 1995). Mineral soil exposure did not affect early survival. Overall, coastal sites showed greater height growth, higher second-year survival rates, and seedling emergence rates than interior sites. On interior sites, establishment sites were limited to sheltered habitats such as stream channels, gullies, and the steepest portions of north-facing slopes, perhaps due to low soil moisture and high surface soil temperatures at interior sites (Haeussler et al. 1995). Direct seeding or natural regeneration on these sites may not produce the desired number of surviving seedlings (Haeussler et al. 1995). Red alder site requirements may thus be more restrictive than was previously imagined, especially at interior sites in the central Coast Range (Haeussler et al. 1995). Red alder most commonly established on north-facing sites close to the coast. However, some of the observed intolerance of inland sites may be a result of the unusually hot and dry growing seasons seedlings experienced during the study years (Haeussler et al. 1995).

Reports of high early growth rates are widespread for red alder (e.g. 9 m at age 5 in Harrington 1990). However, Haeussler et al. (1995) found that mean heights for the first and second growing season fall far below this estimate, with 2-5 cm tall seedlings present on average after the first growing season and 8-23 cm tall seedlings present after the second. This may indicate that the first few years of alder seedling growth are slow, and precede a later burst of growth which occurs only after an adequate root and shoot system has been developed. At an early age, red alder is reported to have higher growth rates than Douglas-fir (Hibbs and DeBell 1994).

Nitrogen Fixation and Amendment to Forest Soils

Aside from its role as a significant riparian species and producer of seed which feeds many organisms, red alder is an important component in coastal forest patches because the tree has the ability to fix atmospheric nitrogen, a nutrient shown to be limiting for conifer growth in the Pacific Northwest, via a symbiosis in root nodules with an actinomycete (*Frankia* spp.) (Tarrant and Trappe 1971; Tarrant et al. 1969). Levels fixed for mixed species patches range from 50-100 kg/ha/yr, depending on overal patch vigor (Binkley et al. 1994). Nitrogen inputs may also decline as a stand ages. In a stand planted in a 75:25 mixture of Douglas-fir:red alder, at 30 years, nitrogen input to the stand from alder diminished from earlier measures (Hibbs and DeBell 1994).

Nitrogen is added to the soils of mixed forests by red alder in a number of ways. Root nodules excrete nitrogen into the soil; root nodules or free-living microorganisms have been reported to produce 60% of soil nitrogen in pure red alder patches (Atkinson and Hamilton 1978). Nitrogen from red alder is also added to forest soils via the decomposition of dead roots, litterfall and fog-drip. In a comparison between a planted mixed stand of red alder and Douglas-fir and an adjacent purely Douglas-fir stand, after 48 years site index of Douglas-fir was increased on average by 6.4 m, wood accumulated at a faster rate in the mixed stand, accumulating 159 m^3/ha (88 m^3/ha fir; 71 m^3/ha alder) in the mixed stand but only 82 m^3/ha in the adjacent pure Douglas-fir stand (Miller and Murray 1978). However, on highly-weathered, deep, nitrogen-rich soils, repeated rotations of pure alder patches actually may dampen the potential productivity of future ecosystems. Overabundant additions of nitrogen and organic matter produce hydrogen ions which are neither taken up by plants nor captured in the weathering process. In this scenario, nitrate production could be causing cations to be leached into deeper soil horizons (Bormann et al. 1994).

Bigleaf Maple

General Properties

Unlike red alder, bigleaf maple is not a short-lived, pioneer species that fixes nitrogen. It does, however, exhibit rapid growth when sprouts proliferate from burned trees or cut stumps. Its range extends from Coastal British Columbia to patchy sites in Southern California, and from elevations of up to 455 m on the Olympic Peninsula in Washington up to 1220 m in the central Cascades. Typically it is found within 300 km of the Pacific Ocean (Minore and Zasada 1990). It grows over a wide range of temperature and moisture conditions, being found on both moist, flat stream bottoms and arid, south-facing rock outcrops with slopes over 100% (Minore and Zasada 1990), and is considered to be a shade tolerant species and an excellent shade-giving tree. It commonly lives to an age of over 300 years and attains a size of 50 cm diameter and 45-55 meters in height (Franklin and Dyrness 1988), with large trees reaching diameters of 90-120 cm (Minore and Zasada 1990).

Bigleaf maple seed is large (4-12 mm long, and 9 mm thick) and is carried from the tree as a winged samara fruit. It has a fleshy, pubescent seed coat which comprises from 60-70% of the total seed weight and can hold water effectively (Minore and

Zasada 1990). It germinates well under low temperatures, beginning germination in late January or early February (Minore and Zasada 1990).

Seed Predation

The fleshy, water-laden seed of bigleaf maple is highly subject to predation. In unprotected plots in both the coastal and inland zones of the central Oregon Coast Range, no seeds sown remained at the end of a 4-year study period (Tappeiner and Zasada 1993). In a study of 1 to 250 year-old Douglas-fir patches, unprotected plots resulted in from 0-15% emergence, while protected plots resulted in from 16-51% emergence (Fried et al. 1988). In this study, rodents were hypothesized as the primary herbivores.

Seedling Survival, Emergence and Early Growth

Bigleaf maple shows a preference for emergence in thinned and unthinned conifer patches over clearcuts at both a coastal and inland central Coast Range site. Tappeiner and Zasada (1993) found percent emergence to be significantly higher in the thinned and unthinned patches than in clearcuts of both of these sites. At the inland site, seedling survival was significantly lower in the clearcut than in the thinned stand, but at the coastal site, no difference was found in survival rate. Predation on seedlings was heavy at both sites, but was very heavy at the coastal site during the third year of growth. (Tappeiner and Zasada 1993).

Seedlings do not appear to be especially shade tolerant (Fried et al. 1998); in fact, survival appears to be inhibited under low light conditions. Low survival rates under the low light conditions of unthinned patches were found to be exacerbated at coastal sites (Tappeiner and Zasada 1993). In another study in the central Coast Range, at 20% sky overhead, measured using fish-eye photographs, seedling survival was maximized at 60% (an increase of 60% over the 0% survival found with only 5% sky overhead). Further increases in sky seemed to have no effect on percent seedling survival (Fried et al. 1988).

Bigleaf maple seedling growth was inhibited by heavy browsing, especially at the coastal site. Heights after 4 years of growth averaged 16 cm in thinned patches and 12 cm in clearcuts of both coastal and inland Coast Range sites (Tappeiner and Zasada 1993). Heights on average of 9 cm were found in the unthinned, interior site in this study. Browsing by deer is postulated as the most pertinent factor limiting the height of bigleaf maple seedlings (Minore and Zasada 1990).

Bigleaf Maple's Effect on Soils in Douglas-fir Forests

While bigleaf maple is not a nitrogen fixing species as is red alder, soils found beneath bigleaf maple trees have been shown to possess higher nitrogen concentrations than those under Douglas-fir trees in plots in the eastern portion of the central Coast Range. In addition, litterfall weight and nutrient content of all the other macronutrients and many micronutrients were higher on average than those in the soils beneath Douglas-fir trees on adjacent plots (Fried et al. 1990). Overall nutrient rates were greater, but not on all sites. At 4 of 5 study sites, organic carbon levels were also higher under bigleaf maple than under Douglas-fir. Turnover rates for both biomass and macronutrients, however, were found to be higher for soils under bigleaf maple, and the enhanced decomposition rates may mediate some of the nutrient gains potentially attributed to the bigleaf maple trees at these sites (Fried et al. 1990). Because neither bigleaf maple nor its effect on forest soils has been studied widely, much remains unknown about the potential for this species to enhance site productivity. However, the evidence presented suggests that bigleaf maple produces high quality litter and increases the rate of macronutrient cycling in patches in the eastern portion of the central Coast Range.

Other Hardwood Tree Species

Several other hardwood tree species occur in all or part of the study area. Pacific madrone (*Arbutus menziesii* Pursh) is a thin-barked, long-lived (200+ years) tree, most often found in drier areas and on south or west aspects, sprouting readily from stumps, showing rapid growth in early years and seedling establishment predominantly in disturbed areas, and is succeptible to fire (McDonald and Tappeiner 1990). Oregon Ash (*Fraxinus latifolia* Benth.) may be found in seasonally flooded habitats and adjacent sites and along roads, having moderately rapid growth for 60-100 years, and living up to 250 years (Owston 1990). Black *Cottonwood (Populus trichocarpa* Torr. & Gray) may form pure stands on alluvial soils of moderate pH especially in and along larger streams and rivers, sprouts from stumps or cuttings, produces absciseable shoots which may be dispersed by water transport, is fast growing in early years, and may live nearly 200 years (DeBell 1990). Giant Chinkapin (Castanopsis chrysophylla (Dougl.) A. DC.), which occurs in the southeastern portion of the study area, is found mainly on nutrient-deficient deep soils, seems to germinate best in leaf litter in partial shade, sprouts readily from stumps, shows rapid stump sprout growth, is succeptible to heart rot, may live to be greater than 100 years old, and is predominantly an understory tree (McKee 1990). Other hardwood trees occuring in the study area include common dogwood (*Cornus nuttallii* Aud. ex T. & G.), bitter cherry (*Prunus emarginata* Dougl.) and cascara (*Rhamnus purshiana* DC).

Species Involved in the Conversion from Hardwood to Other Patch Types

Conifers

Conifer species occurrence in the study area may be roughly divided into two zones: the Sitka spruce zone, a narrow strip approximately 2 kilometers wide along the coast with some extensions up river valleys (Franklin and Dyrness 1988), and the western hemlock zone, an inland zone covering the remainder of the study area. Along the coastal strip, Sitka spruce (*Picea sitchensis* (Bong.) Carr.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western redcedar (*Thuja plicata* Donn) predominate., with *Pinus contorta* occurring along the immediate coastline. In the inland zone, Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) is typically the dominant species, and has been planted extensively throughout the region. In mixed conifer-alder stands, alder must maintain the upper canopy to survive because of its shade intolerance. As Douglas-fir densities were increased in a pure alder stand of high density, alder growth was diminished (Shainsky and Radosevich 1991). In addition, alder in these plots shifted carbon from leaf area production to root growth as a result of decreased water availability with increased conifer densities (Shainsky et al. 1994; Shainsky et al. 1992). This shift in root growth altered the light environment for understory species which could then better compete with alder.

Shrubs

Salmonberry (*Rubus spectabilis* Pursh) and vine maple (*Acer circinatum* Pursh) may be the two shrubs most likely to dominate sites after the senescence of red alder in the central Coast Range. (Carlton 1988). These shrubs have been found to dominate the shrub layer in hardwood tree patches, and may preclude the regeneration of tree species when present (Carlton 1988; Tappeiner and Zasada 1993; Tappeiner et al. 1991). Salmonberry has been shown to produce clones of diffuse, rapidly growing shoots produced by an extensive network of rhizomes (Tappeiner et al. 1991); while these clones may be small, linear, or not present in dense Douglas-fir patches (Tappeiner et al. 1991), they may provide dense cover in alder stands (Franklin and Pechanec 1968). Vine maple seeds are not long-lived and are subject to predation , and salmonberry seed sown in unthinned conifer patches has shown less than 0.5% survival over a 4-year period (Tappeiner and Zasada 1993). In a study of understory vegetation in alder-dominated stands of varying ages in the Alsea basin, the presence of either of these two shrubs was associated with an absence of tree regeneration under senescing stands of red alder (Carlton 1988). However, Franklin and Pechanec (1968) found, in three 40-year-old stands at Cascade Head, that suppressed sitka spruce saplings persisted in alder stands having a dense shrub layer and might therefore be available for release at the time of stand senescence. It may be that a dense shrub layer under a hardwood tree canopy limits the regeneration of shade intolerant conifer species but that shade tolerant species can survive these conditions until stand senescence occurs. Salmonberry would likely hinder bigleaf maple establishment in riparian zones, while salal would be the most likely competitor in upland sites. Anecdotal evidence indicates that western hazel

(Corylus cornuta Marsh) may be another shrub limiting tree regeneration beneath an alder stand (Newton et al. 1968), but this has not been confirmed.

APPENDIX B -- USES OF RED ALDER AND BIGLEAF MAPLE

Red alder wood is used commonly for fine furniture, cabinets, paneling, paper products, grocery pallets, and fuelwood (Harrington 1990; Plank and Willits 1994). It has high workability, a uniform color, low warpage, and provides a greater value than less than 100-year-old Douglas-fir wood, even on a log scale basis, over similar diameter ranges (Plank and Willits 1994). A comparison of small tree values for Douglas-fir and red alder showed that while most small Douglas-fir trees may be sold at an average value of $225 to $250/mbf, alder trees of similar size may be worth from $250 to $900/mbf, because of the ability of alder to produce clear wood on these small trees (Plank and Willits 1994).

Bigleaf maple is used primarily for furniture, including piano frames, and for decorative veneer (Minore and Zasada 1990). It is highly valued and increasingly cultivated in Sweden and the Netherlands for furniture and flooring. Its wood may be used for fuelwood, but it is also of indirect economic value as the greatest carrier of mosses and other epiphytic plants in the region (Pojar and MacKinnon 1994), which are harvested as highly valuable secondary forest products (Mater, personal communication; Vance and Thomas 1997). These two hardwood tree species thus provide unique and diverse utility values.

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