CONGRUENT MANAGEMENT OF MULTIPLE RESOURCES: PROCEEDINGS FROM THE WOOD COMPATIBILITY INITIATIVE WORKSHOP

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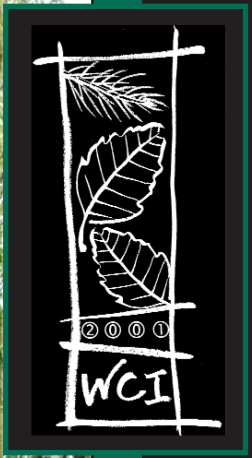

Keynote papers • Aquatic studies • Scale issues • Silviculture studies • Nontimber forest products • Social/economic studies

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CONGRUENT MANAGEMENT OF MULTIPLE RESOURCES: PROCEEDINGS FROM THE WOOD COMPATIBILITY INITIATIVE WORKSHOP

Adelaide C. Johnson, Richard W. Haynes,
and Robert A. Monserud, Editors

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ABSTRACT

Johnson, Adelaide C.; Haynes, Richard W.; Monserud, Robert A. eds. 2002. Congruent management of multiple resources: proceedings from the Wood Compatibility Initiative workshop. Gen. Tech. Rep. PNW-GTR-563. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 252 p.

The Wood Compatibility Initiative (WCI) addresses options that may increase the compatibility between wood production and other societal values derived from forestlands. The set of 25 papers included in this proceedings presents the summaries of WCI-related research, compiled from a workshop held December 4-7th 2001 at the Skamania Lodge in Stevenson, Washington. The workshop proceedings papers are grouped into six general topics: 1) workshop keynote papers, 2) aquatic-related studies, 3) issues relating to scale, 4) silviculture studies, 5) nontimber forest products related research, and 6) social/economic studies. These papers set the context for scientific and management inferences as well as illustrate the complex and diverse array of information needed in the development of land management strategies at different spatial scales.

KEY WORDS: Forest management, societal values, wood production, tradeoffs, compatibility.

ENGLISH/METRIC EQUIVALENTS

When you know:	Multiply by:	To find:
Meters (m)	3.28	Feet
Square meters (m^2)	10.8	Square feet
Centimeters (cm)	2.54	Inches
Hectares (ha)	2.47	Acres
Kilometers (km)	.62	Miles
Kilogram (kg)	2.205	Pounds
Feet (ft)	.305	Meters
Square feet (ft^2)	.093	Square meters
Inches (in)	.394	Centimeters
Acres	.405	Hectares
Mile	1.609	Kilometers
Pounds (lbs)	.454	Kilograms

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Proceedings from the Wood Compatibility Initiative Workshop, number 1.

EMERGENT RESULTS FROM THE WOOD COMPATIBILITY INITIATIVE

Richard W. Haynes[1], Robert A. Monserud[2], and Adelaide Johnson[3]

ABSTRACT

The Wood Compatibility Initiative (WCI) was stimulated by the public debate over forest management, which often portrayed management choices as involving tradeoffs between biophysical and socioeconomic components of ecosystems. Its purpose is to expand information on the options that may increase the compatibility between wood production and other societal values derived from forestlands. The WCI addresses two aspects of the compatibility issue. First, how can various forest management practices be related to an array of associated goods and services? Second, how can the effects of different approaches to forest management be derived across relatively large and complex ecosystems? The goal is to enable a richer public dialogue about the ability of land management options to produce timber, nontimber forest products, fish, and wildlife.

KEY WORDS: Forest management, forest production, tradeoffs, compatibility.

INTRODUCTION

The Pacific Northwest (PNW) Research Station has a 75-year tradition of discovery in forest and range research (see Duncan 2000 for details). Since 1998, scientists at the PNW Research Station have been engaged in an effort called the Wood Compatibility Initiative (WCI) to develop a greater understanding of potential compatibility among commodities, ecological values, and social and cultural values (Peterson and Monserud 1998). Compatibility in this sense refers to forest management approaches that focus on sets of outcomes that can be managed for simultaneously.

This initiative was stimulated by the public debate over forest management, which often portrayed management choices as involving tradeoffs between biophysical and socioeconomic components of ecosystems (Peterson and Monserud 1998). This portrayal often leads people to focus on dichotomous tradeoffs rather than on the possibility that opportunities for compatible changes in outputs (either goods or services) exist among alternative management strategies. In the simplest sense, a management action is compatible if it simultaneously produces wood and at least one other forest value without decreasing any other value. Considered in aggregate at the regional scale, compatible wood production increases the overall level of some forest value(s) without decreasing others. The goal is to remove forest management from the divisive arena of either or choices.

The WCI addresses two aspects of the compatibility issue. First, how can various forest management practices be related to an array of associated goods and services? Second, how can the effects of different approaches to forest management be derived across relatively large and complex ecosystems? The purpose of the WCI is to expand information on the management options that may increase the compatibility between wood production and other societal values derived from forestlands.

The set of papers included in this proceedings presents summaries of WCI-related research. These summaries are important steps in developing synthetic themes as well as scientific and management inferences. They also illustrate the complex and diverse array of information needed in the development of land management strategies at different spatial scales. Our purpose here is to set the context for the summary papers. We summarize forest management history

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in the Pacific Northwest, the conceptual model underlying discussions of compatibility, the scope of the Station's research on compatibility, and conclude with a brief discussion of where we go from here.

MANAGEMENT HISTORY

Before the mid-1970s, there was general agreement that timber production was the primary objective in management of most forestland (Curtis et al. 1998; Peterson and Monserud 1998). It was generally accepted that wood production in old-growth stands was essentially static (no net growth) and insects and disease were diminishing the amount of usable wood in such stands. It therefore seemed desirable to replace old-growth forests with young, rapidly growing stands (Curtis et al. 1998). Furthermore, clearcut logging and broadcast burning in the Douglas-fir region (western Washington and Oregon) were justified as a mimic of the catastrophic, stand-replacing fires typical of the region prior to fire suppression (Halpern 1995). Consequently, most of these management practices in the Pacific Northwest (western Oregon, western Washington, coastal British Columbia, and southeastern Alaska) attempted to increase wood production to meet increasing wood demands, relying on the economic efficiencies of clearcutting and plantation management.

Over the years, conflicts among demands for forest values have intensified (Peterson and Monserud 1998; Cissel et al. 1999). The public has become increasingly aware that a broad spectrum of additional products and values are available from the forest (Behan 1990; Beese and Phillips 1997), from old growth to conservation and restoration of wildlife and fish populations. Central to the current public debate on forest management of public lands are interactions between wood production and *wildlife* needs, *aquatic* needs, *biodiversity* needs, and *social* acceptance (Peterson and Monserud 1998). Together, these include most of the major factors setting the public agenda on the future of forest management in the Pacific Northwest. The public has strong expectations for values and uses of forest land, especially public land. In short, the process of deciding how best to manage those resources has become increasingly polarized and value-laden.

As a consequence, the past decade in the Pacific Northwest has seen a major shift from timber-stand management to sustainable forest-ecosystem management (Behan 1990), culminating in the Northwest Forest Plan (USDA and USDI 1994a, 1994b) for western Oregon and Washington, the new Forest Practices Code of British Columbia (1994), and the Tongass Land Management Plan (USDA 1997a, 1997b, 1997c) for southeastern Alaska. Instead of the traditional goal of efficient wood production with even-aged plantations, the focus has shifted toward "old-growth" management and multi-resource ecosystem management, with related goals of protecting endangered species and fish habitat and promoting biodiversity (FEMAT 1993; Clayoquot Scientific Panel 1995). There is great interest in and need for science-based silvicultural practices and management regimes that will reduce conflicts among user groups, while providing concurrent production of the many values associated with forestlands on a biologically and economically sustainable basis (Curtis et al. 1998; Committee of Scientists 1999). Smith's (1986, p. 1) definition of silviculture is appropriate: the various treatments that may be applied to forest stands to maintain and enhance their utility for any purpose.

A common, but largely mistaken, perception of traditional forest management is that it is based on scientific experimentation (Franklin et al. 1999). Rather, it is rare that resource management approaches are formulated from a systematic scientific approach that is tested prior to widespread application (Franklin et al. 1999). Dispersed patch clearcutting was widely adopted on national forest land after World War II without experimental testing, largely with the support of Isaac (1943) and other forestry experts of the day. Alternative silvicultural approaches were rejected (Isaac 1956) based on a few ill-chosen case studies rather than a scientific test of alternative methods (Curtis 1998). The consequent lack of research into alternatives to clearcutting has severely handicapped current efforts to meet changing objectives and public concerns (Curtis 1998). Other harvest experiments were implemented on a very small scale and generally lacked statistical rigor and replication (Tappeiner et al. 1997b; Franklin et al. 1999). Since then, methods for regenerating vigorous young stands of primary timber species following clearcut logging have been thoroughly researched and tested throughout the Pacific Northwest (Loucks et al. 1996; Smith et al. 1997). Foresters have accumulated an enormous amount of information and experience on even-aged silviculture and plantation management in the past 50 years (Curtis et al. 1998), but this scientific basis for management was seriously lacking when widespread implementation of modern plantation management began decades earlier in the Douglas-fir region. After a half century of implementation, it was a short step to the belief that this intensive plantation management was the only silviculture that worked in the continent's most productive ecosystem (Peterson and Monserud 1998).

Basically, the management history of the coastal forests of British Columbia and southeastern Alaska is quite similar to that in the Douglas-fir region, with a strong reliance on clearcut logging (especially old growth) followed by even-aged plantation management (Beese and Bryant 1999; McClellan et al. 2000). With the exception of several experiments with shelterwood cutting in mature and old-growth stands (e.g., Williamson 1973), well-documented comparative trials of other possible silvicultural systems in the Pacific Northwest were conspicuously lacking before the mid-1990s (Curtis 1996).

Recently, several new large-scale, multidisciplinary silvicultural experiments from the Pacific Northwest have been initiated (e.g., Carey et al. 1999; Curtis 1996; Halpern and Raphael 1999; McClellan et al. 2000). All are implementing silvicultural alternatives (e.g., variable retention, variable density thinning) to the widely-used plantation management of the previous half century (Monserud 2002). Some are attempting to hasten the approach to old-growth structure and composition. All are multidisciplinary, examining some forest value other than wood production (e.g., biodiversity). In a strong break with past experiments, all have randomized treatment units large enough to be operational (e.g., 13-20 ha units in experimental blocks of 50-200 ha). Thus, treatments are implemented as part of normal forest management sales programs and are installed on tracts of land large enough to be economically efficient for wood production (Tappeiner et al. 1997a). Because the large-scale context is designed into these experiments, results can be directly interpreted at the scale of management that produced the manipulation, eliminating a change-of-scale bias common in smaller management experiments (Monserud 2002).

Forests of the Pacific Northwest

The temperate rainforests of the Pacific Northwest (from the Douglas-fir region of western Oregon and Washington north to the coastal spruce/hemlock forests of British Columbia and southeastern Alaska) contain the highest quality wood-producing lands on the continent and are among the most productive forests in the world (Franklin and Dyrness 1973; Walter 1985). These coniferous forests exhibit some of the greatest biomass accumulations and highest productivity levels of any in the world, temperate or tropical (Franklin and Waring 1981; Fujimori et al. 1976; Franklin 1988). The outstanding structural feature is the huge biomass accumulation typically present (Franklin and Dyrness 1973). These forests have extremely high value for scenery and recreation, watershed protection, and fish and wildlife habitat (Peterson and Monserud 1998). The northern extent of this moist, coastal forest is the vast *Picea sitchensis-Tsuga heterophylla* zone of British Columbia and southeastern Alaska. Vast tracts of this coastal rainforest are relatively unaltered and have unique values of great importance (Everest et al. 1997).

Mild, moist maritime conditions characterize the region, producing expanses of forest dominated by massive evergreen conifers, including *Pseudotsuga menziesii* (Douglas-fir), *Tsuga heterophylla* (western hemlock), *Thuja plicata* (western redcedar), *Picea sitchensis* (Sitka spruce), *Abies amabilis* (Pacific silver fir), and *Abies procera* (noble fir). A mediterranean climate of wet, mild winters and relatively dry summers (Walter 1985) favors needle-leaved conifers by permitting extensive photosynthesis outside of the growing season and reducing transpiration losses during the summer months (Waring and Franklin 1979). The summer climate is controlled by a large, semi-permanent high-pressure center in the Pacific, which greatly reduces the frequency and intensity of Pacific storms (Meidinger and Pojar 1991). Very infrequent catastrophic events such as wildfires and hurricanes, at intervals of several hundred years, allow for the accumulation of enormous biomass and the phenotypic expression of extremely tall and long-lived forest trees.

The vegetation zone classification of Franklin (1988) is used, which is based on the system of Franklin and Dyrness (1973) but has larger geographic coverage. For almost all of the studies covered in this collection, only three forest vegetation zones are needed to describe the temperate rainforest from southeastern Alaska down to central Oregon, on the west side of the Cascade Range: the broad *Pseudotsuga menziesii-Tsuga heterophylla* zone, the coastal *Picea sitchensis-Tsuga heterophylla* zone, and the montane *Abies amabilis-Tsuga heterophylla* zone.

THE CONCEPTUAL MODEL

The intent of the Wood Compatibility Initiative rests on two conceptual models. The first represents a highly abstracted version of the challenge facing land managers. It does provide a framework for considering the nature of the various relationships involved in the compatibility arguments. The second model represents the more traditional view of the challenge facing land managers. It also provides a framework for looking at the linkages among the components of the land management problem.

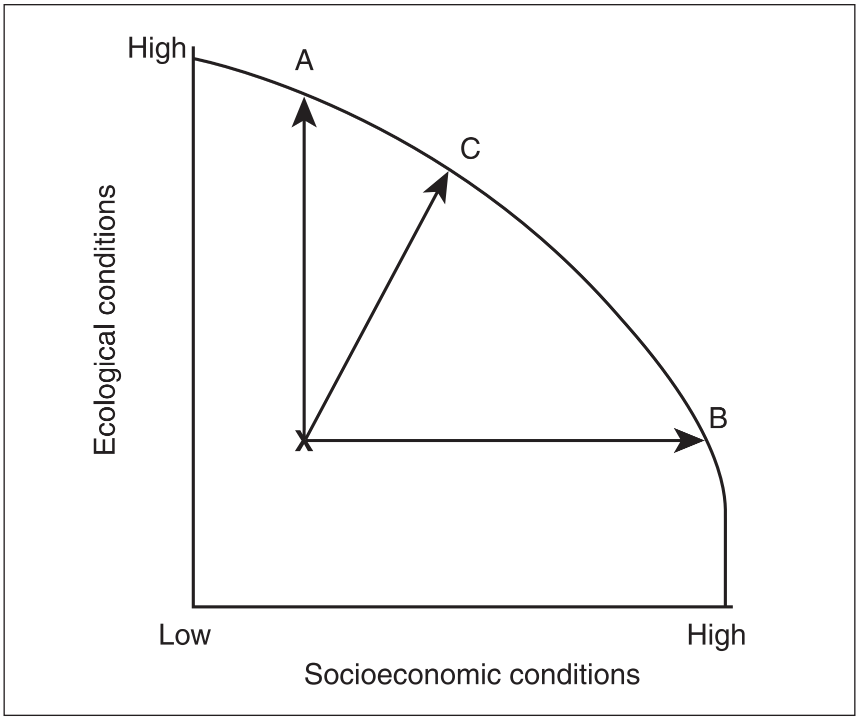

Figure 1—Hypothetical joint production function between ecological and socioeconomic conditions showing opportunities for compatible changes of both.

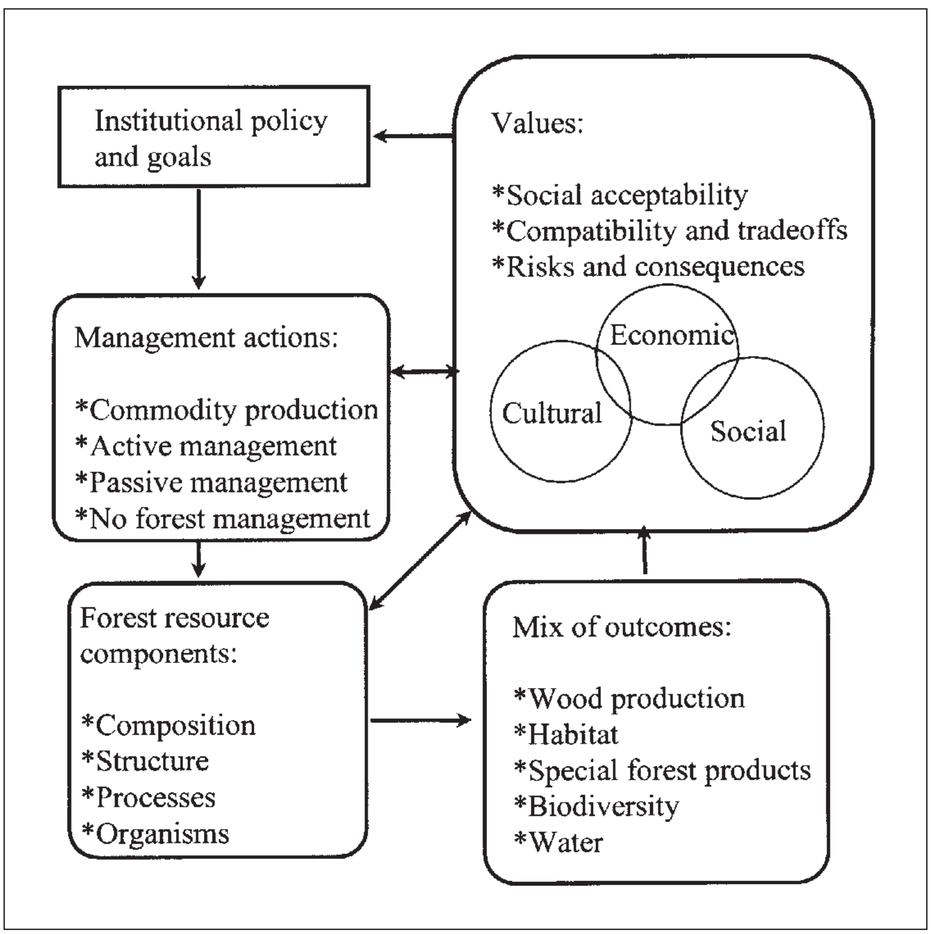

Figure 2—Wood Compatibility Initiative general conceptual model including forest resource components with interactions among social values, institutions, management, and outcomes.

Figure 1 illustrates the challenge facing land managers who are trying to manage for both ecological and socioeconomic well-being [the general problem for forestry has been described by Gregory (1972)]. The curve represents the production possibility frontier (the set of all combinations of ecological and socioeconomic conditions with no waste and no inputs left over, from which more of one output could be achieved without giving up some of the other). If, for example, our current position was point X, society would theoretically be better off if we moved closer to the production possibility frontier in any positive direction. However, people who place high value on socioeconomic conditions are concerned that improvements in ecological conditions will likely mean a move to the left of point A, at which point socioeconomic conditions will be reduced. Similarly, people who place high value on ecological conditions are concerned that improvements in socioeconomic conditions will likely mean a move below point B, at which point ecological conditions will suffer. Resistance to change means we forgo opportunities to move toward point C, at which both ecological and socioeconomic conditions improve and everybody is better off. This last condition—in which nobody is worse off and at least someone is better off— is a move closer to Pareto optimality, a useful concept that does not require the marketplace to determine value. In this simple two-dimensional example, all points bounded by X-A-B are desirable, for the amount of each of the two resources is at least as good as a point X, the status quo. The challenge is to identify points like C—and the path to reach them—in a complex world with multiple inputs and multiple desired outputs.

Figure 2 illustrates the basic interactions among these multiple values, ideas, actions, and outcomes/outputs, providing the context for research. Social values influence institutional policy that in turn affects managerial decisions and actions, resulting in both a change in forest resource components and the associated mix of outcomes. Those decisions and proposed actions are evaluated—often challenged—by society prior to being implemented, as a normal part of the planning process. Note that social concerns are not just at the top of this cycle in constructing policy and goals, but that social actions are woven through water quality, biodiversity, economic dimensions, and so forth. Thus, we will need to distinguish social activity and public use from the outcome of social acceptability. Once management takes action, the final evaluation will be to what extent and success was the desired mix of measurable outcomes achieved. A complication is that many of the values are realized in different areas and over varying lengths of time after the management action (spatial and temporal scale differences). This also suggests that much of the research information should be amenable to socioeconomic evaluation of risks and consequences.

The first conceptual model largely serves as a guiding star in discussions of broadscale policy and science issues. Some scientists see Figure 1 as too simple. They might argue that, for example, ecological integrity should have two or three axes given the complexity and sometimes competing or contradictory dimensions to the problem. Though this would add more dimensions to Figure 1, the essential policy and science issues illustrated would be much the same.

The second conceptual model (Figure 2) provides a practical framework of the various components and links that can be used at multiple spatial scales. This conceptual model specifies the management regimes and considers the multiple ownerships making up different broad-scale landscapes. Thus, questions regarding the management of public lands will be examined within the context of broader, spatially complex landscapes. Figure 2 also has a relatively short list of products that reflects recognition of the limited information available on the relation between land management actions and outputs.

These models are applied at three different spatial scales in the WCI efforts. The first scale is the traditional *stand* scale of forest management. Compatibility issues at this scale usually involve choices between management actions to achieve relatively specific land management objectives. The emphasis may be on a selected stand but there is also interest in the cumulative effects of actions in that stand across neighboring stands. The second scale is composed of broader *landscapes* that include multiple sub basins or counties. The importance of this scale is that it sets context for finer scales where much of the Station's ongoing work takes place. In this case, most tradeoffs still involve choices between management actions, but notions of public tradeoffs in terms of social acceptability regarding specific land management actions are noticeable at this scale. The third scale is the *ecoregion* scale that roughly corresponds, for example, to western Oregon and Washington (the Douglas-fir region). At this scale, these tradeoffs involve choices and the linkages between different land management/owner strategies and broad scale resource conditions and various outputs.

RESEARCH SUMMARY

This group of papers, compiled from the WCI workshop held December 4-7, 2001 at the Skamania Lodge in Stevenson, Washington, includes 25 out of a total of 33 presentations (the remaining six papers are syntheses that will be published in another volume). The workshop proceedings includes six general topics: (1) workshop keynote papers, (2) aquatic-related studies, (3) issues relating to scale, (4) silviculture studies, (5) nontimber forest products related research, and (6) social/economic studies.

Four keynote papers outline broad research topics. The first, a landscape and regional scale analysis, describes conceptual challenges and gives examples of linking wood production and biodiversity with other socioeconomic values. The second paper, a reach-scale study, describes the effects of streamside forest management on the composition and structure of headwater stream and riparian fauna. The third paper is an outline of socioeconomic factors influencing land use changes in the Pacific Northwest. The final keynote paper, a case study of wood compatibility within young-growth stands in southeastern Alaska, examines mixed alder-conifer forests in order to manage upland ecosystems for wood products, wildlife, and fish.

Most of the five papers with an aquatic emphasis describe the importance of understanding the influence of physical disturbance processes within broad time and spatial scales. Papers also describe possibilities for accelerated development of old-growth forest characteristics in riparian zones (third paper); the effects landscape pattern, riparian buffers and timber harvest on vertebrate assemblages (first paper); and the biophysical role of alder in headwater channels (fifth paper). Three additional papers include summaries of the effects of upslope forest stand management on riparian ecosystems (second paper) and studies that have been conducted by the Center for Streamside Studies at the University of Washington (fourth paper).

One of the scale-related papers emphasizes that future management of forests and watersheds in the Pacific Northwest can be most effective when it is placed in broad time and space contexts, considers multiple goods and services from these natural resource systems, and is based on effective communication amongst the many relevant audiences. An example of a large-scale study is the Coastal Landscape Analysis and Modeling Study (CLAMS). Another study develops and applies a set of measures in an analysis of the relative differences in value of wood production and different measures of ecological integrity for alternative forest policies and different ownerships in the Oregon Coast Range. Results from a small-scale, or stand level, study in southeastern Alaska suggest that mixed red alder-conifer stands may provide improved understory plant production and availability for deer forage and valuable habitat for small mammals and other wildlife.

Studies relating to silviculture presented at the workshop focus on wood quality, forest growth models, understory plant communities, and tree genetics. The first silviculture-related study focuses on yield appearance products and the economic incentives associated with longer rotations. Another study evaluates how silvicultural practices alter stem characteristics and wood properties for western hemlock, red alder, black cottonwood, and western redcedar. In order to evaluate compatibility of alternative silvicultural systems with increasingly heterogeneous structures and mixed-species compositions under experimentation in the Pacific Northwest, one study compares seven forest growth simulation models. A fourth study examines understory species—specifically the response of understory vegetation to changes in overstory density, flowering for several forest shrub species, and growth of tree species in forest understories. The final study in this set of papers, focusing on tree genetic diversity, concludes that seed orchards with 20 or more selections should provide the same level of risks (potential for loss of genetic diversity) as wild collected seed from the natural population.

Four papers present information on nontimber forest products (NTFP). In order to provide more information on forest management and forest conditions affecting understory species, one paper uses forest inventory data to determine if forest condition and environmental variables provide useful correlations with the abundance and cover of NTFP plant species. A second paper assesses current inventory methods and databases for understory species and assesses the adequacy of these methods to provide information about commercial quality and quantity of NTFP and, in addition, determines how management prescriptions might affect the supply of selected commercial understory species in Douglas-fir habitats of western Oregon. Another paper describes a theoretical model that outlines management and economic factors relating to the productivity and harvest of edible forest mushrooms, another NTFP. The fourth paper develops and illustrates processes for involving NTFP stakeholders (including commercial and noncommercial harvesters and resource managers) and conducts research relevant to identified stakeholder interests and needs.

The final set of papers presented in this proceedings address social and economic issues. One paper describes the general structure of a logic-based model for evaluating the sustainability of forests at regional and national levels, and illustrates how a logical formalism can be used to represent and evaluate compatibility among resource values and uses. Another paper examines a means to address cost effective management for biodiversity and wildlife. A third paper reviews lessons learned from an assessment of temporal trends in forest inventory and analysis data within western Oregon. The final paper summarizes key findings of an in-depth study on use of and problems associated with using the knowledge-based logic modeling system for organizing and analyzing the social acceptability of natural resource management decision processes.

PROBLEM STATEMENT

The research problem is twofold. First, how can we assemble the scientific information that is available on the compatibilities and tradeoffs between commodity production and the other values (e.g., nontimber forest products, fish, and wildlife) that the public desires from our forests? Second, how can we integrate key scientific findings to enhance good stewardship of our forest lands, both public and private?

The outcome will be scientific information that land managers can use to increase opportunities for producing compatible bundles of goods and services made up of wood, wildlife habitat, scenery, recreation, water quality (including water as a commodity), and riparian habitat, in a manner that is socially acceptable and economically viable. This outcome will be consistent with the intent of the Congressional appropriation language for this research initiative:

> *"The production of commodity outputs from National Forest land is dropping dramatically. The Committee is concerned that research priorities may not reflect the need to evaluate improved methods of increasing commodity production in an environmentally acceptable manner."*

The Hypothesis

In developing the final WCI products, we will consider testing the hypothesis: *"Timber, nontimber forest products, fish, and wildlife habitat can be simultaneously produced for the same area in a socially acceptable manner."* This hypothesis can be expanded to consider natural and managed systems across a range of scales, uniform and nonuniform landscapes, and both dynamic and static systems. Inferences can also be drawn about the nature and extent of joint production at different geographic and temporal scales. Inferences can also be drawn about how joint production capability varies by the inherent productivity of the land (stand, watershed, province) and the legacies of past land management.

Adopting this approach will enable a richer public dialogue about the ability of land management options to produce timber, nontimber forest products, fish, and wildlife. The emphasis is on informing the broader public dialogue, not just the land management community.

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SECTION A

KEYNOTE PAPERS

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CHALLENGES TO INTEGRATING WOOD PRODUCTION, BIODIVERSITY, AND OTHER SOCIOECONOMIC VALUES AT BROAD SCALES: AN EXAMPLE FROM COASTAL OREGON

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ABSTRACT

The process of assessing tradeoffs among different forest uses to help inform debates about sustainable forestry is complex and full of challenges. These challenges include: (1) definition of problems and formulation of a conceptual model, (2) identification of policies and policy alternatives, (3) development of spatial information about regions, (4) development of spatial and temporal projections of landscapes, (5) quantifying ecological responses, (6) integration of components, (7) conducting scientific research in a public policy environment, and (8) institutional barriers. Our experience indicates that meeting these challenges requires a combination of suitable institutional support; environmental crises; and tools and information to help visualize and analyze the problem. We meet these requirements in our Coastal Analysis and Modeling Study (CLAMS). Our continued success rests upon other elements including patience and the ever-changing role and acceptance of science in public debates. The time and effort required to work on this scale while simultaneously meeting scientific standards and those of policy makers and managers is enormous. We don't yet know how much this work influences policy making and informs public debates, however, we are more aware of linkages among disciplines and information needs at broad spatial scales.

KEY WORDS: Integrated regional assessments, forest landscape management and planning, multi-ownership landscapes, ecological indicators.

INTRODUCTION

Answering the question "Can we reduce tradeoffs among wood production and ecological and other values?" requires solving a number of conceptual and technical problems. We can think of the process as following threads back from general or strategic policy questions to increasingly fundamental and focused research questions. In this paper we identify one approach to addressing the major questions of producing wood in a manner compatible with production of other forest resources. We use the Coastal Landscape Analysis and Modeling Study (CLAMS) (Spies et al. 2002) to illustrate some of the challenges in addressing multi-resource assessments and briefly describe how to meet these challenges. In CLAMS, we are using a variety of linked spatial models to simulate the ecological and socioeconomic effects of alternative forest policies 100 years into the future in the Oregon Coast Range, a 2.5 million ha multi-ownership province. Although other approaches are clearly possible, we suggest that all efforts must, in someway, address the following challenges: (1) definition of problems and formulation of a conceptual model, (2) identification of policies and policy alternatives, (3) development of spatial information about regions, (4) development of spatial and temporal projections of landscapes, (5) quantifying ecological responses, (6) integration of components, (7) conducting scientific research in a public policy environment, and (8) institutional barriers. In the following sections, we briefly describe these challenges and our approaches to meeting them in CLAMS.

Continues on page 16.

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Table 1—Elements of components in conceptual model[a]

Policies	Natural patterns and processes	Land-owner behavior	Landscape/ watershed condition	Measures of bio-diversity	Socio-economic outputs	External system
Federal Forest Plans	**Climate**	**Landuse change**	**Stand structure and composition**	**Amount and quality of habitat for vertebrates**	**Jobs by sector**	**Population growth**
State Forest Practices Act	**Geology, soils**	**Harvesting rate and Rotation age**	**Stand/patch size and pattern**	**Quality of watershed conditions to support anadromous fish**	**Income by sector**	**Timber prices**
State Forest Management plans	**Topographic effects**	**Silvicultural system**	**Age class structure and pattern**	**Amount and quality of habitat for selected plants, fungi, lichens and mosses**	**Timber volume and quality**	Climate change
	Floral and Faunal patterns	**Thinning**	**Streams and topography**	**Ecological landscape-scale indices**	**logging costs**	Wildfires
	Succession	**Planting stock**	**Road density**	**Population viability for Northern Spotted owl**	**Recreational opportunity spectrum**	Pathogens
	Stand growth and mortality	**Harvest Unit size**	Road distribution and quality	**Potential to deliver large woody debris to streams**	**Contingent value of biodiversity**	Ocean effects on anadromous fish and other vertebrates
	Woody debris decay	**Riparian Management**		Population viability of other species		
	Landslides **Debris Flows** **Canopy gap dynamics** Blowdown Wildfire Forest Pathogens					

[a] Elements in bold are included in current version of the approach.

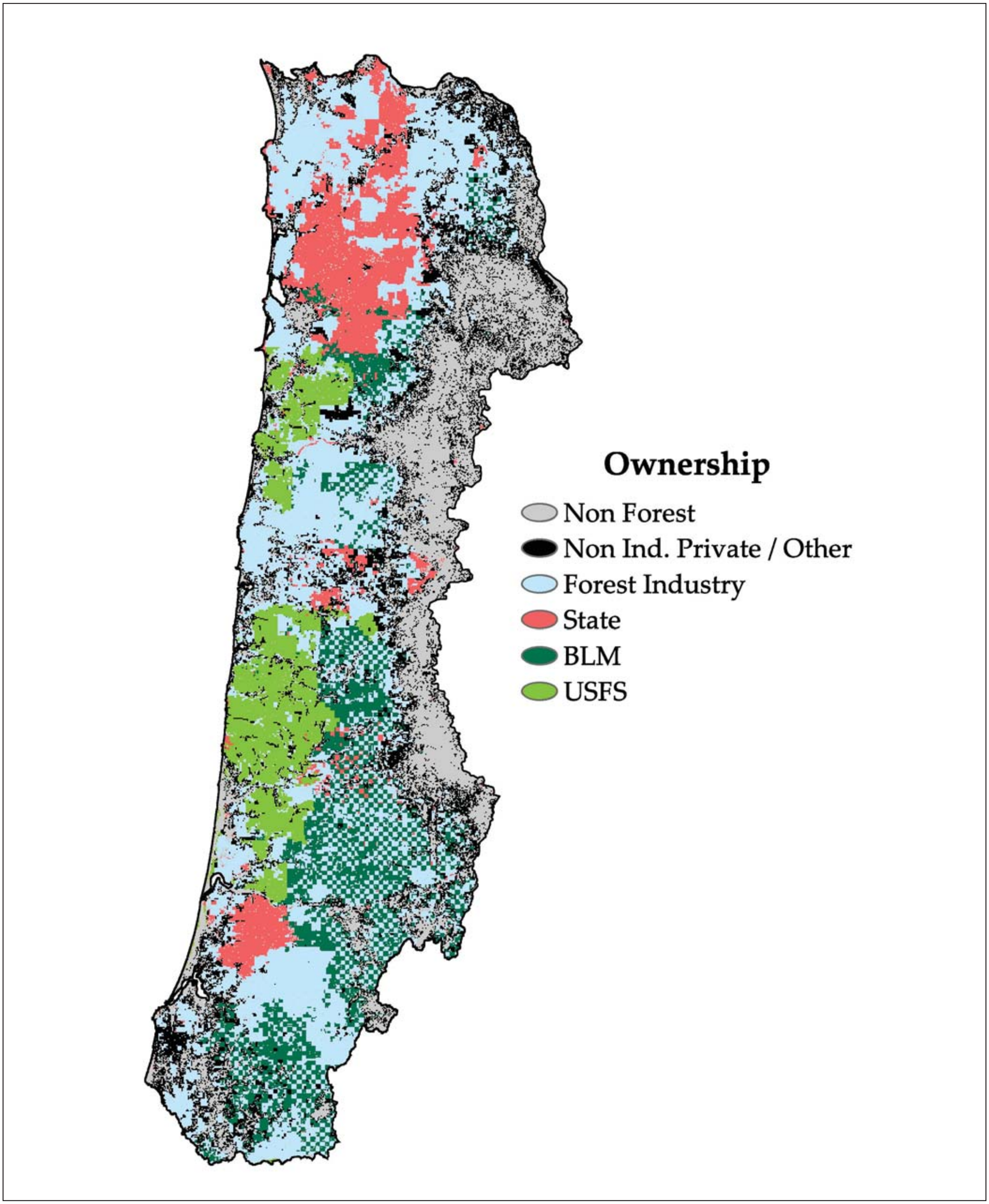

Figure 1—Ownership patterns in the Oregon Coast Range physiographic province.

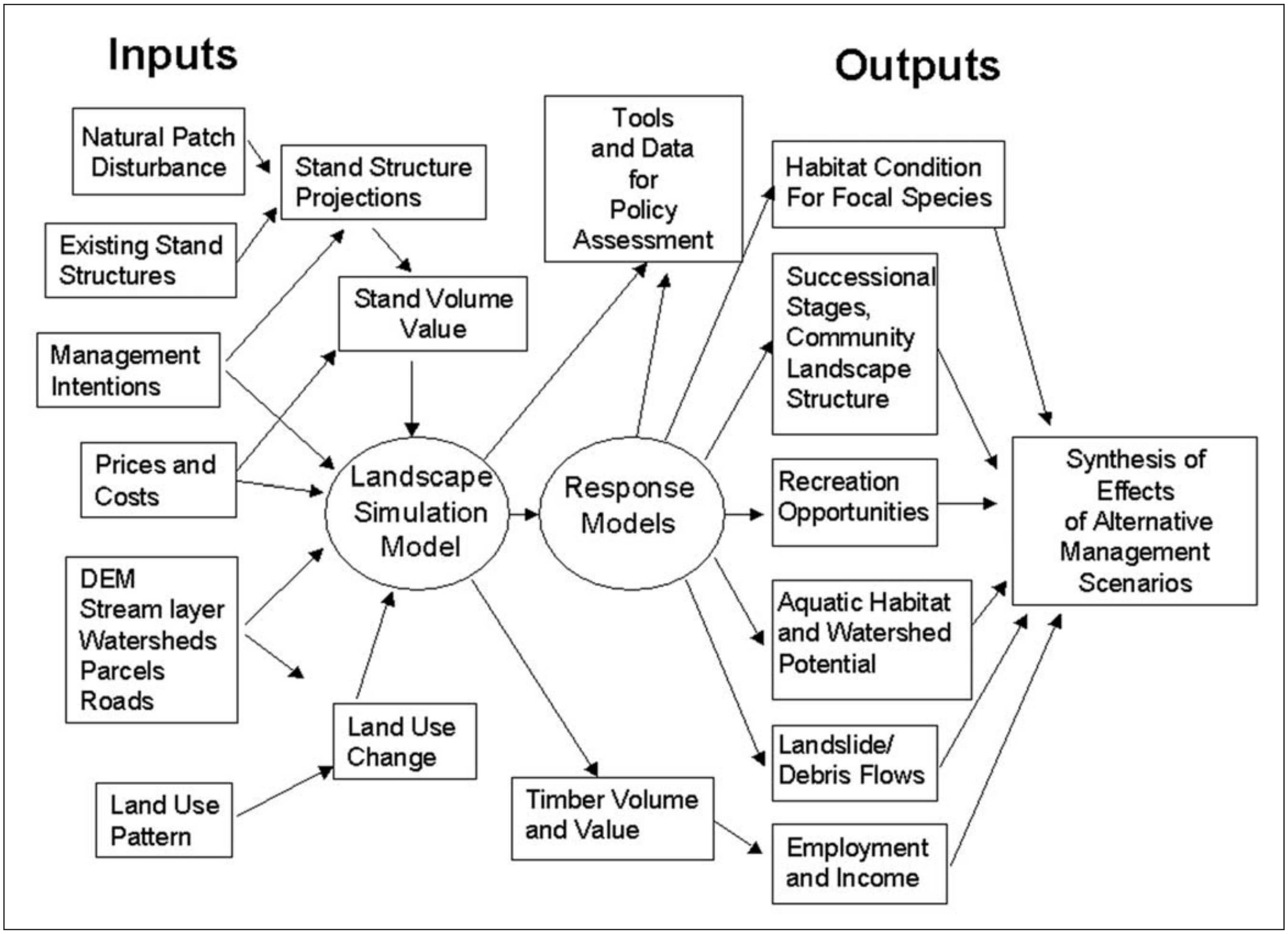

Figure 2—Conceptual model of components and linkages in CLAMS.

PROBLEM DEFINITION AND CONCEPTUAL MODEL

Problem definition is a critical element in scientific studies. It is especially critical in interdisciplinary environmental studies where problems are "wicked" or seemingly intractable because of uncertainty, diversity of perspectives, and absence of a single true solution. Defining the problem drives the assumptions and study course toward solutions (Bardwell 1991; Janssen and Goldsworthy 1996). In order to examine compatibility of wood production and other values in CLAMS, we first must answer the fundamental question: How can forest management policies, through their influence on landowner actions, affect biological diversity, watershed processes, and socioeconomic conditions?

The motivation for this general question comes from recent policy debates in the Pacific Northwest and from the particular ownership and environmental patterns of the Pacific Coast Range. The diversity of policies (Table 1) and mosaic of ownerships (Figure 1) create a landscape where the potential for spatial interactions and cumulative effects is high.

We developed a conceptual model that identified the key components and linkages of our system, the location and spatial scale of the work, and the time frames considered. We use a systems approach because it is particularly well suited for multidisciplinary environmental problems (Janssen and Goldsworthy 1996) focusing on interactions among diverse components of a system. Our conceptual model assumes that the structure, composition and dynamics of forest vegetation overlain on the physical environment (hydrology, topography) is key to understanding how forest policies and management activities affect biological diversity and socioeconomic conditions (Figure 2, Table 1). Forest policy influences landowner behavior and has at

Table 2—Forest policies, goals, and strategies dealing with biological diversity in the Oregon Coast Range by major ownership categories

Ownership	Policies	Goals[a]	Strategies
USDA Forest Service	NW Forest Plan Forest Plans	Late successional/ Old-growth Forests, T&E Species, Aquatic ecosystems, Commodities	Reserves, Matrix, Green-tree retention, Stream buffers, Adaptive Management Areas
BLM	Same as above	Same as above	Same as above but with different matrix prescriptions
State of Oregon	Forest Plans	Healthy forests, Indigenous species, Abundant Timber, T&E species	"Structure-based" active management, HCP
Private Industrial	State Forest Practices Act	Growth and harvest of trees, Protection of environment and fish/wildlife	Limited retention of individual trees, Limited stream-side protection for fish-bearing streams
Private Non-industrial	Same as above	Same as above	Same as above

[a] Goals are listed in approximate order of priorities.

least partial control over some natural processes such as forest development and wildfire. It also acts as the primary feedback among biological diversity, social values, and economic subsystems.

POLICY MAKERS, SCENARIOS, AND USERS

Past bioregional assessments such as the "Gang-of-Four" (Johnson et al. 1991), Forest Ecosystem Management Assessment Team (1993), and the Interior Columbia Basin Ecosystem Management Plan (USDA Forest Service 1996), have started with a specific set of questions from an identified policy-maker. CLAMS is an anticipatory assessment (assessment done primarily by researchers anticipating policy needs), yet, it is still important to identify policy makers and policy questions to help insure their relevancy and to prioritize questions which might guide the study. For this reason, we identified four different policy-makers that could use CLAMS results:

1. The Oregon Board of Forestry while regulating authority for Oregon's private and state lands, it considers all of Oregon's forest land in its objectives and analysis.

2. The State of Oregon, under Governor leadership, has taken responsibility for recovery of the coho salmon (*Oncorhynchus kisutch*). The Governor's plan is a combination of improved State agencies practices, forest landowners voluntary measures, and State legislature and forest industry funding of planning and monitoring.

3. The federal land management agencies (Forest Service and Bureau of Land Management) responsible for implementing the Northwest Forest Plan (FEMAT 1993).

4. The United States Fish and Wildlife Service and the National Marine Fisheries Service responsible for recovering several wide ranging species in the CLAMS area —the northern spotted owl (*Strix occidentalis caurina*), marbled murrelet *(Brachyramphus marmoratus*) and coho—listed under the Endangered Species Act as threatened or endangered.

It is important to identify the policies and potential policy issues that the methodology will address. This step helps to determine ecological and technical information needs and define the spatial and temporal grain, extent, and context of the problem. For example, analysis of riparian forest policies requires information about first- and second-order streams and vegetation within certain distances of a stream. Consequently, we must have a high resolution stream and vegetation layer and a simulation model that is sensitive to riparian management and natural disturbances.

Although our methodology is designed to address existing forest policies (Table 2), it should also prove useful to policy-makers as they consider the development of new forest policies, i.e., enable policymakers to "try out" new policies before they adopt them and to consider more fundamental alternatives such as using natural disturbance regimes to guide forest management (Landres et al. 1999). Given the application of the model to a diverse region, it is also important to identify stakeholders and involve them in developing alternative scenarios. These stakeholders include policy makers as well as watershed councils, landowners, NGOs and other public groups. These groups will have different capacities of using the information. For example, some may only want maps indicating distribution of certain resources, while others may want data for their own analyses, and some may want to be actively involved in modeling different scenarios.

SPATIAL INFORMATION ABOUT REGIONS

Developing digital spatial information about the current conditions of a large area is an important foundation of regional assessments (Lee 1993). Spatial information is needed because many resources are sensitive to spatial pattern. Furthermore, depicting policy effects on maps is a particularly effective form of communication. High quality spatial data bases typically do not exist for large regions, so regional assessments frequently devote significant resources to spatial data development. Remote sensing and GIS technologies have made it possible to assemble spatial data bases of many kinds but the task is time consuming. It is important at the outset to identify the boundaries of the area, and the type and spatial resolution of information needed. Not all scale and resolution questions can be answered in the planning stages, however. Some scale issues cannot be dealt with until ecological response models are developed and until fundamental biophysical data sources are obtained and evaluated. For example, while high resolution satellite imagery (e.g., 25 m Landsat TM imagery) and Digital Elevation Models (DEM's) at 30 and 10 m may be available for large areas, they may have a coarser or finer resolution than is needed by the biophysical models. Matching data needs with data acquisition is an interactive process given technological, time, and budget constraints.

We used a method (Ohmann and Gregory 2002) similar to the "most similar neighbor method" (Moeur and Stage 1995) to map forest structure and composition across all ownerships. Multivariate, direct analysis (Ter Braak 1986) is used to quantify relations between tree species and structure on inventory plots and remotely sensed and other spatial data such as climate and topography. Each pixel is then assigned the most similar inventory plot based on the multivariate relationships. The method has the following advantages for spatial simulation: complete tree lists, which are required by the stand simulation models, are assigned to each pixel, and the ecological variability of the tree lists (inventory data) is maintained in the spatial model (i.e., covariance structure and range of variation).

In addition to the vegetation data, we also needed digital elevation models, streams, roads and land use, all of which required additional development to make them suitable for our use. We still lack an adequate road layer for the region.

LANDSCAPE PROJECTIONS

Landscape simulations are central to assessing the long-term implications of current forest policies and/or developing new ones. We developed a landscape simulator LAMPS (LAndscape Management and Policy Simulator) (Bettinger and Lennette 2002) to project potential future conditions (Figure 3) but had to solve six problems to do so:

1. Estimating initial conditions consistent with data requirements of forest dynamics models (Ohmann and Gregory 2002).

2. Creating a spatial structure over various domains of scale important to management and resource responses. Functional units in the simulation model are spatially hierarchical ranging in size from a single 25-m pixel to millions of ha (Table 3).

3. Characterizing Landowner Behavior. To simulate forest management behavior, we segregated landowners into four groups: federal, state, forest industry, and nonindustrial private landowners. Other landowners, such as counties, were put into one of these groups based on whose management practices their management most closely resembled.

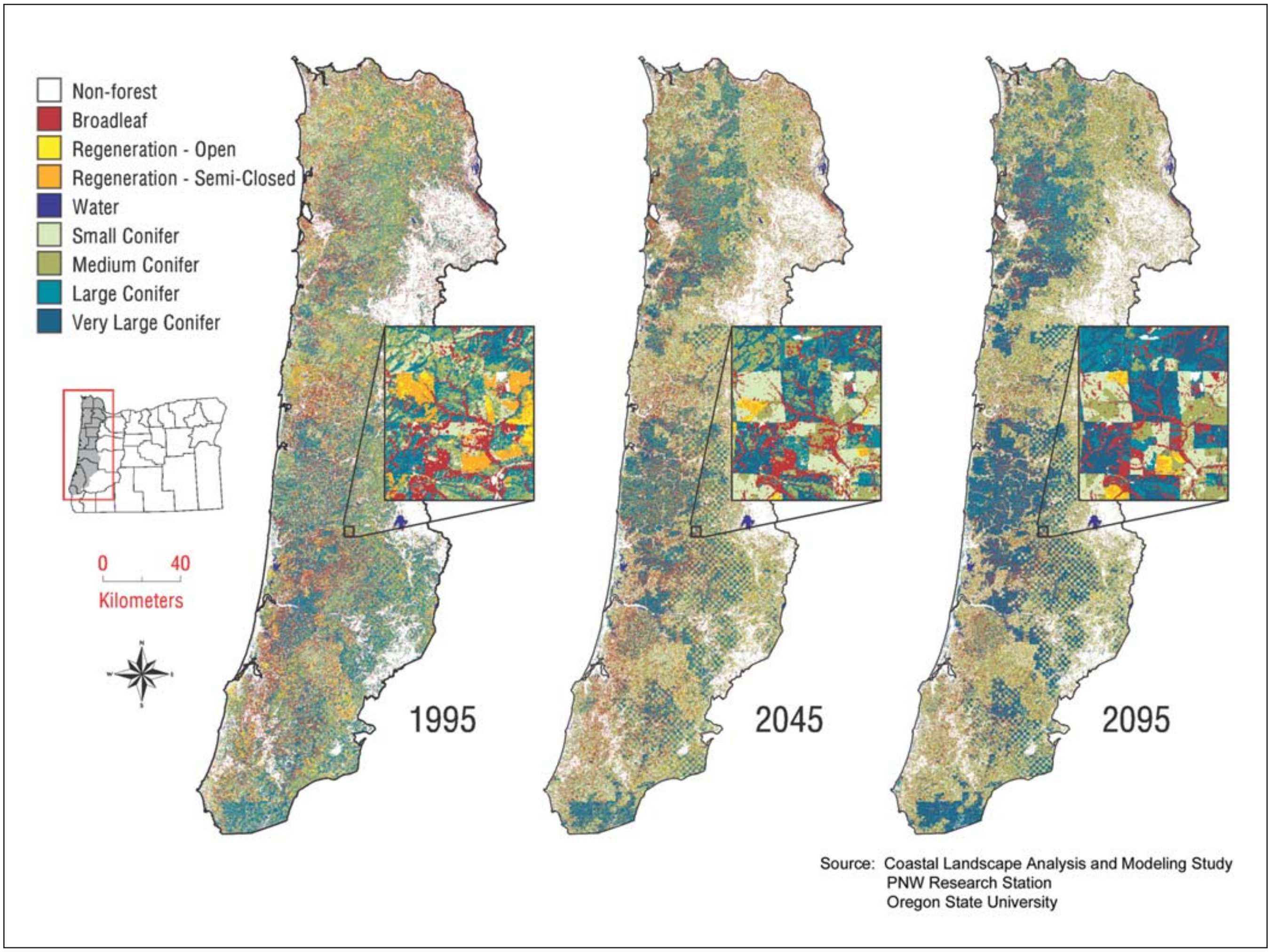

Figure 3—Simulation of changes in forest size classes for 1995-2095 under current policies using the LAMPS model.

Table 3—Hierarchy of spatial units used in LAMPS model

Spatial unit	Size range	Criteria
Basic simulation unit (BSU)	0.06 ~ 0.75 ha	uniformity of vegetation
Parcel (cutting unit)	4 ~ 20 ha	uniformity of ownership and topography
Harvest block	4 ~ 50 ha Depending on ownership	Aggregation of adjoining parcels with relatively high timber value
Land allocation	4 ~ 1000’s ha	Land owner plans
Ownership	4 ~ 10,000’s ha	Ownership patterns

We then developed a digital map of the management emphases of different owners in terms of their management goals, potential activities undertaken to achieve these goals, and the constraints on these actions (Figure 1). For federal landowners, as an example, we recognized areas where harvest is prohibited, areas where harvest is allowed only to achieve ecological objectives, and areas where ecological objectives are the primary goal and timber harvest is the secondary goal, based on the Northwest Forest Plan. As another example, we segregated forest industry lands into areas where timber production was the primary goals (upland areas) and areas near streams where timber harvest is constrained to achieve basal area levels required under the State Forest Practices Act (State of Oregon 1999).

For each landowner, we estimated the likely management intensities (level of investment) that would be used within each management emphasis from surveys (Lettman and Campbell 1997; Lettman 1998a, 1998b) and interviews with representatives from the different landowner groups. Although we assumed all landowners planted their stands after harvest; intensity of precommercial thinning, commercial thinning, and fertilization varied among landowners.

Once we estimated management intensity for each landowner, we estimated the size, and spatial pattern of activities within the different management emphases, especially regeneration harvest. The size distribution of clearcuts on private lands came from recent history (Cohen et al. 2002). The size distribution of regeneration harvests on state lands, on the other hand, is a by-product of the goal of maintaining a size distribution of interior forest leave-patches, called for in the new state plans (Oregon Department of Forestry 2001). The size distribution of regeneration harvests on federal lands reflects the relatively small areas that fall outside the reserves. In addition, clear-cut placement on all lands is controlled so that clearcuts cannot occur in adjacent patches until a specified period of regrowth transpires.

4. Account for natural disturbances. Incorporating natural disturbances into the model is difficult and we did so sparingly. Although terrestrial disturbances from wildfires is an important natural process, they are not included in the current version of the simulation model. Fire intervals are long, over 200 years, (Wimberly et al. 2000) and difficult to predict especially with fire control policies. Floods, landslides, and debris flows are critical drivers of stream habitat and are a focus of finer-scale modeling efforts nested within the larger scale model. We also simulate stochastic small patch disturbances (0.06 to 0.75 ha in size) from a variety of sources including wind and pathogens. The finest scale gap disturbances (<0.6 ha) are incorporated into the stand-level models.

5. Estimate stand growth and succession. We use a growth and yield model (ORGANON) [Hann et al. 1995] and an ecological succession model (ZELIG) [Urban et al. 1999] to project the development of forest stands across the entire assessment area. The growth and yield model is used for forest management regimes characterized by young stands on short rotations (<80 years) and intensive forest management. The ecological succession model is used for management where stands are grown on longer rotations or allowed to grow without harvest or manipulation until stochastic disturbances occur. These models are run non-spatially on every combination of stand types (inventory plots) and management regimes. Results of each projection are stored in a lookup table used in the landscape simulations.

6. Schedule management activities. We simulated forest management activities by scheduling them in accordance with management intentions. For forest industry owners, who historically have produced a relatively even amount of timber volume every year across owners, we can use an "even-flow" constraint to define how much industry volume is harvested in each period. At the start of the modeling process, logging costs are defined and slope classes are used to determine if cable or ground-based systems will be used on each parcel.

   The potential harvest volume and log size is determined for each parcel and its value is then determined by subtracting logging, sale preparation and road maintenance costs from the potential harvest revenue. Where economic income is a high priority, parcels with the highest economic values are selected for first harvest and are used as seeds for creating larger harvest blocks ranging up to 19.8 ha.

DETERMINING ECOLOGICAL EFFECTS

Scientifically-based, ecological measures and indicators are critical parts of policy assessments. However, unlike economic measures, we typically lack comprehensive measures of ecological response and socioeconomic values of biological diversity helpful for informing policy debates on large spatial scales (Norton 1998). Generally, biodiversity indicators for regional assessment are developed through expert judgment based on synthesis of general habitat descriptions or scattered empirical habitat relationship studies.

Table 4—Dimensions and characteristics of integration in CLAMS

Dimension	Characteristics and issues
Scope and focus of project	Conceptual model of states, outputs and linkages and externalities
Spatial	Location, spatial resolution, strata, translations across scale, extrapolation to other areas
Temporal	Horizon, time steps, history, future projections, duration
Disciplinary	Language, scale linkages, problem focus science questions vs. policy questions; least common denominator problem
Technological	Formats, software compatibility/flexibility, capacity, display capability, user friendliness, data quality
Social—team level	Trust; team identity and common vision; motivation, leadership, communication, scientist availability and patience, research support
Social—user/stakeholder	Need; trust, communication, understanding, expectations, feedback
External communications and feedbacks	Audiences: scientific, resource management; political, policy; publics; scientific, policy and public review, What are common denominators of results that transcend audience?
Institutional	Funding; reward system; Identifying clients and users.

Measures of biological diversity in forests fall into three broad classes: species/populations; communities based on broad classes of vegetation; and ecosystem and landscape measures that deal with patterns and processes (Hunter 1990; Noss 1990; Franklin 1993; Silbaugh and Betters 1995). We use all three classes.

Species/population—We focused our efforts on 30 focal species based on a variety of criteria. For each species, we develop a habitat suitability index based on stand and landscape level features. We focus primarily on habitat because of the lack of data to develop population viability models. We have developed these habitat models using individual habitat components (e.g., density of large trees or snags), rather than broad vegetation classes (e.g., early successional or old-growth) to make them more sensitive to different silivicultural practices (McComb et al. 2002).

Community level—We use species groups and total community measures rather than single species and then associate them with vegetation classes (e.g., early successional, late successional), which are mapped (Carey et al. 1999; O'Neil et al. 2000). These multi-species approaches can bridge the gap between single species and ecosystem/landscape approaches.

Ecosystem/landscape level—In this approach, abundance, distributions, and spatial pattern of fine-scale habitat elements (e.g., snags and old-growth trees) and coarse-scale community and ecosystem types form the criteria for assessing current and future conditions (Haufler 1994). In addition, processes such as disturbance regimes can be evaluated in terms of how much current disturbance regimes differ from past regimes (Landres et al. 1999; Wimberly et al. 2000).

INTEGRATION

Integration of diverse disciplines is a critical challenge in regional assessments of natural resources (Clark et al. 1999). Not all efforts require highly integrated studies, but management problems are becoming increasingly complex and multidimensional. Policy makers often must find ways to balance a wide range of divergent interests. The process of pulling together multidisciplinary assessments is typically a large undertaking. High levels of integration of the parts require considerable time and resources (Bettinger and Boston 2001; Cohen and Bailey 1997).

In the CLAMS effort we recognize that integration efforts must occur in many dimensions of the study (Table 4). The general integration framework is set by the conceptual model, but many dimensional details and problems remain. For example, in the spatial dimension, study area boundaries, minimum mapping units and summary strata must be acceptable to all disciplines and compatible with analysis and display technologies.

SCIENCE IN A PUBLIC POLICY ENVIRONMENT

The role of environmental science and technology in public policy issues is essential but controversial (Meffe and Viderman 1995; Baskerville 1997; Nelson 1999; Kaiser 2000). It is a major challenge to develop scientific and technical information that facilitates solutions to problems rather than inhibiting or limiting the solution space. In the past, the scientific models were too narrowly defined to deal with broad and complex policy issues. Efforts based on an approach of using complex models to provide *the* answer were not successful (McLain and Lee 1996) because stakeholders did not understand or trust the models. Yet, science has an important role to play in regional assessments (Swanson and Greene 1999). The problem often boils down to two questions: How much of the scientific process can be incorporated into policy issues?; and What is the role of science and scientists and technology in public policy debates?

Policy assessments typically contain some elements of the scientific process, but not all. For example, hypotheses about policy outcomes may be stated and "tested" with analyses or models, but the uncertainty and error in the models is frequently unknown. Subsequent testing of vital assumptions and long-term monitoring of the effectiveness of a chosen policy typically does not occur. It is often not clear how the level of error that is relevant to management differs from the error standards in scientific studies (Lee 1993).

The role of science and scientists in policy debates and assessments is evolving toward a "civic science" (Lee 1993) in which the scientific process is not only more visible to the public but has political support, is meshed with political pragmatism, and involves policymakers and stakeholders in identifying alternatives to study, or specifying parameters of the models to be tested. The value of scientific models in assessments is increased if they are used to help set frameworks or forums for shared learning (McLain and Lee 1996). Scientists can also take on more of an advocacy role for a particular policy action, however, this is controversial and many scientists who do this qualify their opinions as reflecting their personal values (Kaiser 2000). A less controversial advocacy role is to promote the consideration of scientific knowledge in the debates. Once a policy is implemented, scientists can provide a "science consistency check" to evaluate how well managers are implementing the policy in ways that are consistent with the scientific findings and recommendations (Mills and Clark 2001).

INSTITUTIONAL CHALLENGES

Institutional support is often a major hurdle to conducting large integrated anticipatory assessments. Funding is the obvious hurdle but a less obvious hurdle is what institution(s) should provide people whose job is to conduct these types of analyses and interact with interested parties about the results. Without public or private funding, large integrated and costly assessments will not happen. Most competitive funding sources are not well-suited to undertake long-term and risky integrated research projects that are closely tied to policy/management issues.

In CLAMS, our funding comes primarily from federal and state research and management agencies involved in forest policy crises who see the value of this type of work. Consequently, we have a level of funding (about $750,000/year) well beyond the typical competitive grant. However, when distributed across 10-12 scientists, this is not much support on a per scientist basis. We rely heavily on tenured university professors and U.S. Forest Service research scientists who have the freedom and support to work on integrated assessments.

A more formidable institutional challenge is transporting the processes and approach to address new questions or examine other geographic areas. For example, who will encourage use of the models or make the changes necessary to successfully implement them and modify them to address new questions (Bettinger 1999). These are institutional problems that are not yet solved. Other hurdles are the problems of working across institutional cultures and reward systems. For example, it is more difficult for assistant professors in universities to be team members of large projects that are slow to publish and publish large multi-author studies, than for senior faculty or agency scientists.

CONCLUSIONS

The process of developing tools and information to assess the effects of environmental policies and inform the debates about sustainable land management over multiple owners is complex and challenging. The challenges include definition of the problem and development of a conceptual model; identification of policies and policy makers; development of spatial information about regions; development of spatial and temporal projections of landscapes; development of measures of ecological effects; integration; and involvement of science in a public policy environment. Our experience shows while these challenges can be met, projects such as this require a combination of suitable institutional support; environmental crises that motivate policy makers to support research, and tools and information to help visualize and analyze the problem, and potential solutions. The continued success of the CLAMS project rests upon having met these challenges, but it also must rely on patience (Lee 1993) and the ever-changing role and acceptance of science in public debates.

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EFFECTS OF STREAMSIDE FOREST MANAGEMENT ON THE COMPOSITION AND ABUNDANCE OF STREAM AND RIPARIAN FAUNA OF THE OLYMPIC PENINSULA

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ABSTRACT

We conducted a retrospective study of the influence of timber harvest on vertebrate assemblages in and adjacent to small streams on the Olympic Peninsula, Washington, 1996 to 1999. Sixty-two sites were selected, with adjacent sites representing old-growth conditions and five site conditions resulting from silvicultural treatments: young, mature, thinned mature, buffered old, and buffered mature sites. To determine site-level patterns of species composition and structure, we developed an integrated sampling design targeting specific vertebrate taxa along and perpendicular to the axis of the stream. We also characterized the vegetation and habitat characteristics of streams and streamside buffers. Instream and near-stream amphibians were the best indicators of stream and streamside habitat condition, probably because of their low mobility, tendency to reside in or return to specific locations, lengthy larval period, ability to populate beyond obstacles to movement, and narrow limits of environmental tolerance. Small buffers contributed to site structural diversity, but fish communities were highly variable and not strongly related to buffer width. Effects of forest management on headwater stream and riparian-associated vertebrates were often difficult to assess, probably because other factors such as local geomorphic features, weather patterns, long-term disturbance histories, and characteristics of surrounding landscapes obscured these patterns.

KEY WORDS: Amphibians, birds, fish, mammals, riparian, buffer.

INTRODUCTION

Management of streamside vegetation is a major component of the Northwest Forest Plan for federally managed lands (FEMAT 1993) and plans for management of state and private lands [e.g., Washington State's Habitat Conservation Plan (WDNR 1997)]. One of the fundamental concepts behind the conservation strategy embodied in the Northwest Forest Plan and other plans is the importance of riparian habitat buffers in providing functional stream and streamside ecosystems. These buffers, as proposed by the scientific analysis team (Thomas et al. 1993) and FEMAT (1993) are meant to conserve habitat conditions not only for at-risk stocks of fish but also a diverse range of riparian-associated organisms including lichens, liverworts, fungi, vascular plants, invertebrates, and vertebrates (USDA and USDI 1994). The size of these buffers, and their placement on all stream orders including headwater and intermittent streams, has resulted in the reservation of a large portion of the landscape, ranging from 30% to 70% of the federal land base (USDA and USDI 1994). Although the size of these buffers was determined from a thorough review of existing literature, little field data were available comparing the efficacy of alternative buffer designs. Understanding relations between biodiversity and watershed function and condition may lead to opportunities to better balance commodity production and protection of streamside habitat.

As a preliminary effort toward better understanding the importance of riparian buffers in providing habitat for associated organisms, we initiated a retrospective study of responses of aquatic and terrestrial organisms to various streamside management options. Experimental manipulation of riparian systems, which would evaluate conditions

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both before and after treatment, is a preferable approach, but such treatments were not possible on federally managed lands. Although we still hope to initiate such experimental work, we believe a retrospective approach to past management practices is a necessary precursor to a manipulative study.

METHODS

Sixty-two study sites were located on the west and south sides of the Olympic Peninsula, Washington, on state, federal, and private lands outside the Olympic National Park (Figure 1). A study site included a 300-m stream reach plus the surrounding stands. We chose 300 m as our standard because we suspected a shorter reach would likely reflect the effects of upstream influences rather than the channel and adjacent stands. Streams were usually first to third order and less than 3 m across the wetted portion. We selected areas representing six site conditions:

1. Old sites: unmanaged with intact forest on both sides of the stream.
2. Buffered old sites: old forest with adjacent clearcuts leaving buffers of 10 to 30 m.
3. Mature sites: second-growth stands that were 35 to 100 years old with no adjacent harvest.
4. Thinned mature sites: intact second growth with commercial thinning.
5. Buffered mature sites: second growth with adjacent clearcuts leaving 10- to 30-m buffers of second-growth forest.
6. Young sites: cutover sites with no intact buffers, generally up to 35 years old.

Site types were not equally distributed across the study area because of differing ownerships and management practice histories. Bisson et al. (2002, in this preceedings) offer more details on site types and buffers.

Our approach was a retrospective analysis that examined existing forest condition resulting from past management practices with different intervals since logging, with and without streamside buffers. The null hypothesis was that there would be no association between the relative abundance and species richness of small-stream vertebrates and the condition of the streamside forest. Acceptance of the null hypothesis would suggest that buffers of late-successional forest would not be needed to conserve populations of stream-dwelling or streamside vertebrates inhabiting small streams. Rejection of the null hypothesis would indicate that certain riparian treatments do not support populations of the native vertebrate fauna.

The overall sampling design was an integrated approach to sample common, readily detectable vertebrate species in the stream, near-stream, and upslope environments. Our design was a broad approach to sample a variety of taxa rather than intensively sample a few specific sites; because of this, some taxa that require more specialized sampling were not captured frequently enough for analysis. To accommodate spatial variability, sampling was conducted along and perpendicular to the axis of the stream. All sampling was in or adjacent to the 300-m stream reach. In-channel sampling was conducted for fishes and amphibians, whereas above-channel sampling was performed for amphibians, birds, and mammals. Not all sampling methods were conducted at each site, owing in part to the limitations of specific sampling methods. Bisson et al. (2002, in this proceedings) discuss stream habitat characterization and fish sampling in detail, so that will not be repeated here, except to say that fish sampling was a habitat-based electrofishing method.

Two methods were used to sample amphibians: instream belt surveys and streambank surveys. Instream surveys targeted stream-dwelling forms: Cope's giant salamander (*Dicamptodon copei*), Olympic torrent salamander (*Rhyacotriton olympicus*), and tailed frog (*Ascaphus truei*). Instream surveys consisted of thirty 1-m long belts spaced at 10-m intervals per site. The belts spanned the area between the wetted edges of the main channel, plus all braids and seeplike habitats. The basic method is an intensive search and seine technique (Bury and Corn 1991; Jones and Raphael, in review[5]) during summer low flow. Streambank surveys targeted the western red-backed salamander (*Plethodon vehiculum*), Van Dyke's salamander (*P. vandykei*), ensatina (*Ensatina eschscholtzii*), and Olympic torrent salamander. Most streambank surveys were conducted during spring, but some were conducted during fall. They consisted of a series of three transects, aligned at every third instream belt, that went upslope from the wetted edge of the stream to 35 m above the valley (inner gorge) wall, or treeline, if a distinct valley was absent. All potential cover objects within transects were searched for

[5] Jones, L L.C.; Raphael, M.G. [In review]. Systematic spotlight survey: a non-destructive method for detecting stream-associated amphibians. Herpetological Review. On file with Martin G. Raphael, Olympia Forestry Sciences Laboratory.

amphibians. In both methods, animals were captured, then identified, measured, weighed, and released. Seeplike habitats were sampled by both methods, which is why the Olympic torrent salamander was a target species for either method.

Birds and mammals were sampled along transects that ran parallel to the axis of the stream. We established two transects along each stream reach, one close to the stream (generally within 20 m) and one upslope, spaced 100 m apart. In this paper, we report only results from the near-stream transect. Transects began at a point perpendicular to the first belt and ended at a point perpendicular to the last. For birds, there were four sampling stations on each transect, spaced at 100-m intervals. Each station was visited three to six times during the spring survey period. We used a variable-radius, circular plot method (Reynolds et al. 1980). Observers recorded all birds detected at or between stations, primarily from aural detections. They recorded species, distance, and direction from the station. Small mammals were trapped with Sherman live-traps. Two traps were placed at 10-m intervals along transects for a total of 62 traps per transect. Traps were baited with oats, molasses, and peanut butter, and checked for five consecutive days. Observers wore protective gear, including goggles, gloves, and high efficiency particulate air (HEPA)-filter respirators to guard against epizootic pathogens. Mammals were captured, identified, marked, measured, weighed, and released. The deer mouse (*Peromyscus maniculatus*) and Keen's mouse (*P. keeni*) were differentiated by range in tail length (Allard et al. 1987): we assigned adults with tails less than 96 mm to *P. maniculatus* and those with tails at least 102 mm to *P. keeni*. Subadults were not identified to species and were not included in results presented here. We will address the distribution, abundance, and morphological characteristics of this genus more thoroughly in a subsequent paper.

We used data from all sites in this paper. Detection indices were standardized for differences in effort. For consistency among fishes and amphibians, we computed an index of mean detections per 100 m^2. For in-channel data, fish detections were from electrofishing and amphibian data were from instream belt surveys, although each method often detected the other taxon. Because Olympic torrent salamanders were targeted by two methods, we included results from both methods. All transect data for streambank surveys were combined for each site. For birds and mammals, we used only the near-stream transects for comparison. We computed relative abundance of birds as total detections up to 50 m from the station per 10 station-visits. Because many of the forested buffers were less than 50 m wide, bird observations include individuals that could have been located in the buffer itself or in adjacent cutover forest. Mammals are reported as first captures per 100 net trap-nights. For fishes and amphibians, our comparisons addressed target species. For birds and mammals, our comparisons addressed species with greater than 20 detections.

In this paper, we emphasize site- and reach-level variables, whereas a companion paper (Bisson et al. 2002, in this proceedings) reports within-stream and watershed attributes. For consistency, we will use onsite habitat variables from our stream characterization surveys (Bisson et al. 2002, in this proceedings). Our principal nominal data include site type, dominant parent rock type (igneous, sedimentary, unconsolidated glacial), and stream classification (cascade, step-pool, pool-riffle, plane-bed) (Montgomery and Buffington 1993). All nominal data were compared nonparametrically, as most comparisons had non-normal distributions or heterogeneous variances, or both. For comparisons of measures of relative abundance in relation to categorical attributes of sites (e.g., forest condition or parent rock), we computed the Kruskal-Wallis *H* statistic, which is based on mean ranks. For continuous variables, including stream width, mean stream gradient (measured along the reach), and elevation (at first belt), we computed nonparametric correlations of relative abundance of each species and the site attribute by using Spearman's *rho*. To compare species richness among sites, we counted all species encountered at each site then computed means across all sites within each of the six site conditions. We used a hierarchical cluster analysis based on Euclidian distances to assess similarity of bird communities among the six site conditions. For this analysis, we first computed mean abundance of each species in each of the six site classes and then computed Euclidian distance from mean abundance. Data were analyzed with Statistical Package for the Social Sciences (SPSS)[6], version 10.01. Tests were two-tailed, and we identified as significant those variables whose association with vertebrate abundance resulted in a Type 1 error of less than 10 percent.

[6] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

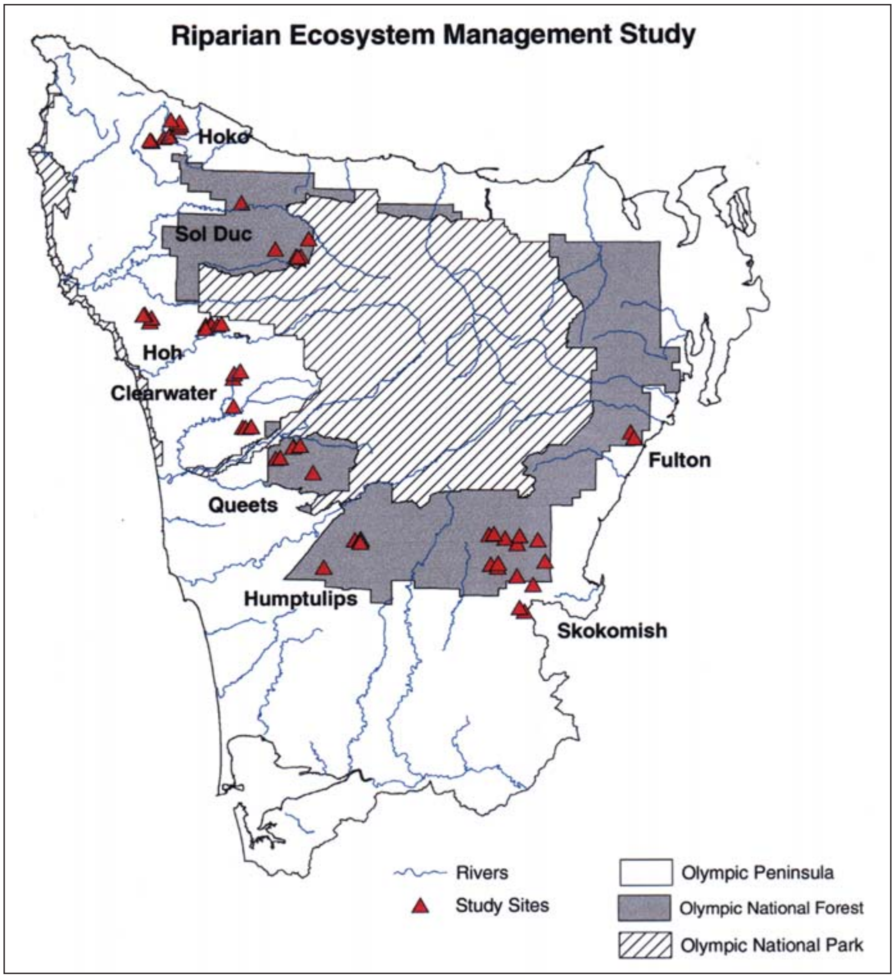

Figure 1—Study sites on the Olympic Peninsula, Washington. Names of major river basins in which study sites occurred are given.

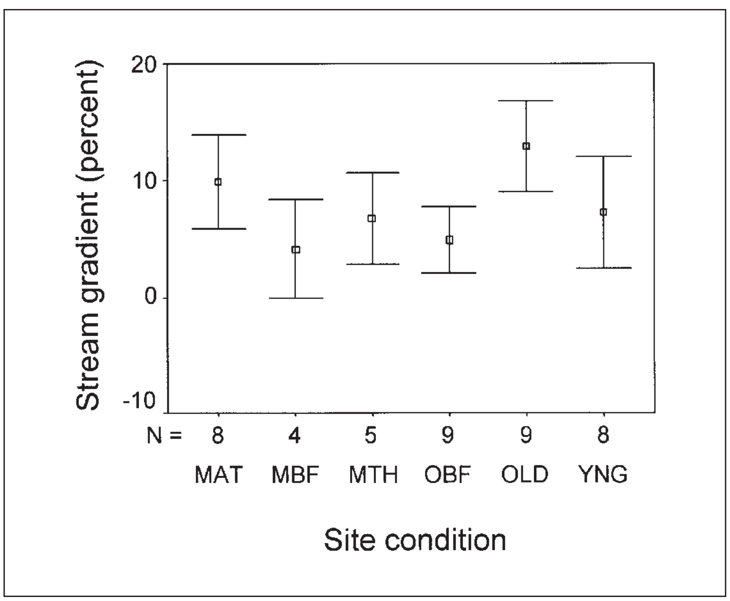

Figure 2—Comparison of stream gradient among site conditions, Olympic Peninsula, Washington, 1996–1999. Values represent means and 95 percent confidence intervals; numbers of sites are indicated on x-axis. Abbreviations are MAT (mature sites), MBF (buffered mature sites), MTH (thinned mature sites), OBF (buffered old sites), OLD (old sites), and YNG (young sites).

Table 1—Number of study sites, capture results, and sampling effort for each primary sampling method, Olympic Peninsula, Washington, 1996–1999

Method	Number of study sites	Total number of species	Number of detections	Total effort
Aquatic amphibians	38	6	1,909	1,032 1-m belts; 2 082 m^2
Terrestrial amphibians	41	11	1,687	42 835 m^2 area search
Birds	52	70	2,815	1,164 plot visits
Mammals	49	17	768	13,082 trapnights
Fishes	52	5	1,403	17 660 m^2 search

RESULTS

We established 62 sites distributed within the Olympic Peninsula, generally at elevations below 700 m (Figure 1). Sample sizes of the six forest conditions were old forest, n = 13 sites; buffered old forest, n = 10 sites; mature forest, n = 15 sites; buffered mature forest, n = 8 sites; thinned mature forest, n = 6 sites; and young forest, n = 10 sites. Site conditions differed among these sites: old forest sites differed from the managed sites; they had smaller streams with steeper gradients (Figure 2).

The number of sites we sampled ranged from 38 for stream amphibians to 52 for fishes (Table 1). Sample sizes of each site condition for each taxonomic group are summarized in Table 2. Responses of major groups of organisms, and species within these groups, were highly variable with respect to site conditions (Table 2). Relative abundance of none of the fish or mammal species differed significantly among site conditions (summarized with other stream attributes in Table 3). Relative abundances of about half of the species of birds and terrestrial amphibians differed significantly among site conditions; abundances of all of the stream-dwelling amphibians differed significantly among site conditions.

Although abundance of fishes did not differ significantly by site type, they differed among all other stream attributes except stream width (Tables 3 and 4). Abundance of fishes also differed significantly by elevation. Parent rock appeared to be more important for fishes than for other vertebrate classes.

Among both stream-dwelling and terrestrial amphibians, species were most abundant at old-forest sites; abundance was lowest in young sites (cutover sites with no buffer) and intermediate in mature sites, including buffered and thinned conditions (Table 2). Abundance of amphibians was generally lower in buffered sites versus unbuffered sites in each forest age class, but these relations are difficult to interpret because of confounding influences of elevation, stream width, and stream gradient (see below). However, Van Dyke's salamander was only detected in old and buffered old sites (with qualitatively higher densities in old), regardless of elevation and gradient. Van Dyke's and Olympic torrent salamanders were both associated with higher elevations and gradients (Table 4). In most cases, Olympic torrent salamanders showed similar patterns from both detection methods. However, some differences were probably because of the tendency of the terrestrial sampling method to detect adults (55%), which favor the water's edge, whereas most of the instream detections were larvae (70%), which are typically found in deeper water.

Responses of birds to forest conditions along streams were highly variable. Of the 20 species whose abundances differed significantly among site conditions (Table 2), a majority (13 species) reached their qualitatively highest abundance in mature sites with buffers. Mean number of species detected per site was also highest in mature sites with buffers; richness was similar among other site types (Figure 3). By using mean abundances of all common birds to compute similarities of avian communities among the six site types, we found that old forest, buffered old forest, and mature sites were most similar to each other; avian communities of buffered mature and young sites were also similar to each other; birds in mature thinned sites were least similar to any other site type (Figure 4).

Abundance of 21 of the 34 bird species was correlated with at least one of the physical stream features. Abundance of birds was generally greater at lower elevation sites with

Table 2—Mean detection indices of common vertebrates species in and near streams, by site condition, with χ^2 and P-values from Kruskal-Wallis tests, Olympic Peninsula, Washington, 1996–1999. (continued on next page)

Taxonomic class and species	Old	Buffered old	Mature	Buffered mature	Thinned mature	Young	χ^2	P
Fishes (n = 52 sites):	(12)[a]	(10)	(12)	(4)	(5)	(9)		
Cutthroat trout								
Oncorhynchus clarki clarki	1.24	9.30	6.82	7.85	7.14	5.71	8.16	.15
Coho salmon								
Oncorhynchus kisutch	2.91	.81	2.13	0	0	0	2.87	.72
Coastrange sculpin								
Cottus aleuticus	1.92	1.55	6.00	0	9.28	.91	6.53	.26
Torrent sculpin								
Cottus rhotheus	1.13	.24	16.67	.59	10.31	2.21	2.52	.77
Amphibians, stream (n = 38 sites):	(10)	(4)	(10)	(3)	(4)	(7)		
Tailed frog								
Ascaphus truei	96.87	5.81	32.07	0	0	8.90	12.79	.03
Cope's giant salamander								
Dicamptodon copei	59.31	9.60	38.72	5.76	0	18.97	16.70	.01
Olympic torrent salamander								
Rhyacotriton olympicus	22.01	0	41.17	0	0	5.22	13.74	.02
Amphibians, terrestrial (n = 41 sites):	(11)	(6)	(9)	(4)	(4)	(7)		
Olympic torrent salamander	.73	.02	.11	.11	0	.06	14.08	.02
Ensatina								
Ensatina eschscholtzii	.13	.07	.09	.23	.20	0	6.37	.27
Van Dyke's salamander								
Plethodon vandykei	.56	.09	0	0	0	0	18.50	<.01
Western red-backed salamander								
Plethodon vehiculum	4.10	2.11	3.89	1.88	2.61	1.05	7.68	.18
Birds (n = 52 sites):	(10)	(9)	(11)	(8)	(6)	(8)		
Blue grouse								
Dendragapus obscurus	0	.09	.08	.16	.14	.05	1.57	.90
Band-tailed pigeon								
Columba fasciata	.08	0	0	.16	0	.05	9.44	.09
Vaux's swift								
Columba fasciata	.29	.32	0	.21	.14	.07	4.58	.47
Rufous hummingbird								
Selasphorus rufus	.46	.05	.37	1.30	.28	.27	11.31	.05
Hairy woodpecker								
Picoides villosus	.21	.28	.19	.63	1.25	.10	10.43	.06
Northern flicker								
Colaptes auratus	.04	0	.04	.05	0	0	2.58	.77
Willow flycatcher								
Empidonax traillii	0	0	0	.05	0	0	5.50	.36
Hammond's flycatcher								
Empidonax hammondii	.04	.14	.08	0	0	0	4.51	.48

Table 2 (continued)—Mean detection indices of common vertebrates species in and near streams, by site condition, with χ^2 and P-values from Kruskal-Wallis tests, Olympic Peninsula, Washington, 1996–1999. **(continued on next page)**

Taxonomic class and species	Old	Buffered old	Mature	Buffered mature	Thinned mature	Young	χ^2	P
Pacific-slope flycatcher								
Empidonax difficilis	5.31	5.32	4.95	5.89	5.90	3.01	4.94	.42
Gray jay								
Perisoreus canadensis	0	.09	.04	0	.28	0	3.64	.60
Steller's jay								
Cyanocitta stelleri	.17	.56	.16	1.00	.07	.45	9.88	.08
Chestnut-backed chickadee								
Poecile rufescens	1.86	2.45	3.48	2.14	5.97	.83	6.72	.24
Brown creeper								
Certhia americana	.42	.65	.11	.10	.14	0	11.12	.05
Winter wren								
Troglodytes troglodytes	7.82	7.08	7.77	6.35	10.49	3.96	9.57	.09
American dipper								
Cinclus mexicanus	.07	.37	0	.21	0	.78	15.4	.01
Golden-crowned kinglet								
Regulus satrapa	1.78	2.64	3.70	.63	10.63	.98	23.66	<.01
Swainson's thrush								
Catharus ustulatus	.13	.51	.57	1.61	.35	1.16	16.60	.01
American robin								
Turdus migratorius	.25	.51	.15	1.35	.63	.87	9.70	.08
Varied thrush								
Ixoreus naevius	1.01	.69	.38	.63	.14	.78	7.517	.19
Cedar waxwing								
Bombycilla cedrorum	0	.14	.08	.89	0	.21	7.22	.21
Warbling vireo								
Vireo gilvus	0	.19	0	.31	0	.69	11.54	.04
Hutton's vireo								
Vireo huttoni	0	.09	.19	.47	.49	.37	6.81	.24
Orange-crowned warbler								
Vermivora celata	0	0	0	.26	0	0	23.35	<.01
Black-throated gray warbler								
Dendroica nigrescens	0	0	.27	.05	.56	.10	6.32	.27
Hermit warbler								
Dendroica occidentalis	0	.09	.11	0	.07	0	4.55	.47
MacGillivray's warbler								
Oporornis tolmiei	0	.09	0	.73	.21	.16	16.67	.01
Wilson's warbler								
Wilsonia pusilla	0	.37	.42	2.19	.14	1.13	29.24	<.01
Western tanager								
Piranga ludoviciana	0	.28	.14	1.04	.21	.05	10.53	.06
Black-headed grosbeak								
Pheucticus melanocephalus	.10	.09	0	.31	0	.10	14.23	.01
Spotted towhee								
Pipilo maculatus	0	0	0	.68	.07	.05	21.37	<.01
Song sparrow								
Melospiza melodia	0	.14	0	2.56	.14	1.13	20.65	<.01

Table 2 (continued)—Mean detection indices of common vertebrates species in and near streams, by site condition, with χ^2 and P-values from Kruskal-Wallis tests, Olympic Peninsula, Washington, 1996–1999.

Taxonomic class and species	Old	Buffered old	Mature	Buffered mature	Thinned mature	Young	χ^2	P
White-crowned sparrow								
Zonotrichia leucophrys	0	0	0	.16	0	0	11.22	.05
Dark-eyed junco								
Junco hyemalis	.04	.46	.18	.63	.28	1.04	16.30	.01
Red crossbill								
Loxia curvirostra	.04	.28	.06	.21	0	.10	6.26	.28
Mammals (n = 49 sites):	(10)	(8)	(10)	(8)	(5)	(8)		
Montane (dusky) shrew								
Sorex monticolus	.28	0	.44	.06	.25	.27	7.809	.17
Trowbridge's shrew								
Sorex trowbridgii	.43	.31	.66	.43	.72	.63	2.68	.75
Deer mouse								
Peromyscus maniculatus	.86	.31	1.26	.69	.41	.40	2.07	.84
Forest deer mouse								
Peromyscus keeni	3.45	3.23	5.11	3.42	5.06	2.05	3.88	.57
Pacific jumping mouse								
Zapus trinotatus	.04	.11	.23	.17	.21	.58	10.95	.05

[a] Sample sizes (numbers of sites) are shown in parentheses for each taxonomic class.

Table 3—Percentages of species by taxonomic group having a significant Spearman *rho* or Kruskal-Wallis χ^2 ($P \leq 0.10$) for relation of relative abundance to stream and site attributes, Olympic Peninsula, Washington, 1996–1999

	Attribute					
Species class	Site condition	Stream width	Gradient	Parent rock	Elevation	Stream classification
Fish	0	0	50	50	75	75
Amphibians:						
Stream	100	67	100	33	100	100
Terrestrial	50	0	50	0	50	25
Birds	59	15	26	21	35	6
Mammals	20	40	40	20	60	20

flatter gradients (Table 4). The only exception among those species with significant correlations was the American dipper (*Cinclus mexicanus*), which was more abundant in sites with steeper gradients and at higher elevations. The dipper was also more abundant in wider streams. This species is unique among the birds we sampled in being a true aquatic species that forages on aquatic organisms that it dives to obtain. The dipper was most abundant in cutover, young sites (Table 2).

Total small-mammal captures averaged 5.9 individuals per 100 trap-nights; mean captures did not differ among site conditions (Figure 5). We found no significant differences in relative abundance of the five common mammalian species among site conditions (all P-values > 0.10). Capture rates of four of the five species were correlated with physical stream features. Keen's mouse was more abundant in smaller streams at lower elevations. The deer mouse was also more abundant in smaller streams, but its

Table 4—Associations between species' relative abundance and site attributes using Spearman *rho* correlation or Kruskal-Wallis χ^2 analysis, Olympic Peninsula, Washington, 1996–1999 **(continued on next page)**

Class and species[a]	Elevation	Stream width	Stream gradient	Stream classification	Parent rock
Fishes (n = 52 sites):					
Cutthroat trout	-.29 (0.04)[b]		-.29 (0.04)	11.8 (<0.01)	
Coho salmon				5.78 (0.06)	
Coastrange sculpin	-.43 (<.01)			8.01 (.05)	8.59 (.01)
Torrent sculpin	-.30 (.03)		-.27 (.06)	7.37 (<.06)	
Amphibians, stream (n = 38 sites):					
Tailed frog	.53 (<.01)		.44 (<.01)	12.72 (.02)	9.6 (<.01)
Cope's giant salamander	.26 (.07)	.33 (.02)	.50 (<.01)	7.94 (.02)	
Olympic torrent salamander	.32 (.02)	-.46 (<.01)	.55 (<.01)	9.65 (<.01)	
Amphibians, terrestrial (n = 41 sites):					
Olympic torrent salamander	.27 (.09)		.46 (<.01)	7.1 (.07)	
Van Dyke's salamander	.29 (.06)		.35 (.03)		
Birds (n = 49 sites):					
Blue grouse					
Band-tailed pigeon					
Vaux's swift			-.28 (.07)		
Rufous hummingbird					5.22 (.06)
Hairy woodpecker			-.28 (.07)		
Northern flicker		-.26 (.10)			
Willow flycatcher					
Hammond's flycatcher					
Pacific-slope flycatcher		-.31 (.05)			
Gray jay					4.81 (.09)
Steller's jay					
Chestnut-backed chickadee	-.55 (<.01)				
Brown creeper		.28 (.07)			
Winter wren					
American dipper	.28 (.07)	.43 (<.01)			5.22 (.07)
Golden-crowned kinglet	-.25 (.10)				7.45 (.02)
Swainson's thrush	-.27 (.08)		.50 (<.01)	9.23 (.03)	
American robin	-.32 (.04)		-.35 (.04)		
Varied thrush					
Cedar waxwing					
Warbling vireo		.23 (.07)			
Hutton's vireo	-.53 (<.01)			6.60 (.09)	8.28 (.02)
Orange-crowned warbler	-.26 (.09)				
Black-throated gray warbler					
Hermit warbler					
MacGillivray's warbler			-.26 (.10)		
Wilson's warbler			-.36 (.02)		
Western tanager	-.32 (.04)				
Black-headed grosbeak	-.30 (.05)		-.33 (.03)		
Spotted towhee	-.36 (.02)				

Table 4 (continued)—Associations between species' relative abundance and site attributes using Spearman *rho* correlation or Kruskal-Wallis χ^2 analysis, Olympic Peninsula, Washington, 1996–1999

Class and species[a]	Elevation	Stream width	Stream gradient	Stream classification	Parent rock
Song sparrow	-.38 (.01)		-.28 (.07)		
White-crowned sparrow					
Dark-eyed junco			-.28 (.07)		
Red crossbill					
Mammals (n = 49):					
Dusky shrew	.24 (.09)		.25 (.09)		
Trowbridge's shrew					
Deer mouse		-.55 (<.01)	.29 (.07)	8.64 (.03)	
Forest deer mouse	-.51 (<.01)	-.54 (<.01)			6.75 (.04)
Pacific jumping mouse	-.26 (.07)				

[a] Only species with at least one significant association (P ≤ 0.10) are listed.
[b] P-values are indicated in parentheses.

abundance was not correlated with elevation or stream gradient. The dusky shrew (*Sorex monticolus*) was more abundant at higher elevations in steeper streams. Abundance of the Pacific jumping mouse (*Zapus trinotatus*) increased with lower elevations. Abundance of Trowbridge's shrew (*Sorex trowbridgii*) did not differ significantly with any of the physical attributes of streams.

DISCUSSION

We found that site condition did not have a strong effect on fishes or mammals. Among birds whose relative abundance differed among site conditions, most species reached qualitatively highest abundance in the buffered mature sites; one species, varied thrush (*Ixoreus naevius*), reached highest abundance in old, unmanaged sites. The relatively large number of bird species reaching highest abundance with buffered mature site conditions suggests that these sites offered a diversity of habitats, including large trees, brushy conditions, open ground, a forest edge, and a riparian to upland interface. These results indicate that fish, birds, and mammals (at least the more common species that were abundant enough to make valid comparisons) persisted in sites after logging whether or not buffers were present.

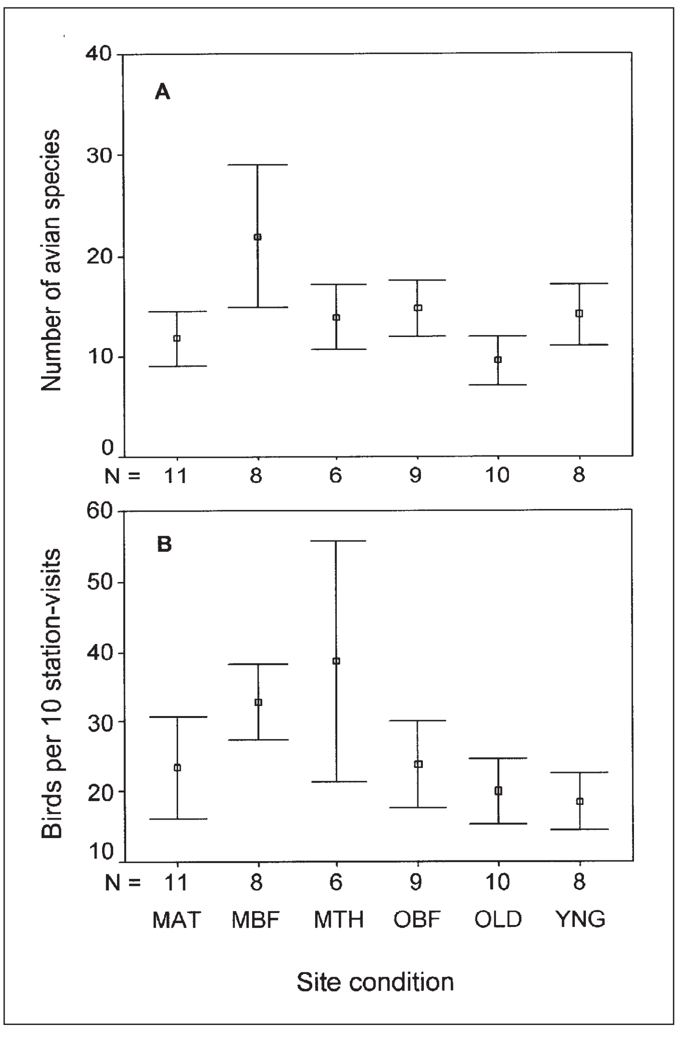

Figure 3—Mean numbers of species of common birds (A) and total abundance (B) among site conditions, Olympic Peninsula, Washington, 1996–1999. Values represent means and 95 percent confidence intervals. Abbreviations are MAT (mature sites), MBF (buffered mature sites), MTH (thinned mature sites), OBF (buffered old sites), OLD (old sites), and YNG (young sites).

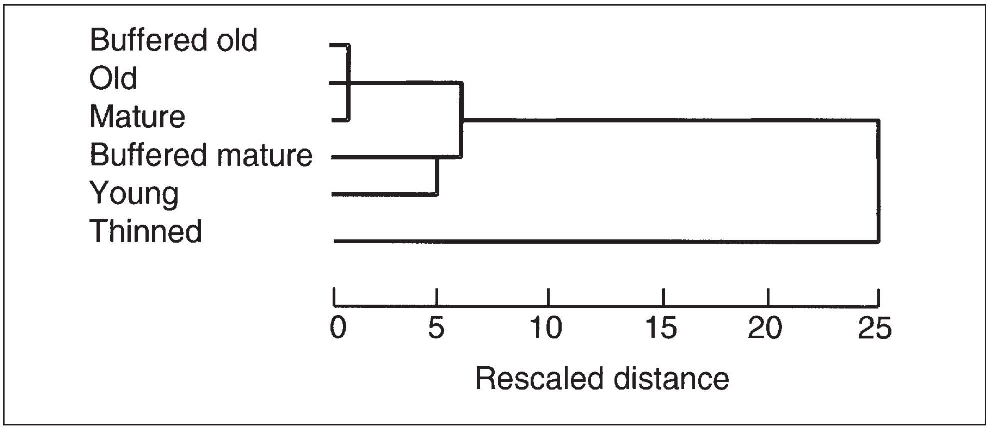

Figure 4—Dendrogram showing relative similarity of site conditions based on mean abundance of common birds, Olympic Peninsula, Washington, 1996–1999.

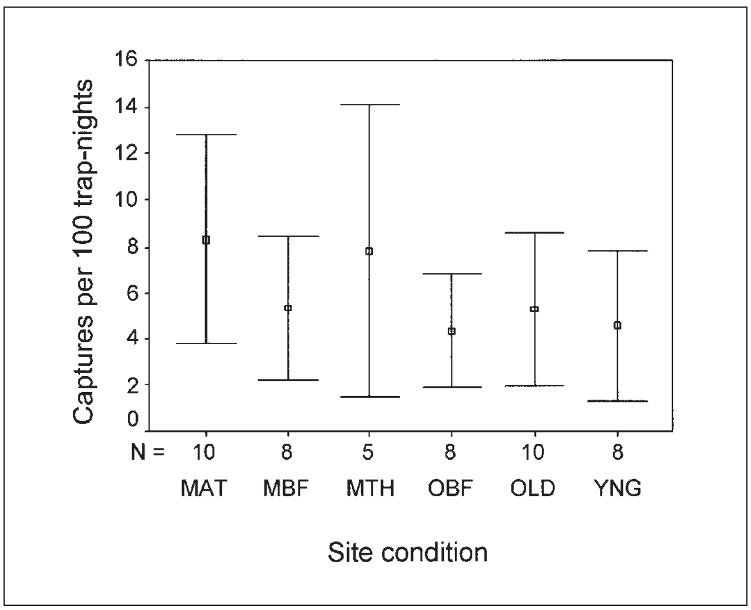

Figure 5—Mean total abundance (captures per 100 trap-nights) of small mammals among site conditions, Olympic Peninsula, Washington, 1996–1999. Values represent means and 95 percent confidence intervals. Abbreviations are MAT (mature sites), MBF (buffered mature sites), MTH (thinned mature sites), OBF (buffered old sites), OLD (old sites), and YNG (young sites).

Amphibians, in contrast, were responsive to differences in site condition, and all species were found in highest abundance in old sites. In all cases except Olympic torrent salamander (instream sample only) and ensatina (a terrestrial species that is associated with upland habitats), highest abundances were reached in old sites. Abundance of these species declined to lowest levels in young sites with no buffers. Abundance was intermediate in mature (second-growth) sites, suggesting that most of these species are capable of at least partial recovery after logging along streams. However, Van Dyke's salamander, a terrestrial species inhabiting the riparian zone, was not found in any previously logged site lacking a buffer. Riparian buffers did not seem to provide the same habitat as uncut forest for stream-dwelling species; their abundances were lower in young sites and both buffered old sites and buffered mature sites compared with mature sites. Van Dyke's salamander was found in buffered old sites, but at much lower levels than old sites.

We caution that results of our study should not be extended beyond the species we were able to sample adequately. We do not conclude, for example, that all mammal species are not sensitive to streamside management. Our

Elevation	High	Moderate	Low
Gradient	High	Moderate	Low
Geology	Igneous/sedimentary	Intermediate	Glacial
Fish access	Low	Moderate	High
Landowners	National Park National Forest	National Forest WA DNR	WA DNR Private
Management history	Unharvested	Moderately harvested	Intensively harvested

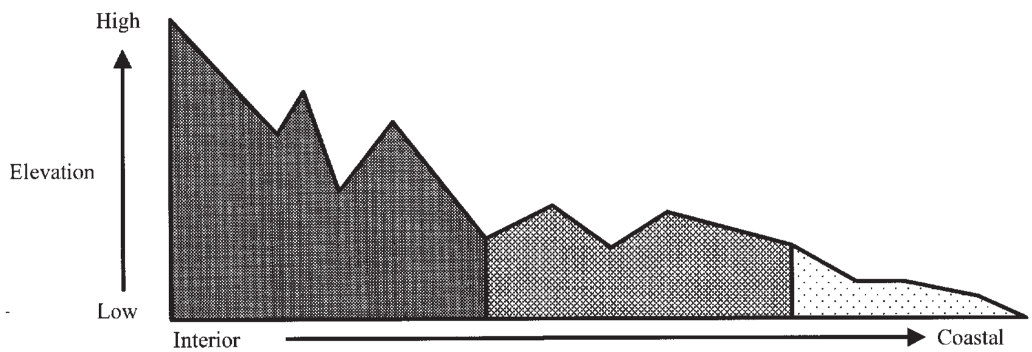

Figure 6—Diagrammatic cross section of the western Olympic Peninsula, Washington, 1996–1999, showing generalized differences in physical and management history attributes. WA DNR = Washington State Department of Natural Resources

results apply only to the five species we were able to capture at sufficient rates. Had we used different sampling or trapping methods targeted for more specialized species, we may have found different results. For example, we captured only five common water shrews (*Sorex palustris*) and three marsh shrews (*S. bendirii*) on near-stream transects. These species are closely associated with riparian systems, having morphological adaptations for a semiaquatic life (Verts and Carraway 1998); water shrews usually occur at elevations higher than many of our study sites (Conaway 1952). Captures of these shrews were insufficient to assess effects of riparian management. Overall, capture rates of 12 of the 17 species of mammals we trapped were too few to draw meaningful conclusions.

We are aware of only one other study of the vertebrate response to riparian buffers in Washington. O'Connell et al. (2000), in their study of riparian sites in managed forests of the Cascade Range of Washington, found that total abundance and species richness of birds and small mammals using areas close to streams before any timber harvest were comparable to the number and kinds after harvest. At the species level, O'Connell et al. (2000) found that abundance of Pacific jumping mouse increased in buffers along streams after harvest; our data, although not conclusive, are consistent with their observation. Pearson and Manuwal (2001), reporting on results from the western Cascade Range as part of the same O'Connell study, found that diversity of breeding birds increased on sites with narrow buffers relative to non-harvested control sites after logging. In their study, total bird abundance did not differ between treatments and controls. Our results were consistent with both of these findings. Pearson and Manuwal (2001) also found that species turnover was greater in sites with narrow buffers; we did not measure species turnover in our study.

Among the vertebrates, amphibians and fishes were most sensitive to physical attributes of streams. This may help explain some of the observed abundance patterns. Figure 6 is a diagrammatic representation of a cross section of the Olympic Peninsula. The peninsula can be viewed as a series of concentric circles. The forested portion of the inner circle (the peninsula's interior) is dominated by unharvested, late-successional forests of Olympic National Park. Streams tend to be small, steep-walled, and dominated by igneous and sedimentary rock. The outermost circle tends to be low-elevation, low-gradient, industrial forest land, with larger streams and rivers dominated by glacial and alluvial soils. Most of our sites were distributed along the midrange of this continuum (moderate elevation and gradient). Not surprisingly, amphibians dominate the interior, while fishes dominate the low-lying areas. Also, fish-dominated systems have received the most protection, in the form of buffers.

Because of the importance of physical attributes of streams and topography on vertebrate abundance, conclusions about the effects of stream buffers per se must be considered tentative. Further work will be needed to separate the confounding influences of buffer condition, stream, and watershed attributes (see Bisson et al. 2002, in this proceedings, for further information on site and watershed influences on fish and amphibians). Although we cannot say that small streamside buffers ameliorate the impacts of logging, their presence may make a difference. An example from our study is the Van Dyke's salamander. It was not found in any sites that had been previously logged. It was, however, present in unlogged stream buffers, and we even documented reproduction at one of the sites (Blessing et al. 1999). This suggests that retention of the buffer trees, with buffer widths considerably smaller than those prescribed on federal lands under the Northwest Forest Plan, provided refugia for some individuals, and provides a source for recolonization as the forest canopy develops and the stream environment stabilizes.

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SOCIOECONOMIC FACTORS INFLUENCING LAND USE AND MANAGEMENT CHANGES IN THE PACIFIC NORTHWEST

Ralph J. Alig[1] and Jeffrey D. Kline[2]

ABSTRACT

We have developed models describing relationships between socioeconomic forces and land use and management changes in the Pacific Northwest. How land is allocated among different uses is a reflection of socioeconomic forces that motivate human settlement and the land management decisions of private landowners. Private landowners are heterogeneous in nature. Their objectives and land use decisions have significant implications across a regional landscape with mixed ownerships, especially concerning sustainability issues and risk-related factors associated with human disturbance of terrestrial and aquatic ecosystems. Our models provide long-range projections of land use change, serving as key inputs into other models of terrestrial and aquatic processes. They describe the probability of developing forests and farmland in the region into residential, commercial, or industrial uses as a function of spatial socioeconomic variables, landownership patterns, and geographic and physical land characteristics. Results suggest that development of forest and farmland is most likely on lands located near population centers and increases in likelihood with the size of those population centers. We project that nonindustrial private forestlands are the most likely to be developed over the next 50 years.

KEY WORDS: Land use change, rural development, population growth.

INTRODUCTION

Human activity, in addition to climatic and other natural forces, is a dominant factor affecting ecological change on land. Growing human populations and their associated use and consumption of natural resources affect economic and ecological compatibility options associated with managing natural resource use on a fixed land base. Natural resource management and policy become increasingly important for the long-term sustainable use of our natural resources while maintaining desired levels of human welfare. Our land use research is designed to help support analyses of the economic and ecological compatibility, and the tradeoffs among different goods and services, when considering future natural resource management and policy alternatives. Land use and land cover changes can greatly influence the possible mix of outcomes and reflect an array of production possibilities, institutional considerations, land management actions, demands, and societal values.

Examining land use changes can be an important part of research concerning forest management and policy. Land use changes can help society adjust to changing demands for and supplies of forest commodities. Relationships between land uses and ecological systems are important considerations when forging forest management actions, policy alternatives, and enhancing ecological systems. We provide a synthesis of findings from data analyses and modeling the impacts of socioeconomic factors on private land use changes in the Pacific Northwest. We discuss how such changes can affect outcomes on the land base.

HISTORICAL LAND USE IN THE PACIFIC NORTHWEST

Private land in the Pacific Northwest (PNW), Westside (west of the crest of the Cascade range in Oregon and Washington) is allocated among land uses in fairly similar percentages in western Oregon and western Washington (Figure 1). Forest industry-owned timberland is just less

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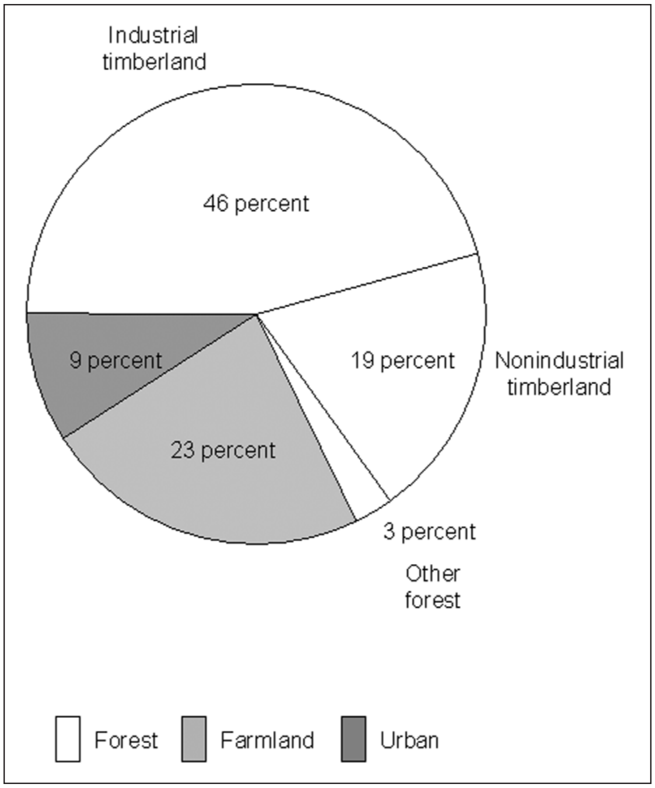

Figure 1a—Current composition of land uses on private land, western Oregon.

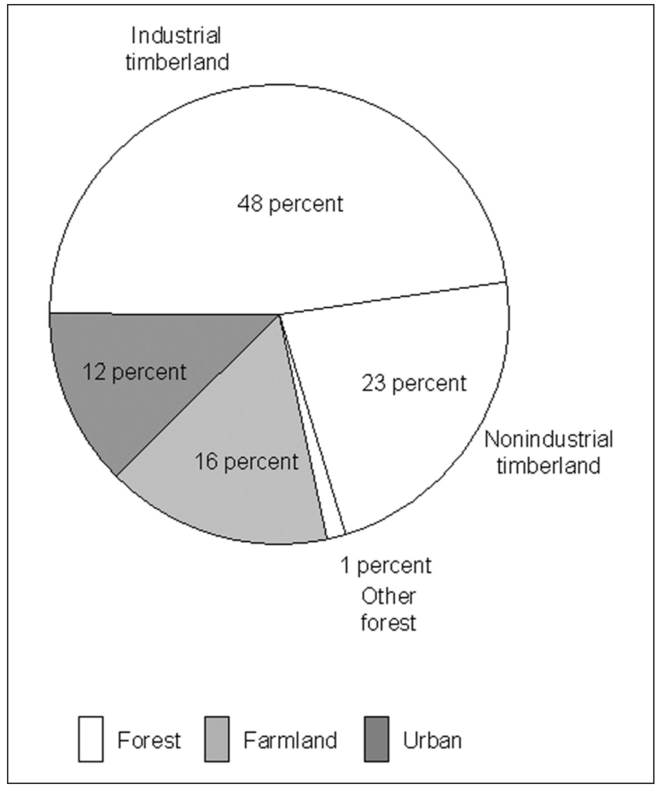

Figure 1b—Current composition of land uses on private land, western Washington.

than half of the private land base in both cases and nonindustrial private-owned timberland covers about one-fifth. Western Oregon has a higher percentage of farmland (23% vs. 16%), while western Washington has a higher urban percentage (12% vs. 9%). Forestland area in the Pacific Northwest declined by more than one million hectares, or about 5% from 1952 to 1997 (Smith et al. 2001). The largest losses are due to development (USDA Natural Resources Conservation Service 2001). Washington lost 8% of its forestland between 1952 and 1997, quadrupling Oregon's rate (Smith et al. 2001). Most forestland losses have been on nonindustrial private owned land converted to agriculture or to urban and other development. Because nonindustrial private owners tend to own a significant share of lower elevation forestland within riparian areas (Bettinger and Alig 1996), forestland losses on nonindustrial private lands often impact aquatic ecosystems.

Although significant forestland clearing for agriculture is unlikely in the future, continued expansion of urban development into historically forested areas is likely (Alig and Healy 1987; Alig et al. 1999a, Kline et al. 2001). Populations in Oregon and Washington have increased faster than the national average in recent years. Most of this increase is in the western part of the region along the I-5 corridor. Portland, for example, was one of the fastest growing cities in the United States over the last decade. Projections suggest that the Pacific Northwest, Westside region's population will continue to grow (Figure 2), converting forestland to developed uses. Such change can lead to a range of environmental stresses such as habitat fragmentation, wetland loss, loss of biodiversity, and water pollution. It can also increase the likelihood of property loss associated with forest fires near homes.

SOCIOECONOMIC TRENDS

Dynamics in the Pacific Northwest are linked to national and global changes. World growth in human populations and income has resulted in social, economic, and technological changes that profoundly affect the global management and use of natural resources. The world population will continue to grow, possibly from six billion in 2000 to about nine billion by 2050 (United Nations Population Division 2000). The U.S. population is also projected to grow significantly, particularly in the southern and western regions of the country, by more than 120 million people by 2050 (U.S. Census Bureau 2002). Projected increases in

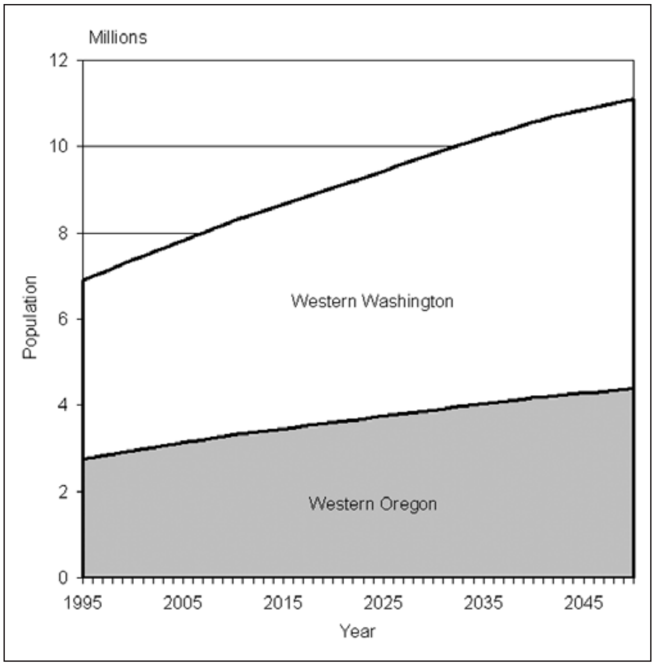

Figure 2—Projected population, Pacific Northwest, Westside.

population and income will, in turn, increase demands for residential and other developed uses of land as well as for use of renewable resources.

A number of socioeconomic factors motivate land use change, including population and personal income growth, demographics, and supply and demand of forest and agricultural commodities. These factors can have important spatial dimensions. For example, because population growth is likely the most significant factor motivating future land use changes, it has important spatial characteristics. Currently, 17% of the U.S. land comprising coastal areas (within 50 miles of the coastline) holds 53% of the U.S. population. The largest projected increases in population over the next several decades are also for coastal areas. This trend will have important implications for aquatic habitat, wetlands, and water recreation.

Changing demographics will also influence future land use change. In addition to population growth, the U.S. population is aging. An aging population will lead to an increasing number of retirees, potentially increasing demands for retirement or second homes, some involving migration based on demands for amenities. On average, Americans are also growing wealthier (U.S. Census Bureau 2000). Personal income in the U.S. has grown significantly since World War II, with personal incomes in the PNW growing faster than the national average. Projected increases in personal income will increase demands for renewable resources while also fueling further conversion of forests for developed uses (Alig and Healy 1987).

LAND USE RESEARCH UNDER THE WOOD COMPATIBILITY INITIATIVE

Empirical Models of Land Use Change

Land use research over the last decade relied on variations of the area-base approach, which describe the proportions of land in different use categories within defined geographic areas, usually counties, as a function of socioeconomic and land characteristics variables (e.g., Alig 1986; Hardie and Parks 1997; Plantinga et al. 1999). Conceptually, these empirical models are based on land rent theory whereby private owners are assumed to tend to choose the land use that offers the highest present net value of the future stream of net returns. For example, if population increases lead to greater urban land rents relative to forest rents, some forestland would probably convert to urban uses.

In recent years, land rent theory has formed the conceptual foundation of more spatially explicit land use modeling methods developed to take advantage of the finer spatial resolution available from geographic information system data (e.g., Bockstael 1996; Nelson and Hellerstein 1997; Wear and Bolstad 1998). These models rely on spatially-defined land use and other data to estimate empirical models to project the rate and location of land use changes on finer spatial scales than previously capable by area-base models. This new capability has greatly expanded opportunities for collaboration between economists and ecologists to conduct landscape-level analyses to jointly assess economic and environmental policy scenarios. We developed empirical models describing historical land use changes in the PNW Westside to aid in characterizing potential future land use change likely to result from changing socioeconomic factors. The models were used to characterize potential future land use changes in western Oregon and western Washington (Kline and Alig 2001) for the 2000 Resources Planning Act (RPA) Assessment (USDA Forest Service 2002) and for the Oregon Coast Range as part of the Coastal Landscape and Analysis Modeling Study (Kline et al. 2001).

Conceptually, the value of land in urban uses is viewed as a function of the spatial proximity to city centers (e.g., Mills 1980; Capozza and Helsley 1989). Although spatial proximity does influence the costs associated with transporting forest and agricultural commodities to market, modern society associates spatial proximity more with maximizing the difference between the costs associated with commuting to work and quality of life factors such as housing and neighborhood amenities. Empirical specifications generally have described urban rents using population density (e.g., Alig 1986; Parks and Murray 1994; Hardie and Parks 1997) or the proximity of land to cities likely to influence the conversion of undeveloped land to urban uses (e.g., Bockstael 1996; Plantinga et al. 1990). However, data used to compute population density variables rarely are sufficiently disaggregated geographically in rural areas to adequately describe the spatial heterogeneity inherent in population growth. Variables that simply measure the proximity of land to select cities do not describe how each city's impact changes as its population grows or declines.

In light of these challenges, we developed empirical models describing historical land use change based on a gravity index (Haynes and Fotheringham 1984) describing the urbanization potential of forest and agricultural land as a combination of population and proximity to existing cities. The gravity index was combined with additional explanatory variables describing forest and agricultural land rents, household income, ownership characteristics, and land use zoning. This was the foundation for estimating probit models describing the conversion of forest and agricultural lands to urban uses as described by land use data available from the USDA Forest Service's Forest Inventory and Analysis (FIA) Program. The estimated empirical models enable us to project the rate and location of future conversion of forest and agricultural lands to developed uses by computing new gravity index values based on the projected future populations of cities in the study region (Kline and Alig 2001; Kline et al. 2001). These projections can be depicted as geographic information system maps that facilitate their incorporation into other models describing economic and ecological conditions and processes.

Forest Cover Changes

Changes within the land base retained in forests over time consist of transitions in forest cover types that are caused by a combination of natural and human-caused disturbances. Such changes can also affect joint production possibilities for different ecosystems. Earlier literature dealing with forests focused on forest succession and natural disturbances, with emphasis on natural forces prompting forest type changes. However, human-caused disturbances, such as timber harvests, dominate most Pacific Northwest forests (Alig et al. 2000). Over the last FIA survey cycle, human-caused disturbances in the PNW Westside were more frequent by at least an order of magnitude than were natural disturbances. Harvesting on private lands was about 2 to 10 times more likely than full or partial-replacement disturbances due to wildfire—the primary natural disturbance agent in the past. In the roughly ten years between FIA surveys, timber harvests affected about 20% of private timberland while wildfire affected less than 1%.

Given this disturbance history, clear-cutting Douglas-fir stands on forest industry-owned lands resulted in 15% stand replacement by hardwoods (primarily red alder), while another 3% was converted to other types (Alig et al. 2000). Clear-cutting red alder stands on forest industry lands resulted in 72% replacement by other forest types. In contrast, only 42% of red alder stands on nonindustrial private forestlands changed forest types after clear-cutting, reflecting fewer intentional conversion efforts after harvest among these owners. Even for undisturbed stands (e.g., no harvest), 12% of Douglas-fir stands on forest industry lands and 23% on nonindustrial private lands changed forest type. Such findings suggest that recognition of ownership differences can be important, beyond coarser public and private classifications most commonly used.

Forest Ownership Changes

A long-standing issue in forest resource supply studies is private forest owner behavior and how it might be affected by incentives and institutional factors. We need to consider how changing owner characteristics and objectives might impact forest resources. Nonindustrial private forest owners, in particular, tend to possess multiple objectives causing them to respond to socioeconomic forces and policies in complex and sometimes unpredictable ways (e.g., Kuuluvainen et al. 1996). Our research conducted in the Pacific Northwest suggests that many nonindustrial private forest owners in Oregon and Washington are motivated by aesthetics and recreation in addition to, or in place of, timber production objectives in their forest management decisions (Kline et al. 2000a, 2000b). As a result, targeting incentive programs toward select groups of nonindustrial private owners with nontimber objectives could enhance nontimber services (e.g., recreation).

Other researchers have found that financial incentives are not as critical to owners' decisions in foresting riparian zones as some have suggested. Other factors may include "neighborly concerns" and concerns about restrictions on land management and loss of flexibility (Kingsbury 1999). Behavior by the diverse nonindustrial private forest owner group is also affected by whether owners live on their forested property in contrast to absentee owners. Another factor is increasing density of people per forested unit, especially in areas such as the Puget Sound region.

The main forest ownership change in the Pacific Northwest has been between forest industry and nonindustrial private forest owner classes. Land exchanges among private owners have been more common than exchanges between private and public owners (Zheng and Alig 1999). For example, FIA surveys in western Oregon indicate a net shift of about 300,000 ha from nonindustrial private to forest industry owners from 1961 to 1994. Forest industries own most of the private timberland in the region, and generally manage their forestland more intensively for timber production than do nonindustrial private owners.

Land Management Intensity

Within a given forest type, investments in forest management can significantly influence options regarding the mix of goods and services produced on forestland. Management intensity includes the timing and type of harvests, which over time, have differed notably by ownership in the Pacific Northwest and with regard to the number and timing of various silvicultural operations conducted on individual stands. Investments in improved planting stock on private land have often resulted in higher forest production per ha, potentially lessening pressures on other areas looked upon for nontimber goods and services. From a broad perspective, demands for different mixes of forest-based goods and services are likely to shift over time with a growing and wealthier population. Because some forest-based processes are decades or centuries in length, planning forest investments with adequate lead-time is critical.

An increasingly important consideration for forest policy analysts is the potentially significant impact that population growth and resulting land use changes will have on forests as they are converted to residential and other developed uses. Researchers believe that forestlands located near low-density residential and other development become less productive due to their fragmentation into smaller management units, and changes in the characteristics and management objectives of newer, more urban-minded forest owners. Empirical studies have found that the propensity of nonindustrial private forest owners to harvest timber (Barlow et al. 1998) and manage for commercial timber production (Wear et al. 1999) is negatively correlated with population densities. Policymakers also hypothesize that such development also has the potential to increase wildfire risk associated with increased human habitation and activity in forests (Lorensen et al. 1993). We are examining the impact of potential low-density residential development on the productivity of forestland to anticipate how an increasing population in the Pacific Northwest and the resulting expansion of urban land uses into traditionally rural areas is likely to impact the timber-producing capability of forests in the region.

We estimated several empirical models describing the propensity of forest owners in western Oregon to harvest timber and conduct silvicultural activities, such as thinning and planting, as a function of stand characteristics, site quality, access, ownership characteristics, and the density of residential and other development within the immediate vicinity of forestland. The models suggest that the density of nearby development does not measurably affect timber-harvesting activities of private forest owners in western Oregon (Azuma et al. 2002). However, the models do suggest that the density of development near forestland may have a small but measurable negative impact on the likelihood that forest owners thin existing stands of planted trees. The results suggest that although future development may recently have had a limited impact on timber harvesting, it has the potential to reduce investment in forest management activities in the future.

Land Use Zoning Influences on Forests

Additional research conducted under the Wood Compatibility Initiative examined the potential influence that land use zoning might have on forests. For example, we examined how well Oregon's land use planning program has protected forest and farm lands from development since its implementation in 1973. We developed an empirical model of historical land use change before and after the program. We based it on socioeconomic factors, land rent, and landowners' characteristics, and the location of land within forest and exclusive farm use zones mandated by the program. Although results suggest that Oregon's land use planning program has concentrated development within urban growth boundaries since its implementation, its success at reducing the likelihood of development on lands located within forest and exclusive farm use zones remains uncertain (Kline and Alig 1999).

In another study, we examined how land-use zoning laws that mandate compactness of development might influence future land use changes and timber production on forestland. The analysis was part of a larger research project designed to quantify potential future fiscal, agricultural production, and timber production impacts of alternative land use zoning scenarios in the Willamette Valley, Oregon. The project compared two scenarios: a historic trend scenario characterized by likely future land use change according to existing land use zoning; and an alternative land-conserving scenario characterized by modified land use zoning to induce more compact development. The historic scenario was designed to result in 10,000 more new houses to be built on Willamette Valley forestland over the next 50 years compared to the alternative land-conserving scenario (Kline and Alig 2000).

Our analysis suggests that timber production impacts that might result from the alternative scenario rather than the historic trend scenario are relatively minor when compared to total timber production in the region. Area of forestland lost to residential development in the Willamette Valley under the historic trend scenario is estimated to increase from a range of 17,407 to 27,727 ha by 2050, and is relatively consistent with historic trends. Area of forestland lost under the alternative land-conserving scenario is estimated to increase from a range of 8,071 to 11,511 ha. Although the proximity of new residential development to forestland can potentially impact timber production, our analysis suggests that the most productive timberland in the Willamette Valley region tends to be located far from existing cities and generally will remain unaffected by residential development over the next 50 years. As a result, we found that modifying existing zoning laws to induce more compact development in the Willamette Valley is unlikely to significantly alter potential future timber production on forestlands in the region (Kline and Alig 2000).

PROJECTIONS OF LAND USE CHANGE

We prepared 50-year land use projections, using empirical spatial models describing the probability that forests and farmland in western Oregon and western Washington would be developed for residential, commercial, or industrial uses. The probabilities were a function of socioeconomic and location factors, ownership, and geographic and physical land characteristics (Kline and Alig 2001). The projections were used in the 2000 RPA Assessment in support of analyses of production possibilities for multiple resources from the region's forestland base (USDA Forest Service 2002). Projected total reductions in areas of forestland from the base year 1997 to 2050 are 1.0% in western Oregon and 1.0% in western Washington. Projected total reductions in farmland area are 4.1% in western Oregon and 13.2% in western Washington. Urban areas in western Oregon and western Washington are projected to increase by 17.7% and 22.5%, respectively. From 1997 to 2050, areas of timberland in western Oregon and western Washington are projected to decrease 0.3% and 0.0% for forest industry-owned timberland and 1.8% and 2.5% for nonindustrial private-owned timberland. The most significant reductions in forest area are on land classified as "other forest" (i.e., forest land other than timberland and productive reserved forest land [Smith et al. 2001]). From 1997 to 2050, the relatively small portion of forestland classified as "other forest" is projected to decline 7.5% in western Oregon and 8.9% in western Washington.

The projections suggest that urban land uses will continue to expand with increasing population in the Pacific Northwest, Westside region. Lands located closest to larger, more rapidly growing cities will face the greatest likelihood of conversion to urban uses over time. The largest percentage reductions in area are for farmland (vs. forests), because farmlands in the region often are located closer to existing cities. Most forest losses to urban uses are projected on timberland owned by nonindustrial private forest owners (Kline and Alig 2001). With respect to policy options, local governmental planners rate agricultural zoning, forestry zoning, and mandatory review of projects involving land use conversion as most effective in influencing development in the Pacific Northwest (Cho et al. 2001).

The projections of land use change are also used to assess impacts on wildlife habitat and bird populations in Oregon and Washington, considering both forest and agricultural biodiversity. Work in progress on impacts of afforestation on biodiversity (e.g., Matthews et al. 2002) indicates that the projected reductions in forest and farmland could lead to a one percent loss in forest-based birds in both states. However, the projected losses are larger for farmland birds, 3.5% in Oregon and 13% in Washington, based on larger reductions in agricultural land relative to what is available. Future work will attempt to address which individual species might decrease at a relatively high rate statewide.

FUTURE RESEARCH

We are currently extending our land use research to examine the influence of land use change and forest fragmentation on private forest management and on terrestrial and aquatic habitat conditions. This work includes integrating econometric land use models with other models describing ecological conditions and processes. This new research will analyze a variety of issues related to the forest-urban interface, including fire risk, biodiversity conservation, and the effectiveness of economic incentives to promote protection and enhancement of endangered species habitat. Examining land use changes within the context of changing ecological conditions and processes can contribute to evaluating the future economic and ecological sustainability of alternative forest management and policy scenarios. Acknowledging the diversity inherent in the characteristics and objectives of forest owners and the broad array of competing public and private interests in forestlands can help to enhance future forest policy. Giving more deliberate consideration of public opinions and preferences regarding alternative forest management and policy outcomes is also important.

Demand for wood products is expected to increase in the future (USDA Forest Service 2002). Efforts to align commercial timber production with conservation objectives have led to increased interest in what is called "sustainable forestry." Similar efforts exist in the context of other major land uses, and invoke similar concepts such as "sustainable agriculture" and "sustainable growth." When considering the management of forest systems for multiple uses within ecological constraints, consideration of the interconnections between forestry and other economic sectors (e.g., capital markets) becomes increasingly important. Changing product markets and institutional factors affect sustainability issues and information crucial in collective natural resource decision-making. The growing area of productive tree plantations in the South that will provide a larger share of the nation's timber harvest is a key trend in the U. S. forest sector (Alig et al. 1999b; USDA Forest Service 2002). This will perhaps allow some forestlands in other regions, such as the Pacific Northwest, to be used increasingly for non-timber purposes. Private timberlands have the biological potential to provide larger quantities of timber than they do today (Alig et al. 1999b). In addition to interregional connections, linkages across sectors also can impact compatibility options in the Pacific Northwest. Improvements in U.S. agriculture have allowed greater production on a fairly constant cropland base and other agricultural land (e.g., pastureland) may be available for afforestation.

As the human population increases, competition among forest, agricultural, and urban uses for a fixed land base will intensify. Increasingly, we will need to examine economic and ecological compatibility issues in an analytical context that includes agricultural and urban land uses along with forest uses. Many environmental policy issues already involve both forest and nonforest factors. For example, the conditions of aquatic systems are significantly affected by agriculture, grazing, and urban land uses in addition to up-slope forest management. In many cases, significant opportunities for improving aquatic habitat may exist on these nonforest lands. Current research and policy, however, tend to focus on public and private forest management. Inclusion of all potential land uses in analyses of economic and ecological compatibilities of alternative natural resource policies would enable a more complete assessment of the economic and ecological tradeoffs associated with managing natural resources while maintaining economic and ecological "sustainability." In some cases, modifying management actions on nonforest lands may yield greater marginal benefits at lower marginal costs than modifying management actions on forestlands. New options for improvements in natural resource conditions are possible if we can better mesh competing interests in and uses of land.

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MIXED ALDER-CONIFER FORESTS: MANAGING UPLAND ECOSYSTEMS IN SOUTHEAST ALASKA FOR WOOD PRODUCTS, WILDLIFE, AND FISH

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ABSTRACT

Historically, red alder (*Alnus rubra*) Bong. has been viewed as an undesirable tree species and has been actively removed from managed forests. Several recent studies suggest that the presence of red alder may help alleviate some of the problems associated with fish and wildlife habitat that develop in the dense conifer-dominated young-growth forests that typically grow after clearcutting. Our study uses an integrated approach to evaluate to what extent red alder may influence trophic linkages and processes in managed young-growth ecosystems. Key components of this study include how logging and natural disturbance favor the regeneration of alder and how different mixtures of alder are associated with timber productivity, woody debris recruitment, terrestrial and aquatic invertebrate abundance, and fish and wildlife habitat. By using one independent variable in all components of this study (i.e., amount of red alder), we simultaneously contrasted many possible responses across this gradient to develop a general response model. Managers may use this model to choose a desirable level of red alder in a particular landscape to meet simple or multiple resource objectives. Both compatibility and tradeoffs among resources will be clearly evident. Active management (i.e., thinning with species bias or planting) can be used to achieve different amounts of alder in managed forests.

KEY WORDS: Red alder, woody debris, invertebrates, fish habitat, wildlife habitat.

WHY STUDY RED ALDER?

Clearcutting has been the dominant regeneration method in Southeast Alaska forests since the 1950s. The resulting dense, uniform regrowth that develops has largely negative consequences for wildlife and fish (Wallmo and Schoen 1980; Schoen et al. 1981,1988; Hanley 1993; Dellasala et al. 1996). Canopy closure in these dense forests generally occurs 25 to 35 years after cutting, and is followed by a nearly complete elimination of understory vegetation, important for wildlife, for 100 years or longer (Alaback 1982; Tappeiner and Alaback 1989). After canopy closure above small streams, trophic status changes from autotrophic (dominated by organisms that manufacture their own energy) to heterotrophic (dominated by consumers) (Sedell and Swanson 1984; Hetrick et al. 1998a, 1998b). The removal of streamside timber also reduces the amount and size of large wood recruited into streams, with a subsequent loss of bird habitat and fish habitat (Bryant 1985; Bisson et al. 1987).

Recent studies of young-growth stands of red alder (*Alnus rubra* Bong.) mixed with conifers indicate that the presence of alder may mitigate some of the impacts of clearcutting in southeast Alaska. Mixed alder-conifer stands have species-rich, highly productive understory vegetation with biomass similar to that of old-growth stands of the region (Hanley and Hoel 1996; Deal 1997; Hanley and Barnard 1998). Habitat quality for small mammals in even-aged alder-conifer stands may be equal to that of old-growth forests (Hanley 1996). Although inclusion of alder will not mitigate all wildlife-habitat problems (e.g., lack of snow

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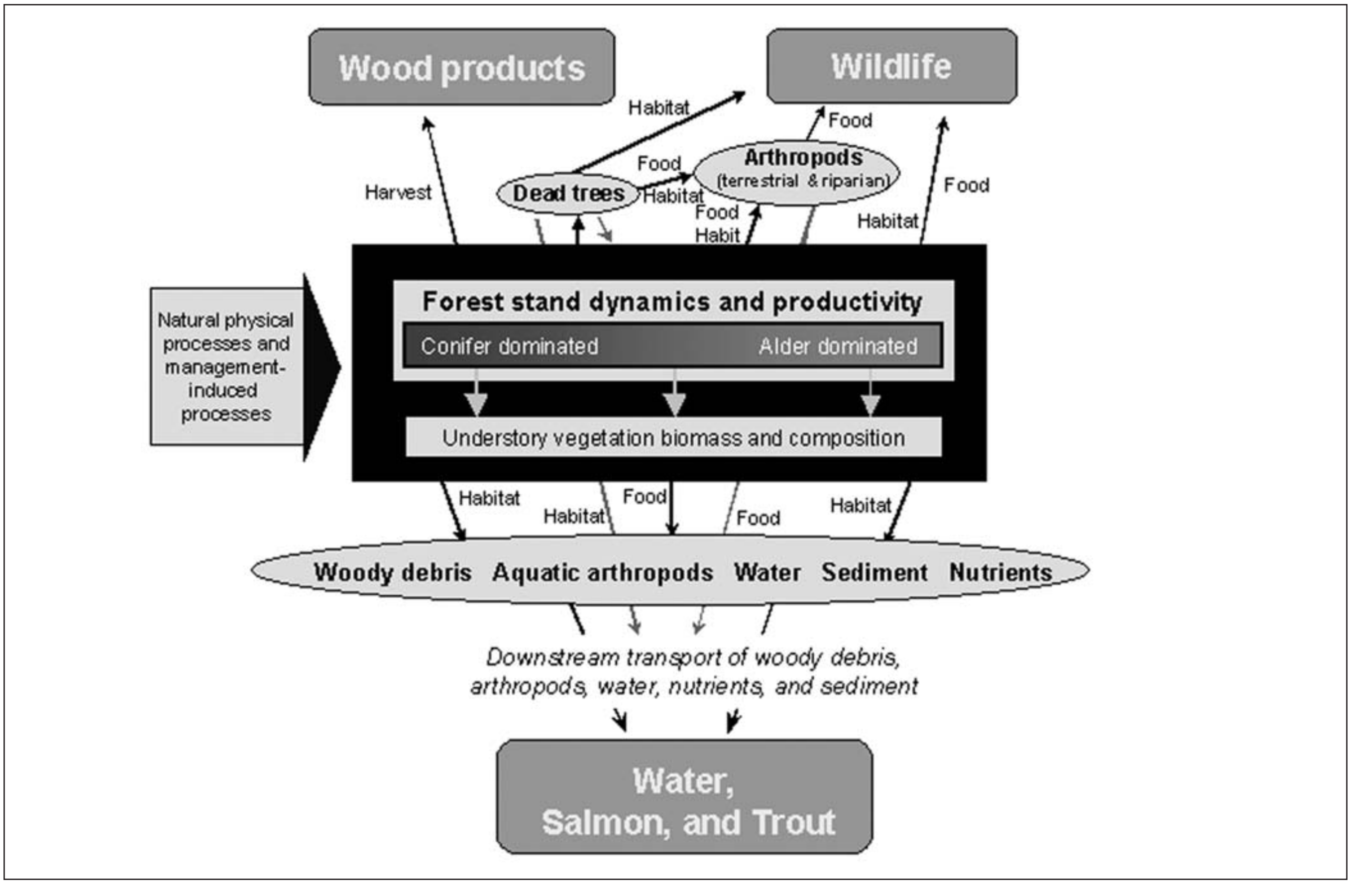

Figure 1—Conceptual diagram illustrating how red alder influences wood, wildlife, and fish productivity. This diagram indicates how each discipline links with others to build an integrated study.

interception for deer winter range), it may provide more benefits than will thinning of even-aged conifer stands. Attempts to reestablish understory herbs and shrubs through thinning without the presence of red alder in young-growth forests have led to conifer regeneration and little new herbaceous colonization. Red alder may convey further benefits in riparian forests by producing more prey for salmon than conifer riparian forests (Wipfli 1997). This is significant because over half of the prey biomass ingested by juvenile salmonids in southeast Alaska is terrestrial and originates from adjacent riparian vegetation. If similar processes occur in upland forests, the presence of red alder may increase invertebrate production, providing more food for animals such as birds, bats, small mammals, and fish, in turn affecting their abundance and production. Headwaters are also important sources of food (invertebrates) for fish in downstream, salmon-producing habitats (Wipfli and Gregovich 2002). If alder in these uplands increases local prey abundance, then it indirectly should provide more prey for downstream fishes via the fluvial transport of prey from uplands to fish in habitats downstream.

DESIGNING AN INTEGRATED STUDY

Our goal was to simultaneously evaluate different resources in young-growth stands across a range of tree composition from pure conifer to nearly pure red alder. Along this gradient of alder occurrence, we hoped to determine where resources such as timber, wildlife habitat, and fish habitat were nearly or fully compatible, and where they were not, to estimate tradeoffs if one resource was selected above others.

With the limitations imposed by a two-year project, we restricted the study to one stand age and one geographic area, 45-year-old stands in the Maybeso Valley of Prince of Wales Island. We included a number of disciplines, however, which expanded the complexity of this study. As a group, we constructed a list of goals that we expected to accomplish for this project:

- assess physical disturbances, both natural and human-induced, associated with red alder establishment.

- compare biomass of understory vegetation and forage for herbivores and invertebrates in young-growth forests with different mixtures of red alder.
- assess the affect of mixed red alder-conifer forests on the abundance of aquatic, riparian, and terrestrial invertebrates that provide food for fish and birds.
- investigate the mode of death of red alder and other trees (i.e., die standing, uprooting or bole snapping) that leads to different structures of woody debris.
- assess red alder's impact on woody debris and sediment input in streams.
- investigate whether red alder in mixed stands enhances conifer growth and total wood production.
- synthesize findings by describing the simultaneous beneficial and detrimental influences of red alder to several key resources across a range of its occurrence in mixed-species stands.

At first, the approach of including 10 discipline areas and a list of uncoordinated goals created chaos. Eventually, we designed a flow diagram that incorporated the goals above, showed linkages among the discipline areas, and produced three key resource outputs (Figure 1). This structure helped each scientist understand the role of their discipline in the overall study. The diagram became a blueprint for articulating program flow, including a budget planning framework, illustrating how the various parts of our research project were integrated. The linkages between disciplines and the manner in which they build to a larger, more complete story became the most interesting parts of this research project. This diagram also indicates with whom each scientist needed to collaborate most closely (i.e., data inputs and outputs along the flow of arrows). Discussions among scientists quickly focused on the type of data needed at each step.

It was helpful to develop the general structure early in the planning phase of our research. This enabled us to evaluate if there were essential missing pieces of information and fill them. Also, data collection procedures were modified, sometimes extensively, to make data more meaningful as they were shared with the next users along the flow lines of the diagram.

KEY ECOLOGICAL THEMES

Several topics of our study were elevated to key ecological themes as they are used to evaluate important outputs and, we believe, demonstrate well-planned integration. These do not represent all aspects of our research. For example, how wood production ranged with varying amounts of red alder was a major component of our study that was assessed with traditional methods within one discipline. The ecological themes were more complex, however; they account for areas where a line of research flows through three or more disciplines to evaluate an important output.

First, we developed each theme (Figure 2) with a qualitative description of the type and magnitude of disturbance that gave rise to the mixture of tree species currently growing in the study forests or along stream reaches. Clearcutting of the previous forest in the late 1950s was common to all of our study sites. Soil disturbance from logging and patterns of landslides and alluvial processes varied among sites, however. This variation in both logging and natural disturbance explained differences in the amount of red alder growing in our stands and along stream reaches. Next, we intensively sampled the live overstory trees in nine forest stands and along 19 stream reaches as a measure of the amount of red alder (i.e., percentage of volume or basal area), the independent variable for nearly all analyses. Data from overstory tree composition fed into estimates of wood production, and into the three key theme areas (Figure 2), which diverge to examinations of how the proportion of alder in these forests may influence processes in the forest canopy, forest floor, and headwater streams.

The first major theme covered forest canopy, insects, and birds. Terrestrial insects that feed on tree boles or in the canopy of stands were trapped and quantified throughout the growing season in 12 of our study areas. Bird abundance and species richness also were sampled at the same sites. We hypothesize that forests with a greater proportion of red alder will produce a greater biomass of invertebrates living in the middle and upper canopies and also will support a greater number of birds. Our objective is to describe the relationship (i.e., curve) between insect biomass and concentration of birds along the gradient of proportion of red alder.

The next theme examined overstory-understory plant relationships with an emphasis on one aspect of deer habitat. We sampled the species composition and biomass of understory vegetation on the same plots where overstory tree composition was sampled. We hypothesize that a greater biomass of understory plants, including key forbs preferred as browse by deer, is positively correlated with increasing amounts of red alder in young-growth forests. Preliminary results from this study indicate that nearly pure red alder stands host a large biomass of brush species (e.g., *Vaccinium* spp., *Rubus spectabilis*) and that moderate amounts of red alder are associated with the highest biomass of understory plants considered the most desirable browse species.

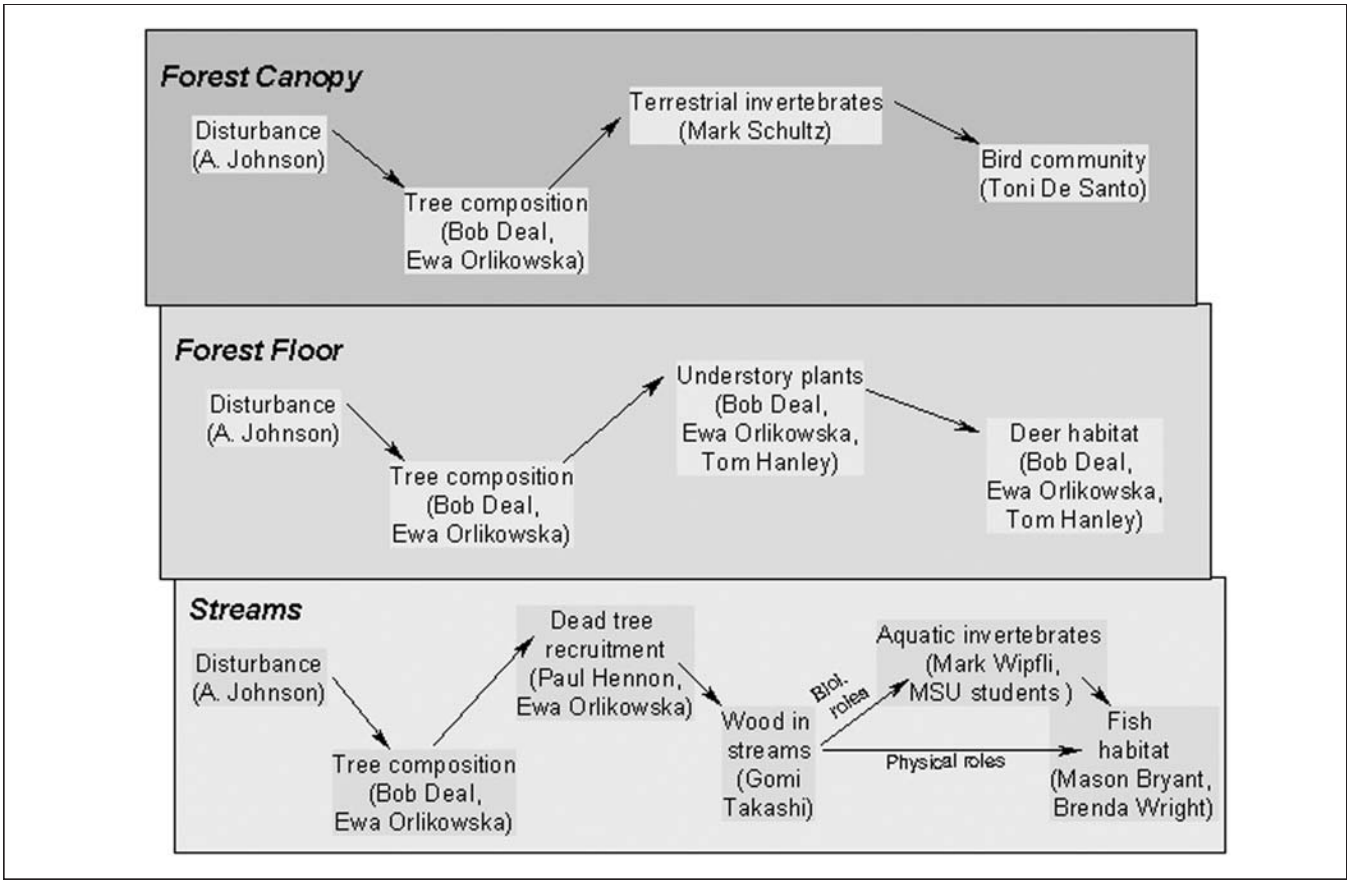

Figure 2—Several key ecological themes in the wood compatibility research on the role of red alder in young-growth forests of Southeast Alaska. Note that these themes do not capture all aspects of our study (e.g., wood production); they highlight areas where we attempted to track an important resource output through three or more disciplines. Names in parentheses denote lead scientists for that study area.

Our last major theme follows the fate and ecosystem use of wood in headwater streams that flow through young-growth forests to fish-bearing streams. It begins with a detailed assessment of the trees that are dying in these forests. The number and size of dead trees, and how they die (i.e., uprooting or standing) dictate the pattern of active recruitment of woody debris along stream reaches. Data on tree death are compared to a meticulous evaluation of woody debris in the same streams. We considered two major functions for wood in streams, biological and physical. The biomass of aquatic invertebrates produced by decaying alder and conifer wood was measured experimentally. We placed segments of alder and conifer wood of two decay wood classes in steams and counted invertebrates that eventually made colonization. Export of invertebrates and organic detritus from headwater streams to downstream fish habitats also was sampled. This was done to determine how alder affects the trophic linkages between upland forests and headwaters, and downstream fish-bearing food webs.

The physical roles of woody debris in streams include trapping sediment and helping to create pools and other stream habitat-enhancing structures. Thus far, we are learning that tree mortality for both alder and conifers is restricted to the smallest trees along these stream reaches. Large trees, especially Sitka spruce (*Picea sitchensis* (Bong.) Carr.), are growing in these forests, but they are not yet dying. Therefore, the woody debris currently being recruited is small in size; also, newly recruited woody debris is in a decayed state before entering streams because trees die standing and deteriorate before falling. Dead wood of alder appears to produce more aquatic invertebrates than does conifer wood. Large pieces of legacy wood (i.e., entering streams before or at the time of logging) are decaying slowly in streams and appear to provide the physical roles that the dead young-growth trees can not.

LIMITATIONS OF A TWO-YEAR STUDY

Although this study is broad in terms of the disciplines represented, its scope is limited to one geographic area and

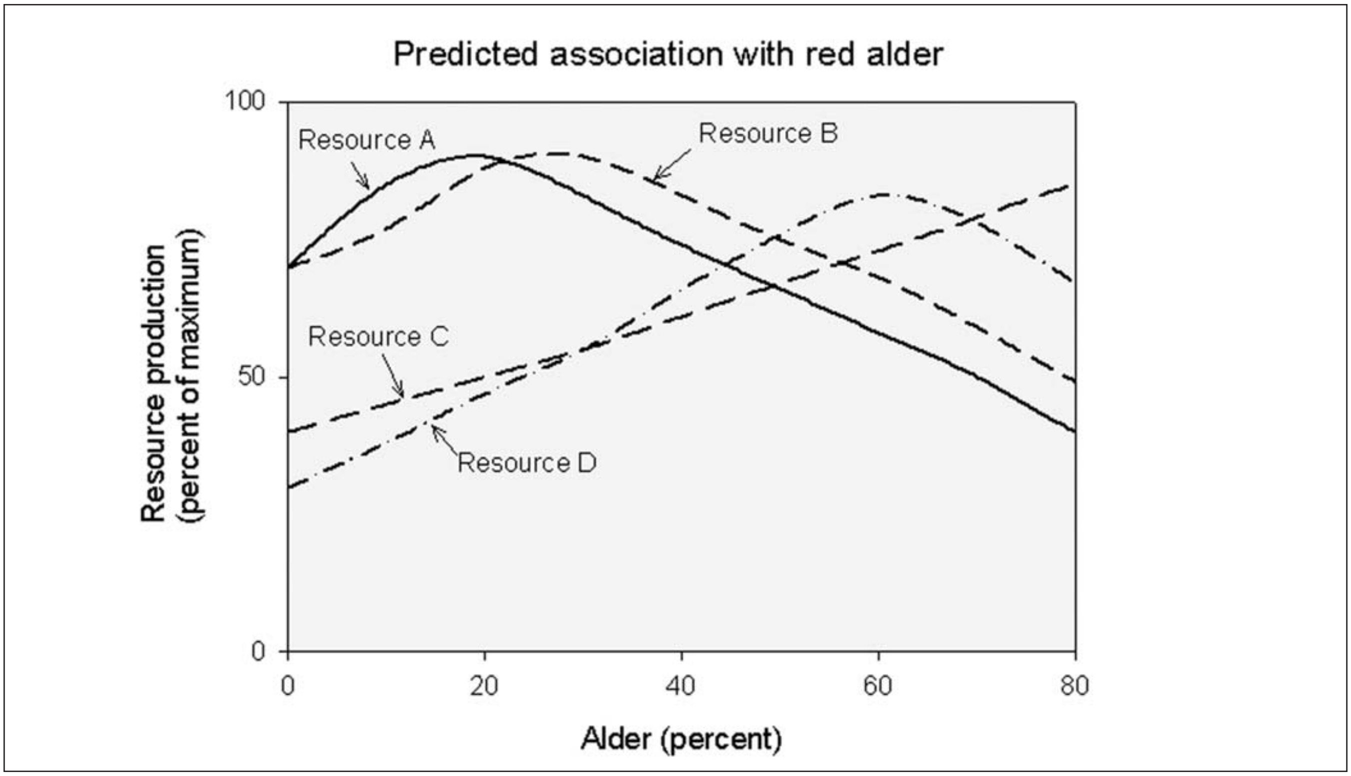

Figure 3—Conceptual depiction of how various resources may vary across the gradient of tree composition (e.g., percentage of basal area of red alder) in young-growth forests from pure conifer to nearly pure red alder. Once supported by data from our sampling, we will use this approach to simultaneously evaluate compatibility (and tradeoffs) among key resources such as timber, large woody debris recruitment and aquatic invertebrates in headwater streams, production of forage species for deer, and abundance of birds.

a particular forest age and stage of stand development. Only forest stands and streams in and around the Maybeso Valley of Prince of Wales were selected for study. From these areas, only stands that were about 45 years old (e.g., harvested in the late 1950s) were sampled. Destructive sampling of individual trees was used to 'grow trees back in time' and reconstruct the heights of trees back to the time that the site was regenerated. This approach allowed us to compare differences in height growth and relative dominance between alder and conifers as stands matured. Photo interpretation aided in the identification of historical disturbance associated with landslides; field observations were used to identify recent disturbance from landslides and floods. All other aspects of the study, however, serve as a snapshot in time of existing conditions in a closed-canopy young-growth forest.

We have knowledge from mixed alder-conifer forests that suggest very different conditions of tree growth and mortality in stands of similar ages on other islands and the mainland of Southeast Alaska, especially those inhabited by porcupines (Eglitis and Hennon 1997). Porcupines thrive in many of these mixed-species young-growth stands, feeding on conifer bark in winter. They preferentially attack the largest and most vigorous conifers, sometimes killing or deforming the majority of these trees, which creates a different pattern of tree mortality and woody debris recruitment than we found on Prince of Wales Island where porcupines animals are absent. This difference would have obvious implications for managers wishing to maintain timber productivity or grow large trees for future woody debris recruitment.

Few components of this study exercise control by experimental treatments. We found stands and stream reaches with differing amounts of alder and measured a range of variables. Our measurements of these variables are not considered "responses" because we did not perform treatments. Some of our dependent variables show trends along the gradient of amount of alder, but they may be associated with other conditions with which alder itself is associated. Our findings, therefore, will be used to develop hypotheses to test with experimental treatments, the next likely step in this research.

INTEGRATING COMPONENTS AND USE OF INFORMATION BY MANAGERS

Managers may have a new appreciation for the potential beneficial roles of red alder in the forest ecosystems of Southeast Alaska. Rather than attempting to eradicate red alder as an undesirable weed, there may be instances where managers can manipulate sites or existing vegetation to favor the establishment or maintenance of red alder. Altering the composition of young-growth forests to encourage a component of red alder may help improve habitat for deer, songbirds, and fish, thereby offsetting some of the negative consequences and main criticisms of timber harvesting, particularly clearcutting.

The approach to our multidisciplinary study was to share one independent variable, the amount of red alder (i.e., as a percentage of volume or basal area of live trees), in all aspects of our sampling. By doing so, we constructed a model that depicts how each of our important resources varies along the continuum of amount of alder (Figure 3). Once our analyses are complete, we will replace the variables displayed in Figure 3, resources A to D, with actual resources (i.e., timber, deer browse, birds, large woody debris, etc.) representing values based on our field measurements. Managers could use the eventual predictive model as a tool for selecting the amount of red alder that is associated with single or multiple resources at the stand or stream-reach scale. With more research based on experimental methods, we might then use the word "response" rather than "association" in the application of this model.

The compatibility and tradeoffs among multiple resources should be clearly evident. For example, resources C and D appear compatible with one another across most of the red alder gradient (Figure 3). Examples of these resources may be bird and fish habitat, as both may be responding favorably to increased inputs of invertebrates associated with more alder. Note that a resource such as fish habitat (e.g., Resource D) is potentially optimized with a mixture of benefits derived from red alder (i.e., inputs of both terrestrial and aquatic invertebrates) and from conifers (i.e., inputs of larger, more persistent coarse woody debris).

Resources A and D are incompatible at some parts of the alder continuum (e.g., in nearly pure conifer conditions), but fairly compatible at levels of nearly equal amounts of alder and conifers. Note, however, that achieving this compatibility produces minor tradeoffs for both resources as neither is near its maximum value. We expect that the volume of timber growing will diminish but deer forage may increase with higher proportions of alder (e.g., resources A and D, respectively). The falloff in timber is likely less severe with a more balanced mix of conifers and alders than in stands approaching a pure alder condition where total timber production is lowest. The production of alder as a timber resource should be recognized in its own right, however. It has become a valuable wood in the Pacific Northwest. Preliminary results indicate that the optimum production of deer browse is at something short of the pure alder condition, as was the case for fish habitat. A manager may want to give up a small amount of total timber production to meet deer habitat requirements by selecting mixed-species conditions at a particular point along the alder continuum. This is an example of a quantified tradeoff. The degree to which a manager might choose to favor one resource or the other is likely be dictated by the management objective for that particular stand or stream reach. Conceivably, it is possible to achieve true multiple resource management, even at the scales of stands or stream reaches, with only minor reductions in any key resource, to the point where nothing is really "traded off." By understanding resource outputs associated with stands varying in amounts of red alder, managers may take information and scale up to watershed or larger scales for purposes of forest planning. Managers should pay careful consideration to which forests in the landscape would benefit the most by the presence of red alder.

Armed with knowledge that red alder is potentially beneficial in a managed forest, how would a manager manipulate the composition of a stand? Opportunities for increasing alder in forests involve encouraging its reproduction in new harvested areas or disturbed areas and favoring alder when thinning existing forests where the tree species already occurs. Developing methods for favoring the regeneration of red alder in new harvest sites are beyond the scope of this study. Because of concerns about sedimentation, managers might be reluctant to intentionally create soil disturbance along streams in an effort to regenerate red alder. Riparian forests, however, are perhaps where red alder is most needed. Planting of red alder seedlings or cuttings is a method of regeneration that avoids the issue of sedimentation. As a pioneer species, red alder requires nearly full exposure to sunlight and, as planting stock, would grow only if planted in a harvested or heavily disturbed exposed environment. Planting red alder in clearcuts and commercially thinned young-growth forests is planned for 2002 on the Tongass National Forest.

Thinning to favor red alder will likely succeed to promote the species in Southeast Alaska on sites where it is already established. An interesting pattern of red alder regeneration is present throughout harvested landscapes of

Southeast Alaska. It is common in young-growth stands that regenerated before 1970 and is rare or absent on sites regenerated after that date. These latter sites are often completely dominated by conifers, except where alder grew back on closed logging roads. The 1970 date corresponds to a time when yarding practices changed from variable methods, where logs were often dragged across the forest floor and streams, to a high lead system of yarding where logs were partially suspended[12]. Much less soil disturbance occurred in the post-1970 logging. The current trend towards partial harvest or clearcutting with helicopter yarding also will result in minimal soil disturbance. Also, harvesting that avoids streams and steep slopes minimizes the chance for natural regeneration of red alder. Thus, unless the location and type of yarding changes, efforts by managers to promote the occurrence of red alder will focus on the pre-1970 harvested sites, such as our study sites in the Maybeso Valley of Prince of Wales Island.

NEXT STEPS FOR RED ALDER RESEARCH

Our study generated ideas about the beneficial roles that red alder can play in managed young-growth forests. These ideas could serve as hypotheses for testing in a more rigorous study involving stand level treatments with experimental control. Such an approach could lead to more confidence about which factors are real responses to the presence of red alder and which are merely associated with the same site factors that favor red alder regeneration or growth.

Another extension of the current study is to follow the fate of red alder as stands age. Observation from Oregon, Washington, and British Columbia suggest that red alder dies out of even-age stands before 100 years (Newton and Cole 1994). We have found several older forest stands in Southeast Alaska (e.g., 85 years old at Whitewater Bay, Admiralty Island and 110 years old at Goose Cove, Chichagof Island) where walk-through observations suggest that red alder is still very much alive. We also need to know how long after timber harvesting the legacy wood in streams contributes its physical roles. The legacy wood in streams that run through the 45-year-old harvest units appears very functional. At what point will it decay, or will it persist and retain function until large trees begin to die in these even-age stands once they are over 100 years old? By allowing a glimpse of future conditions, study of these older, even-age stands could begin to provide ideas for the best current management of stands at ages similar to those we studied (e.g., 45 years old).

Research on red alder can be extended to landscape and regional scales because red alder is easily detected using remote sensing techniques (e.g., supervised classification of false color infrared images). With an understanding of the distribution of red alder in young-growth and old-growth forests, we can begin to discern ecological differences between natural disturbance and human-caused disturbance in landscapes. Along with the information gained from this study on the role of red alder at the scale of stand and stream reach, this knowledge will be useful in directing restoration projects.

CONCLUSIONS

Our multidisciplinary research will produce a predictive model for managers to simultaneously evaluate compatibility and tradeoffs of key resources across a continuum of red alder occurrence in young-growth forests of Southeast Alaska. Managers might use this model to target optimal levels of one resource or attempt to achieve the best compromise among several important resources. Our preliminary results are encouraging; live and dead red alder are biologically active substrates that generally appear to favor fish and wildlife. Mixed alder-conifer forests produce large conifer trees that are valuable both commercially and ecologically. Once viewed as a weed that merely competed with conifers, red alder may hold the key to achieving mutual compatibility among several key resources in managed young-growth forests.

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SECTION B

AQUATIC STUDIES

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INFLUENCE OF SITE AND LANDSCAPE FEATURES ON VERTEBRATE ASSEMBLAGES IN SMALL STREAMS

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ABSTRACT

The relative influence of site- and landscape-level habitat features on fishes and stream-dwelling amphibians was evaluated at 62 headwater streams on the Olympic Peninsula in Washington state. Watershed areas at the study sites ranged from 16 to 2,817 ha (average 265 ha) and the catchments had varied geologic, land use, and natural disturbance histories. Site-level features included stream habitat type, channel substrate, and riparian forest condition. Landscape-level features included forest age, drainage characteristics, elevation, road density, and landslide frequency. There were important differences in habitat associations among species within the two major headwater vertebrate groups (fishes and amphibians) as well as between the two groups themselves. In general, fishes were more strongly influenced by in-stream habitat parameters than by riparian or watershed variables. Stream-dwelling amphibians, however, were influenced by riparian and watershed features and were less affected by in-stream habitats. Thus, fishes may be the best overall indicators of site-scale stream conditions; amphibians seem to be more sensitive indicators of landscape-scale riparian and upland features. Preliminary comparison of the information value of different landscape-level variables (their importance to stream-dwelling vertebrates relative to the cost of obtaining them) showed that certain variables had much greater utility for landscape-scale assessments than others.

KEY WORDS: Streams, fish, amphibians, riparian, watersheds.

INTRODUCTION

Riparian zones are recognized as fundamentally important interfaces between aquatic and terrestrial ecosystems (Agee 1988; Gregory et al. 1991; FEMAT 1993; Naiman et al. 2000). In addition to mediating the transfer of materials between land and water, riparian zones provide key habitat elements for many species of fish and wildlife. Virtually all aquatic species and many terrestrial plant and animal species closely associated with riparian zones are sensitive to management-induced changes in riparian condition (Thomas et al. 1979; Naiman et al. 1995). The way in which these species respond to anthropogenic disturbance is usually complex and strongly influenced by ecological processes at a particular site (Hayes et al. 1996); therefore, it is often difficult to predict how a particular aquatic-riparian ecosystem will change following a management activity. Recent studies have demonstrated a reduction in aquatic and terrestrial biodiversity in watersheds containing primarily young, managed forests (Reeves et al. 1993; Thomas et al. 1993), and the emerging application of ecosystem-based forestry in the Pacific Northwest has embraced deliberate attempts to restore riparian areas to conditions more like those produced by natural processes (FEMAT 1993; Quigley et al. 1996).

Despite the acknowledged importance of riparian zones to fish and wildlife, relatively few studies have examined the response of riparian systems to management alternatives for commodity production, riparian protection, or

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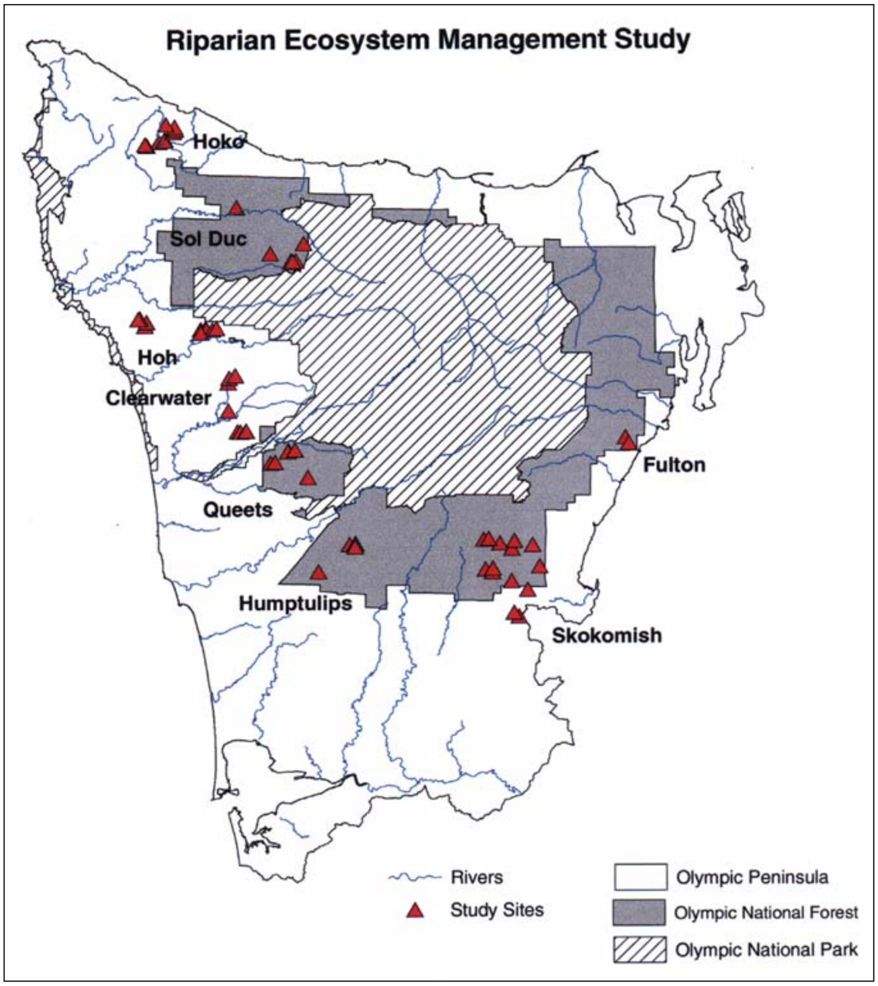

Figure 1—Location of study sites on the Olympic Peninsula, Washington state. Names of major river basins in which study sites occurred are given. The crosshatched area bounds Olympic National Forest and Olympic National Park.

restoration. The Coastal Oregon Productivity Enhancement (COPE) program in Oregon sponsored investigations of riparian rehabilitation, chiefly involving the re-establishment of conifers in alder- and brush-dominated riparian zones[5], and similar research programs have begun in coastal areas of Washington (Berg 1995). In addition to the challenge of re-establishing conifers in riparian zones dominated by deciduous trees or herbaceous vegetation, a number of other important questions exist pertaining to riparian management, e.g., what buffer widths and configurations are needed to protect fish and wildlife habitat along different stream types, what proportion of riparian zones should remain in different seral stages over broad landscapes, whether acceleration of mature forest and old-growth conditions can be achieved through thinning and other silvicultural treatments in a cost-effective manner, and whether riparian vegetation can be deliberately managed for the benefit of aquatic or terrestrial wildlife.

The Riparian Ecosystem Management Study (REMS) examined the effect of different streamside buffers on the major aquatic- and riparian-associated vertebrates, i.e., fishes, amphibians, birds, and small mammals. A total of 62 streams and associated riparian zones were examined on Washington's Olympic Peninsula from 1996 to 1999. Most of our study sites were located in small watersheds, and in fact, about one-third of the streams were too small or too steep to support fishes. Nevertheless, such small streams comprise a majority of the stream network and their riparian zones can occupy a significant portion of the landscape in areas with high drainage densities. The fundamental question we asked was: *Does the structure of managed riparian zones in small streams influence the presence and/or abundance of aquatic and riparian-associated vertebrates?*

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Table 1—Top: common names of headwater stream vertebrates[a]. Bottom: site- and landscape-scale variables examined in this study

	Taxa	
Fishes	**Amphibians**	**Assemblages**
Cutthroat trout	Tailed fiog	All fish species
Torrent sculpin	Cope's giant salamander	All stream-dwelling
Coastrange sculpin	Torrent salamander	amphibian species
	Environmental variables	
	Site	*Landscape*
In-stream	**Riparian**	**Watershed**
Stream channel gradient	Canopy density	% watershed in early-seral forest
% channel in scour pools	% riparian early-seral forest	% watershed in mid-seral forest
% channel in fast-water habitats (riffles, cascades)	% riparian mid-seral forest	% watershed in late-seral forest
	% riparian late-seral forest	Road density
% channel in glides		Drainage density
% channel in silt and sand substrate		Watershed area
		Elevation at base
% channel in gravel and pebble substrate		% watershed area in recently active landslides
		% watershed area in southerly aspect
% channel in large and small cobble substrate		% watershed area with steep slopes (>60%)
% channel in boulder and bedrock substrate		

[a] Other taxa (e.g., coho salmon, western redback salamander) were occasionally sampled in the streams, but their frequencies were too low to be included in the analyses.

Although REMS was designed to evaluate vertebrate responses to riparian conditions at the site level (typically, 300 m reaches), we could not ignore the possibility that fishes and amphibians may have been influenced by broad-scale characteristics of the watersheds they inhabited, irrespective of the condition of the immediately adjacent riparian zone. Because our initial analysis of the relationship between different vertebrates and site-level features left many unanswered questions regarding what environmental factors were most influential, we expanded the assessment to include landscape-scale features such as forest age, drainage characteristics, elevation, road density, and disturbance history. This paper reports on the relative influence of site- and landscape-level habitat characteristics on headwater stream vertebrates. Correlation analysis was used to determine the association between abundance of different organisms and site- and landscape-level parameters. We further compared the information value of different parameters (i.e., their overall importance to stream-dwelling vertebrates) to the relative cost of estimating those parameters, in order to identify cost-effective landscape-level indicators of environmental suitability for these organisms. Additional information about the study is found in a companion paper (Raphael et al. 2002, in this proceedings).

STUDY LOCATION AND METHODS

Study Sites

A total of 62 sites consisting of 300-m reaches of stream channel and adjacent riparian zone was selected in first- to third-order, forested streams on Washington's Olympic Peninsula (Figure 1). Most streams were small, 1 to 7 m wide; a few slightly larger streams were 7 to 11 m wide. Elevations of study sites ranged from 120 to 720 m. Riparian conditions at each site were assigned to six different classes depending on whether they were (1) unmanaged with intact forest on both sides of the stream, (2) old forest buffers 16 to 150 m wide (mean = 65 m) within adjacent clear-cuts, (3) second-growth forest 35 to 100 years old with no adjacent harvest, (4) intact second-growth forest

Table 2—Description of site- and landscape-scale (watershed) parameters used in the analysis

Variable	Variable Type	Description
Site variables		
Stream gradient	In-stream	An average of five or more clinometer measurements along the study reach.
% channel in scour pools	In-stream	Ratio of scour pools (eddy, lateral, mid-channel, plunge) to the total of all habitat units along the study reach.
% channel in fast water habitats	In-stream	Ratio of fast water habitats (rapids, riffles, cascades, chutes and falls) to the total of all habitat units along the study reach.
% channel in glides	In-stream	As above, includes other non-turbulent, fast water habitats such as sheets and runs as well as glides.
% channel in silt and sand substrate	In-stream	Visually estimated % of the wetted substrate in particle sizes <1 to 2mm.
% channel in gravel and pebble substrate	In-stream	Visually estimated % of the wetted substrate in particle sizes 3 to 64mm.
% channel in large and small cobble substrate	In-stream	Visually estimated % of the wetted substrate in particle sizes 65 to 256mm.
% channel in boulder and bedrock substrate	In-stream	Visually estimated % of the wetted substrate in particle sizes >256mm.
Canopy density	Riparian	An average of five or more measurements taken along the channel of each study reach with a canopy densiometer.
% riparian early-seral forest	Riparian	The percentage of the riparian zone adjacent to the study reach in early-seral forest <30 years old.
% riparian mid-seral forest	Riparian	The percentage of the riparian zone adjacent to the study reach in mid-seral forest 31 to 100 years old.
% riparian late-seral forest	Riparian	The percentage of the riparian zone adjacent to the study reach in late-seral forest greater than 100 years old.
Landscape variables		
% watershed early-seral forest	Watershed	A ratio of area of the watershed occupied by early-seral forests less than 30 years old to the total watershed area.
% watershed mid-seral forest	Watershed	A ratio of area of the watershed occupied by mid-seral forests 31 to 100 years old to the total watershed area.
% watershed late-seral forest	Watershed	A ratio of area of the watershed occupied by late-seral forests greater than 100 years old to the total watershed area.
Road density	Watershed	Ratio of road length to watershed area expressed as km/km^2.
Drainage density	Watershed	Ratio of the length of streams to the total watershed area, expressed as km/km^2.
Watershed area	Watershed	The two-dimensional area of the catchment, as measured from the down stream end of each study reach.
Elevation	Watershed	Elevation at the downstream end of each study reach
Recently active landslides	Watershed	A ratio of the area of recently active landslides to the total watershed area, as estimated from aerial photos up to 30 years old.
% watershed in southerly aspect	Watershed	Derived from DEM, a ratio of area of watershed slope aspects between 90° and 270°, to the total watershed area.
% watershed in slopes greater than 60%	Watershed	Derived from DEM, a ratio of area of watershed slopes steeper than 60%, to the total watershed area.

with commercial thinning, (5) second-growth buffers 14 to 32 m wide (mean = 22 m) within adjacent clearcuts, and (6) logged sites up to 35 years old, lacking riparian buffers.

Channel unit surveys (Hawkins et al. 1993) were conducted along the entire length of each stream reach and the dominant streambed substrate was estimated visually. Sites were located on lands administered by the Olympic National Forest, Washington State Department of Natural Resources, and private industrial forest landowners. We studied 3 fish species, 3 amphibian species, 2 vertebrate assemblages (fishes, amphibians), 8 in-stream habitat variables, 4 riparian forest variables, and 10 landscape variables (Table 1). An explanation of the environmental variables is presented in Table 2.

Within the context of this investigation we found no streams that had large Northwest Forest Plan buffers (either 1- or 2-site potential tree heights wide), so we were unable to evaluate that particular buffer treatment. Virtually all study sites were in unmanaged watersheds or areas previously logged according to older buffer strip guidelines that permitted timber harvesting to within 10 to 30 m of the channel. Furthermore, we found that even riparian buffers of mature or old forest had often experienced considerable windthrow. Most of the riparian zones we examined, even those on National Forest, had been managed with a heavy emphasis on wood production.

Vertebrate Samples

Fish were sampled by electrofishing using a complete removal summation method. Several randomly selected channel units of each type (Hawkins et al. 1993) present in the reach were repeatedly sampled until no more fish were captured; the combined number of captures represented the estimate for the channel unit. The average density of each fish species in a particular type of channel unit was then extrapolated to the reach as a whole based on the areal percentage of that channel unit type in the stream. Estimated fish densities for each channel unit type, weighted according to the frequency of that type in the overall reach, were combined to produce a stratified estimate of the average fish density throughout the reach. Approximately 40% of the 62 sites we examined possessed no fish, either because they were upstream from an impassable barrier that prevented fish colonization or because they were intermittent and did not provide sufficient surface flow for fish habitation during summer.

Amphibian surveys utilized a randomized transect sampling design. Transects or belts, located perpendicular to the stream channel, were located at 10 m intervals along each study reach. Belts were 1 m wide with variable lengths depending on the wetted width of the stream at that specific location along the channel. Transects were extended beyond the wetted channel for short distances where there were springs or seeps along the channel edge.

Environmental Parameters

GIS data layers were used to characterize environmental parameters at the landscape level. Catchment areas were delineated from 10-m digital elevation models (DEMs) obtained from the Olympic National Forest (ONF). Road data were from transportation system maps developed by the ONF in 1990, then updated with 1997 digital ortho-imagery. Forest stand age was derived from a combination of stand data from several watershed analyses conducted on the Olympic Peninsula from 1994 to 1997, and all stand maps were combined and updated with 1997 digital ortho-imagery. Stream networks were derived from a hydrography cover created in 1992 by the ONF and updated with 1997 ortho-imagery at 10-m DEMs. Landslide coverages were also derived from recent watershed analyses on the Olympic Peninsula. Landslide locations were verified with low elevation aerial photographs taken between 1970 and 1999.

Analyses

We utilized a retrospective approach involving comparisons of many sites with different times since logging and different buffer characteristics, instead of long-term analyses of a few sites before and after logging (i.e., the "substituting space for time" approach). The null hypothesis was that there would be no association between the abundance of small stream vertebrates and the characteristics of the adjacent riparian zone assessed in this study. Rejection of the null hypothesis would indicate that certain types of riparian stand conditions affect the composition of some vertebrates.

We used a non-parametric correlation coefficient, Spearman's *rho*, to measure the strength of association between rank-ordered data. The more commonly used parametric correlation coefficient, Pearson's coefficient, was not used because it assumed a linear relationship between two variables, and it was clear from initial scatter plots that associations between vertebrate densities and many variables in the REMS data set were not linear. We standardized all species and assemblage densities to the number of organisms per 100 square m of the wetted stream channel. Tests were two-tailed, and we identified as significant those variables whose association with vertebrate abundance resulted in a Type 1 error of less than 10%. Zero captures

Table 3—Association between headwater stream vertebrates and site- and landscape-scale variables[a]

Species/sample size	In-stream	Riparian	Watershed
Cutthroat trout, n = 27	Stream gradient (+) % scour pools (+) % glides (-) % small/large cobble (-)		Watershed area (-)
Torrent sculpin, n = 15	% scour pools (+) % fast water habitats (-) % glides (-) % gravel and pebble substrate (-)	% of riparian zone in mid-seral forest (+) % of riparian zone in late-seral forest (-)	% of watershed in late-seral forest(-) Watershed area (-) Recently active landslides (-)
Coastrange sculpin, n = 17	% scour pools (+) % fast water habitats (-) % glides (-) % silt and sand substrate (+) % pebble and gravel substrate (-)	% of riparian zone in late-seral forest (-)	% of watershed in late-seral forest (-) Elevation (-) Drainage density (-)
Tailed frog, n = 20	% boulder and bedrock substrate (+)	% of riparian in late-seral forest (+)	Elevation (+) Watershed area (+) % of watershed with steep slopes (+)
Cope's giant salamander, n = 24	% silt and sand substrate (+)		Road density (-) Recently active landslides (+) Drainage density (-)
Torrent salamander, n = 16	Stream gradient (+) % small and large cobble substrate (-) % boulder and bedrock substrate (-)		% of watershed with steep slopes (+) Elevation (+)
All fishes combined, n = 37	% scour pools (+) % fast water habitats (-) % glides (-) % silt and sand substrate (+) % pebble and gravel substrate (-)	% of riparian zone in late-seral forest (-)	% of watershed in late-seral forest (-) Elevation (-) Recent landslide activity (-) Southerly aspect (+)
All stream-dwelling amphibians combined, n = 29	% silt and sand substrate (+) Stream gradient (+)	% riparian in early-seral forest (+) % riparian in late-seral forest (+)	% of watershed in seral forest (-) % of watershed in late-seral forest (+) Road density (-) Elevation (+)

[a] Only variables with Spearman's *rho* correlation coefficients having a probability less than 0.10 are shown; all other associations were considered non-significant. Plus signs in parentheses indicate a positive correlation between organism density and a variable. Minus signs indicate a negative correlation. Sample sizes refer to the number of sites in which taxa occurred.

were included in the analyses and all independent variables (Table 1) were included in the model. Statistical tests were performed using SPSS[6] software.

Some of the landscape-scale parameters in the analysis were expensive and time consuming to quantify, often requiring hours of map reading and digitizing. Furthermore, field surveys required many hours of labor, data transcription, and analysis. Because some parameters turned out to have more influence on headwater vertebrates than others, we also compared the "information value" of the variables that were studied, i.e., their weighted average value in correlation analysis of all taxa (irrespective of sign) to the relative cost of obtaining quantitative values for them. Equipment costs were not included; we based our estimates solely on the number of hours required to measure or otherwise quantify each parameter. The goal was to assess the relative cost and benefit of including different site- and landscape-scale features in the analysis of vertebrate abundance.

RESULTS

Fishes

There were important differences in habitat associations between species within major groups (fish and amphibians) as well as between species themselves. In general, fishes were more closely associated with in-stream habitat parameters than with adjacent riparian or watershed variables (Table 3). Cutthroat trout (*Oncorhynchus clarki clarki*) preferred small watersheds and streams with abundant pool habitat. Their lower densities in streams with glides, habitats with cobble substrate, and larger watersheds may have been indicative of reduced abundance in low-gradient, alluvial streams. Cutthroat trout were not sensitive indicators of riparian forest condition.

Torrent sculpins (*Cottus rhotheus*) preferred streams in small watersheds with abundant pool habitat, mid-seral riparian forests (*not* late-seral riparian forests), and watersheds in which there was little mass wasting (landslides). Like cutthroat trout, torrent sculpins were less abundant in low-gradient streams dominated by glide habitat and substrates of moderate size (Table 3). The negative association between torrent sculpins and fast-water habitats could not be explained and may have been caused by factors that were not examined, including interactions with native amphibians.

Coastrange sculpins (*C. aleuticus*) primarily inhabited low elevation alluvial streams with abundant pool habitat. They preferred habitats with fine-grained substrates to those with coarse-grained substrates. Coastrange sculpin densities were reduced in streams with late-seral riparian forests and old-growth dominated watersheds.

Amphibians

Tailed frogs (*Ascaphus truei*) were associated with boulder-dominated streams in high-elevation watersheds with steep gradients and riparian zones dominated by late-seral forests (Table 3). If elevation was associated with cooler stream temperatures, tailed frogs may have been responding to colder waters in high-elevation streams, as this species is known to prefer cold water (Corkran and Thoms 1996).

There was no apparent relationship between the stream-dwelling Cope's giant salamander (*Dicamptodon copei*) and forest age within either the riparian zone or the entire watershed. There was reduced giant salamander abundance in watersheds with high road density and high drainage density. Greater Cope's giant salamander densities in watersheds with recent landslides and in habitats with fine-grained substrate suggest this species responds positively to both fine and coarse sediment inputs, but the reason for this apparent response could not be determined with the data at hand.

Olympic torrent salamanders (*Rhyacotriton olympicus*) preferred high-elevation watersheds with steep topography and high gradient stream channels. They appeared to avoid habitats with coarse-grained substrates (Table 3). There was no correlation between the abundance of torrent salamanders and the composition of riparian or upland forests.

Vertebrate Assemblages

Abundance of all fishes combined was greater in streams with frequent pools and fewer riffles and glides (Table 3). The positive association between fish assemblages and sand and silt substrate was probably also related to pools since pool habitat possessed deeper, slowly moving water where fine particles settled out. Overall fish density was reduced in coarse-grained, fast water and glide habitats, suggesting that riffles and cascades were less favorable habitats than pools. Fishes were also generally less abundant in streams with late-seral riparian and upland forests, as well as in high-elevation watersheds and those with recent landslide activity. The somewhat weak but significant correlation between fish abundance and watersheds

[6] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

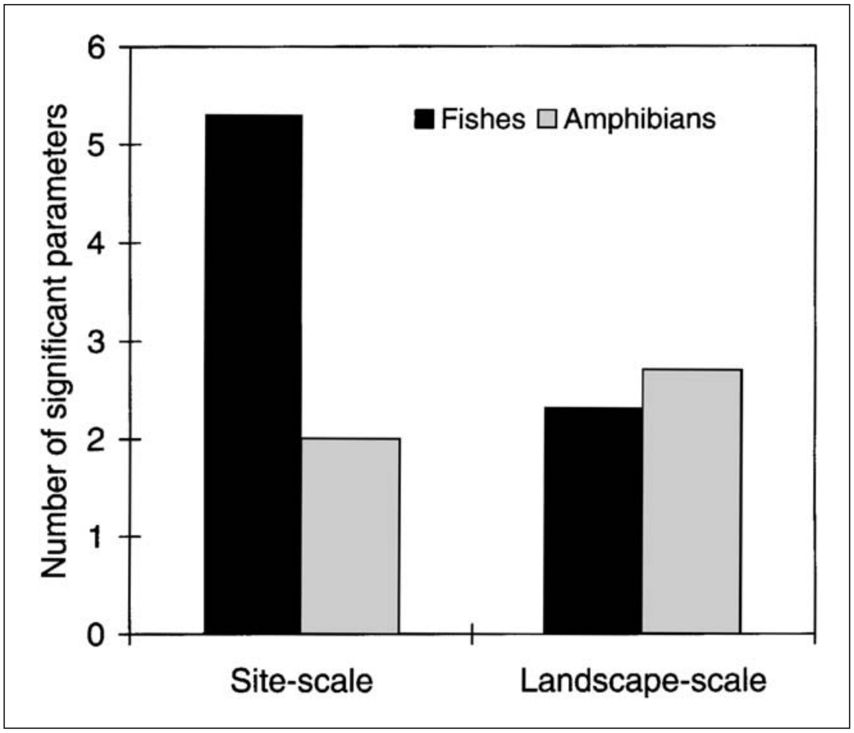

Figure 2—Comparison of the average number of site-scale and landscape-scale variables (Table 1) significantly influencing fish and amphibian species in headwater streams on the Olympic Peninsula.

with southern aspect (which would receive greater solar input) is consistent with the hypothesis that fish populations in headwater streams respond positively to increased solar radiation, resulting in elevated primary and secondary production (Gregory et al. 1987).

Amphibians as a group were more abundant in steep, montane streams than in low gradient coastal streams. Their positive association with sand and silt substrate suggested that most amphibians selected depositional habitats away from swift, turbulent areas of flow. Tailed frog tadpoles were an exception; they preferred turbulent cascade habitat with coarse substrate. Overall, amphibians favored streams with late-seral riparian and upland forests and avoided those with early-seral forests (Table 3). Abundance was greater in high-elevation watersheds but reduced where road densities were above average. The apparent preference of stream-dwelling amphibians for watersheds with late-seral forests and low road density is consistent with the hypothesis that they prosper in landscapes where human disturbance is minimized.

Fishes appeared to be more responsive to local conditions than to landscape-scale features, while amphibians were less sensitive to site conditions and were more influenced by the characteristics of the landscape (Figure 2). On average, about five in-stream and riparian site parameters significantly influenced each species, although the parameters themselves differed from species to species. At the watershed scale only about two features, on average, influenced fishes. Amphibians, however, appeared to be more sensitive to landscape-scale parameters than to local conditions. While the reasons for this difference in sensitivity to site and landscape features between fishes and amphibians is not entirely clear, it may have been related to the strict dependence of fish on aquatic habitats, while some amphibians also rely on terrestrial habitats and their movements may have included some upland areas. Thus, amphibians as a group may better integrate overall watershed condition.

Some landscape-scale parameters had greater influence for vertebrate abundance than others, and some were considerably more costly to estimate. The relative cost of obtaining the estimates for landscape-scale parameters was plotted against the information value, i.e., their average score in correlation analysis, of these estimates for headwater vertebrates in our study (Figure 3). We also included two site-level parameters–riparian vegetation and channel gradient–that could have been estimated from air photos or DEM analysis instead of the ground-based methods used in this study, and thus included in landscape assessments. As expected, on-site surveys provided very useful information. However, on-site data were far more expensive to obtain than remote-sensed or map data (Figure 3). Age of riparian vegetation, watershed elevation, and the forest age distribu-

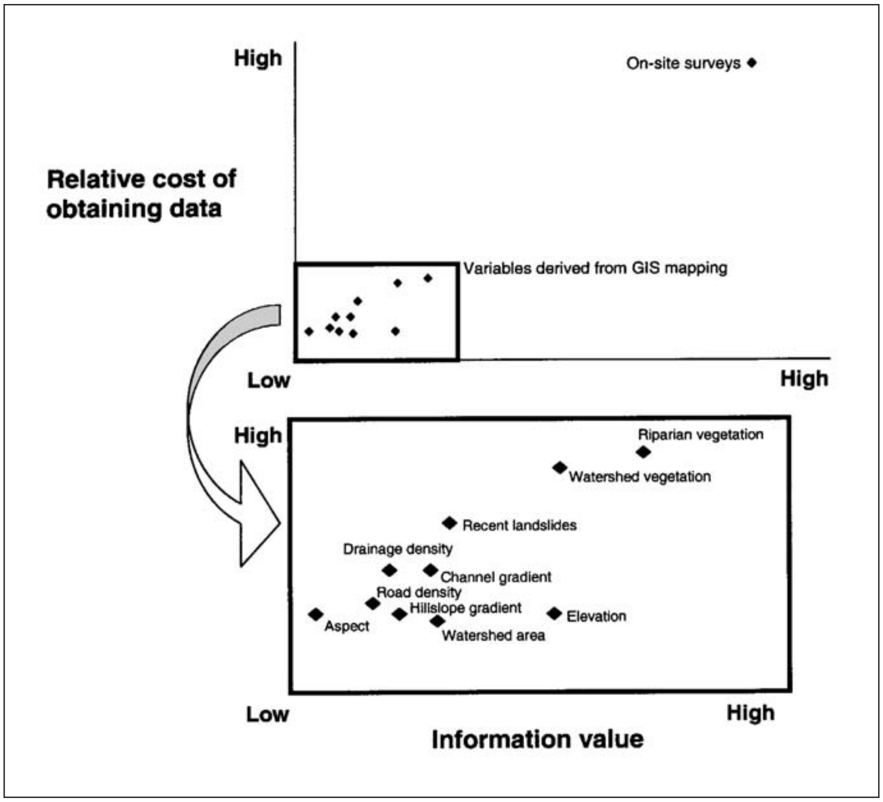

Figure 3—Cost-benefit comparison of various landscape-scale parameters. Information value is the relative influence of each parameter on headwater vertebrates.

tion within the watershed had moderate to high information value. The importance of elevation tended to be high for fishes, and forest characteristics were often valuable for interpreting amphibian abundance. However, the seral age of forest stands was relatively expensive to quantify, both from ground-based surveys and from GIS analyses. The frequency of recent landslides, watershed area, hillslope gradient, drainage density, and road density all had low to moderate average information value, with mass wasting (landslides) being the most expensive to quantify because landslide coverage must be estimated from air photos. Watershed aspect was relatively inexpensive to measure but yielded little information about environmental suitability for headwater vertebrates.

We do not wish to infer that only the parameters scoring high in correlation analysis are worth pursuing, or that those parameters of low information content should not be investigated. Rather, we suggest that this crude cost-benefit analysis may help planners prioritize environmental parameters in landscape assessments of the effects of forest management on headwater vertebrates, and provide hypotheses for other investigators attempting to understand the abundance of fishes and amphibians in small watersheds.

DISCUSSION AND SUMMARY

Results of the study were not consistent across different types of organisms. For fishes, there was little association between species abundance and riparian forest age or the percentage of late-seral forest in the watershed; however, fishes tended to be strongly influenced by the condition of in-stream habitat. Although the riparian forest probably influenced in-stream habitat, our results suggested that the number and size of pools and other habitat parameters important to fishes was likely controlled by a number of other factors, including recruitment of logs and large boulders to the channels by landslides, debris flows, and other disturbance mechanisms. Other parameters associated with the local abundance of fishes in these headwater systems included the elevation of the watershed, gradient of the channel, and the amount of primary production (aquatic plant production as controlled by light and nutrients). Overall, headwater fish populations were highly variable from site to site, which was expected in these disturbance-prone environments (Zalewski and Naiman 1985). Thus, *at the site-level*, we did not reject the hypothesis that the characteristics of the riparian forest had no influence on fish abundance in Olympic Peninsula streams.

Amphibians, however, proved to be more responsive than fishes to riparian forest condition and the amount of late-seral forest in their watersheds. Some amphibians were found to be adaptable generalists, while others were more sensitive to forest management in or near the riparian zone (see Raphael et al. 2002, in this proceedings). Our study suggested that stream-dwelling amphibians were negatively affected by timber removal near small streams. Riparian areas composed of young, early-successional forests did not support amphibian populations at the densities observed in late-seral sites. Buffers of old-growth trees apparently provided habitat refugia for some species and were valuable source areas for recolonization. On the whole, results support the hypothesis that the characteristics of riparian buffers do influence amphibian abundance in Olympic Peninsula streams.

It was clear from our study that the relationship between forest management and the integrity of aquatic and riparian ecosystems was complex. We doubt that it is possible to produce a model or series of models that would predict, quantitatively and with a high level of certainty, the response of headwater aquatic- and riparian-associated vertebrates to management actions at the landscape scale, unless those management actions involved such drastic changes that there would be significant and irreversible alteration of the environment. Likewise, our research suggests that it would be difficult to tailor management actions *at the site level* to produce desired changes in small stream vertebrates *at the population level*. In other words, it seems unlikely that varying the age of riparian buffers at the scale of an operational unit (e.g., 20-100 ha) will predictably and measurably affect the distribution or abundance of most stream-dwelling vertebrate populations within the management area. This is because there will be a spatial mismatch between the distributional boundaries of vertebrate populations and the boundaries of stand-level operations, and because most organisms are free to move from unfavorable to favorable habitats (Schlosser and Angermeier 1995). Local reductions or increases in suitable habitat resulting from stand-level operations may be too small to affect overall population abundance within remaining patches of habitat.

On the other hand, consistent changes in riparian forest properties across large areas may be sufficient to influence population change. If changes in riparian forest structure and composition are pervasive enough to eliminate habitat refugia, populations of headwater vertebrates could decline because suitable habitat is not present throughout their native range and there are insufficient travel corridors to allow for recolonization (Fausch and Young 1995). Because of the unique habitat requirements of different species, linkages between management actions and species' abundance requires understanding at the local population level. For certain species, e.g., resident headwater trout or amphibians with limited distributions, breeding populations can be confined to relatively small areas. For others, e.g., anadromous salmon or neotropical migrant birds, population boundaries are very large. Our study suggests that predictable relationships between species abundance and management activities will require calibration with locally derived data.

A single broadscale measure of ecological performance probably does not exist for headwater vertebrates. Landscape-scale measures of ecosystem condition and performance such as the percentage of a watershed in late-successional forest, the time since the last major disturbance, or the density of roads in an area, may be important to aquatic- and riparian-associated vertebrates but they are insufficient, by themselves, to explain changes in populations over time. Most headwater organisms are controlled by multiple biotic and abiotic factors, each of which can be more or less important during different periods of the life cycle or over different years (Reeves et al. 1998). Significant associations between some organisms and certain landscape measures were detected in our study, but it is incorrect to assume that a quantitative shift in a single landscape variable (e.g., % old-growth forest, buffer width, density of logging roads) will produce a predictable shift in a species of interest.

Although we conducted correlation analyses between populations and watershed characteristics, none of the watersheds in which sites were located possessed buffers of uniform width and stand age throughout the drainage network. Therefore, we do not have a real basis for assessing the compatibility or tradeoffs between riparian buffer characteristics and vertebrate communities at the ecoregion level. The Olympic Peninsula, where this study was carried out, contains a large inner core of unmanaged, pristine forest (Olympic National Park) surrounded by lands that have been intensely managed for wood production. We found comparatively few *major* differences among the vertebrate populations of headwater streams regardless of buffer properties, but results might have been different if the large, central refuge area of Olympic National Park had not been present.

Our failure to detect consistent differences among riparian treatments was influenced by the limited size of our study sites, usually about 300 linear meters of stream and riparian zone. In spite of our efforts to locate watersheds in which riparian treatments were applied more uniformly across the landscape, or to arrange for deliberate riparian management experiments involving manipulation at a much larger scale, we were unable to locate any study areas that possessed uniform buffers throughout the stream system. Complex patterns of land ownership on the Olympic Peninsula involving public, state, private industrial, small private, and tribal forest lands, each with different riparian management prescriptions, further exacerbated the problem of finding study sites with uniform conditions. In this sense, our study was unable to answer the general question: *"Does the structure of managed riparian zones in small streams influence the presence and or abundance of aquatic- and riparian-associated vertebrates?"* because we could not examine biophysical responses at a scale appropriate to the question.

Finding the right approach to this question remains problematic. The prospect of locating study sites large enough to experimentally implement different buffer treatments at a scale permitting evaluation of variable buffer widths or tree spacing on vertebrate populations is daunting. The alternative approach, relying on simulation modeling or landscape analysis to predict those same effects, often involves many untested (and often incorrect) assumptions. We believe knowledge of life cycles and species' habitat requirements is a necessary precursor to large-scale modeling; therefore, we advocate continued investigations at the species level while exploring alternate methods of scaling up hypothesis testing to the assemblage and landscape level using a combination of controlled small watershed studies, as in the Hubbard Brook or Alsea Watershed investigations, and new methods of landscape analysis. Information derived from such studies will more effectively inform decision-makers charged with balancing the tradeoff between wood production and environmental protection of headwater aquatic and riparian ecosystems.

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A SURVEY OF RESEARCH ON RIPARIAN RESPONSES TO SILVICULTURE

Patrick G. Cunningham[1]

ABSTRACT

Some of the most critical issues that federal land managers and researchers are facing in the Pacific Northwest are centered around riparian processes and management, and how upslope management activities affect riparian systems. Researchers are developing a literature on riparian-related questions dominated by observational studies of riparian-area processes, vegetation, and wildlife species. Some experiments were conducted, and more are on the way. Issues that led to the development of the Northwest Forest Plan motivated many of these past and present studies. Very few of these studies, however, have examined the relation between upslope forest stand management and its effects on riparian ecosystems. The Bureau of Land Management density-management and riparian-buffer studies are among the few exceptions to this development. Some questions are emerging from this and other work that, when addressed, will help researchers and managers better understand the interactions between upslope forest management and riparian ecosystems.

KEY WORDS: Riparian area, stand density management, upslope-riparian interactions, Aquatic Conservation Strategy, Northwest Forest Plan.

INTRODUCTION

Current environmental issues are leading federal forest managers and researchers in the Pacific Northwest along new paths of management, research, and collaboration. The Northwest Forest Plan (USDA and USDI 1994) provides a framework under which these new paths are explored. Experience, in some cases, provides some common-sense adaptations of traditional forest management activities into new problem-solving approaches, such as silvicultural prescriptions to achieve ecosystem management objectives useful in addressing some current environmental issues.

Some of the issues that managers and researchers are facing in the Pacific Northwest deal with understanding riparian area processes and management, and the role of forest stand management in young stands for aquatic and terrestrial habitat, wildlife, and ecosystem processes. Some of the questions that researchers and managers are facing related to riparian management issues are listed below.

1. How are wildlife species, riparian areas, and streams affected by different upslope management options?

2. How do wildlife species, riparian areas, and streams respond to different kinds of management in riparian areas?

3. Can buffers around riparian areas protect these systems from adverse effects of management?

4. What are the benefits and costs of various riparian buffer widths?

5. Are general guidelines for riparian buffer widths and management desirable or even possible?

These and other questions are guiding current research on riparian processes and management in the Pacific Northwest. After introducing some of the important literature on problems related to riparian ecology in the Pacific Northwest, I introduce some issues about riparian area function and management, and some research projects that are addressing these issues and the above-stated questions.

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Several syntheses pertaining to riparian ecosystems are available in the literature. Gregory et al. (1991); Naiman et al. (2000); and Swanson et al. (1982) concentrate their syntheses on the northwestern United States and Canada. Hohler et al. (2001) addresses riparian-related research that was conducted under guidelines from the Northwest Forest Plan (USDA and USDI 1994). Naiman and Decamps (1997) synthesize a large body of knowledge about riparian ecosystems and management from many countries. They extend the discussion of riparian issues beyond forest ecosystems to agricultural and industrial contexts .

RIPARIAN FUNCTIONS AND PROCESSES

Riparian ecosystems are described as the area of interaction, or transition, between aquatic and terrestrial ecosystems (Gregory et al. 1991; Swanson et al. 1982). Naiman and Decamps (1997) describe riparian zones as extending from the low-water marks of streams through that part of the terrestrial landscape in which vegetation and soils are influenced by the presence of high water or high water tables. Definitions of riparian zones, however, vary among researchers. They are described as areas that are both difficult (Gregory et al. 1991) and easy (Naiman et al. 2000) to distinguish from their adjacent terrestrial ecosystems. Some riparian areas appear more similar to their surrounding upland forest ecosystems than do others. Riparian ecosystems comprise many communities, processes, and interacting structures (Gregory et al. 1991).

Forman and Godron (1986) and Forman (1995) view riparian areas from the perspective of landscape ecology as corridors that serve many purposes including travel routes for wildlife, buffers for minimizing downstream flooding, filters for dissolved nutrients, and many other functions. Machtans et al. (1996) provided evidence to partially support the role of riparian areas as travel corridors for some, mostly juvenile, songbird species in Alberta, Canada. Some of the landscape functions of riparian areas, however, including the travel role of corridors, which are widely touted as important landscape functions of riparian areas, are not yet sufficiently tested and serve only as conceptual models. Vegetation in riparian areas performs many important landscape and other ecological functions, including wood inputs to streams for developing complex structure for fish habitat and sediment control, shade for maintaining relatively low stream temperatures, organic materials for aquatic and terrestrial organisms, stream bank stability, and many other ecosystem functions (Beschta 1991; Gregory et al. 1991).

OUR PAST

Many researchers ignored vegetation in headwater stream environments in mountainous, forested terrain until the 1980s because of their small relative sizes and their low value of resources relative to upland resource values (Swanson et al. 1982). Research intensity in riparian ecology along these headwater streams has increased in recent years, partly in response to issues that led to the development of the Northwest Forest Plan for western Washington, western Oregon, and northern California (FEMAT 1993, USDA and USDI 1994). This research has included studies of riparian vegetation in the Oregon Coast Range (Minore and Weatherly 1994; Pabst and Spies 1998; Pabst and Spies 1999), microclimate (Brosofske et al. 1997; Danehy and Kirpes 2000[2]; Dong et al. 1998), amphibian responses to clearcutting (Bury and Corn 1988), bird species responses to clearcutting (Hagar 1999), and riparian management (Chan et al. 1997; Hibbs and Giordano 1996). Other studies conducted in upslope ecosystems, such as Chen et al. (1995), were influential in riparian decision-making.

Many of these studies provide information suggesting that forested riparian areas are different from upslope forested ecosystems in many different ways. Among these differences are the changing character of vegetation immediately along streams and the rapid disappearance of riparian vegetation with increasing distance from some streams (Minore and Weatherly 1994; Pabst and Spies 1999), declining populations of riparian amphibians and some birds with increased timber harvesting near streams (Bury and Corn 1988; Hagar 1999), and large differences in microclimate conditions between upslope buffer edges and streamsides when clearcutting is done near streams (Brosofske et al. 1997; Dong et al. 1998).

Bury and Corn (1988) suggested the benefits of riparian buffers to aquatic and riparian wildlife species in headwater ecosystems. They call for research designed specifically to determine appropriate riparian-buffer widths. Research by Brosofske et al. (1997); Dong et al. (1998); Hagar (1999); and O'Connell et al. (2000) suggest installing buffers between streams and timber harvest units. Brosofske et al. (1997) and Dong et al. (1998) use information from Chen

[2] Danehey and Kirpes (2000) report on a riparian microclimate study conducted on private forest lands after thinning in eastern Washington and Oregon.

et al. (1995), along with their own microclimate analyses, to suggest that riparian buffer widths in their study areas should be at least 45 m, and in some cases as wide as 300 m. Hagar called for buffers at least 40 m wide and no reductions of large-tree density inside the buffer to protect bird populations. For western Washington state and private industrial forests, O'Connell et al. (2000) suggest that riparian buffers should be at least 30 m wide. Forman (1995) also suggested relatively wide buffers, although he does not provide specific width recommendations. Forman (1995) suggested that because most of the water, sediment, dissolved particles and other stream inputs originate high in watersheds, buffers around headwater sources and intermittent streams should be the widest of any in the watershed to protect against rapid changes in stream inputs.

The Northwest Forest Plan, through its Aquatic Conservation Strategy, provided interim guidelines for riparian reserve widths until they could be adjusted based on information gained from watershed analysis (USDA and USDI 1994). A site-potential tree, "a tree that has attained the average maximum height possible given site conditions where it occurs" is the basic unit of reference for the guidelines (FEMAT 1993). For streams, the interim guidelines for riparian-reserve widths are (USDA and USDI 1994):

- fish-bearing streams (the area on each side of the stream equal to the height of two site-potential trees, or 90 m slope distance, whichever is greater);

- permanently flowing nonfish-bearing streams (the area on each side of the stream equal to the height of one site-potential tree, or 45 m slope distance, whichever is greater); and

- seasonally flowing or intermittent streams (the area on each side of the stream to a distance equal to the height of one site-potential tree or 30 m slope distance, whichever is greater).

Interim guidance from the Aquatic Conservation Strategy (USDA and USDI 1994) recommends buffers for intermittent streams that are narrower than buffers for perennial, fish-bearing streams. Forman (1995), however, recommends the widest width for buffers around these same intermittent stream and seep areas.

Much of the research relating silvicultural activities and adjacent riparian ecosystems has involved clearcutting in upslope forests and near streams (Brosofske et al. 1997; Bury and Corn 1988; Dong et al. 1998; Hagar 1999; O'Connell et al. 2000). Clearcutting, however, is no longer the dominant forest-management method for a large proportion of federal forest lands managed under the Northwest Forest Plan; rather, along with providing riparian buffers for a broad range of conservation purposes, the Northwest Forest Plan also directs land managers to develop old-growth characteristics in managed stands on federal forest lands (USDA and USDI 1994). At least for the near future, little if any clearcutting is planned for outside matrix lands, and harvests in the matrix will generally include green-tree retention objectives.

Tappeiner et al. (1997) suggested that to best obtain old-growth characteristics in managed forests it is necessary to implement density-management prescriptions on existing plantations and naturally regenerated lands previously managed primarily for wood production. Unlike commercial thinning prescriptions, which are used primarily to release trees from competition and produce revenue, density management prescriptions use thinning to create habitat, stand diversity, stand structure, and to support accelerated growth of overstory and understory trees. Hayes et al. (1997) summarizes the research on the relation of various wildlife species to young-stand thinning, including some riparian-dependent species, and concludes that for some species of insects, birds, and small mammals, young-stand thinning can enhance habitat and promote species abundances.

Little research has centered on harvest methods in the Pacific Northwest other than clearcutting and their relations to riparian ecosystems, and researchers and managers have little experience in riparian silviculture in Pacific Northwest forests. This leaves researchers and managers with little empirical evidence to support decisions about stand density management near streams and about riparian buffer widths when harvest methods other than clearcutting are used. Knowledge is needed on the relationship between density-management prescriptions and riparian ecosystem conditions.

Several operational-scale experiments have occurred in recent years in the Pacific Northwest to address questions about stand and habitat development in young plantations, and, in some cases, development of old-growth characteristics. Among these experiments are the demonstration of ecosystem management options (DEMO) (Halpern and Raphael 1999), the forest ecosystem study (Carey et al. 1999), the Bureau of Land Management density-management study[3, 4], and several other studies. These experiments include thinning treatments in existing young stands to develop growing conditions for understory vegetation layers and habitat for various species of birds, mammals, and amphibians. They are done at similar scales, and their designs have some similarities. In addition to these studies in the Pacific Northwest, researchers in northern California have installed an operational-scale thinning experiment in the Blacks Mountain Experimental Forest (Oliver 2000). The Blacks Mountain experiment is in a ponderosa pine ecosystem and also includes prescribed fire and livestock grazing treatments (Oliver 2000).

In addition to these upslope studies, the Washington State Department of Natural Resources, through its Timber, Fish, and Wildlife agreement, sponsored an experiment of upslope clearcutting and alternative riparian management affects on wildlife in western Washington (O'Connell et al. 2000). Also, Cissel et al. (1998) and Cissel et al. (1999) have designed and are implementing a landscape-management case study on the Blue River watershed in the Willamette National Forest that includes guidelines for managing upslope forests and riparian areas. The density-management study, however, is distinguished from all of the other experiments because it has a companion study (the riparian buffer study) that examines riparian area management, riparian processes, and aquatic and riparian-dependent species, and their relations to alternative upslope density management activities[5].

These studies are addressing some of the questions presented at the beginning of the paper, but it is too early to know what kinds of answers will develop. These studies will also produce new questions to further develop understanding of riparian processes and upslope-riparian interactions.

THE CONCEPT OF RIPARIAN RESERVES

The concept of riparian reserves in the context of managing under the Northwest Forest Plan remains poorly defined. Some managers and researchers also use the term riparian buffer when referring to riparian reserves, but the terms are not used interchangeably by all. The Northwest Forest Plan documents are not clear about the meanings of these terms. For example, the Forest Ecosystem Management Assessment Team defines riparian reserves as "designated riparian areas found outside the late-successional reserves" (FEMAT 1993). Such a definition leaves managers and researchers wondering what, if any, activities they can do inside these areas.

Assuming that riparian reserves are managed differently than adjacent upslope forests, several views are possible for allowable management in riparian reserves, including:

1. no management;

2. light management (where "light" is defined in some specific quantitative or qualitative, and spatial and temporal way);

3. management for different priorities than for non-riparian-reserve lands; or

4. management for major short-term disturbances rather than relatively small areas to obtain long-term benefits to processes and functions.

The effects of these different concepts of management on riparian reserves and aquatic and riparian-dependent species remain unknown. Such possibilities suggest opportunities for designing experiments to assess the effects of the different alternative interpretations of riparian reserves.

Confusion over the meaning, purpose, and allowable management activities inside riparian buffers is related to questions about how wide riparian buffers should be in federal forests managed under the Northwest Forest Plan. If riparian buffers are no-harvest areas, can they be narrower than if they were managed using light-harvest methods? Also, if density-management prescriptions are applied in upslope forests, are riparian buffers needed at all?

Misunderstandings that are generated from such vague management guidelines can lead to paralysis in decision-making. Under such conditions, interim guidelines become default standards. Also, interim guidelines for riparian

[3] Olson, D.H.; Hansen, B.; Chan, S.; Cunningham, P. 1999. A synthesis of forested headwater habitats and species: a case study of the compatibility of resource production and protection. On file with: Deanna H. Olson, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331. [Variable pagination].

[4] Tappeiner, J.; Thompson, C. 1996. Study plan for the density-management studies. On file with John C. Tappeiner, Oregon State University, College of Forestry, Corvallis, OR 97331.

[5] Olson, D.H.; Hansen, B.; Ellenburg, L.; Sedel, J. [N.d.]. Density management study: riparian buffer component; aquatic habitats and vertebrate diversity. Unpublished study plan, on file with: Deanna H. Olson, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331.

reserve widths can consume most of the landscape in some areas. For example, these reserves cover over 80% of the federal coastal forests in Oregon (Chan et al. 1997).

Research is needed on the ecological and economic effects of the alternative views of riparian reserves, and on how upslope management practices affect riparian function and values. In addition, research is needed on the interactions among these effects. Confronting some of these effects and their interactions can clarify the roles of upslope forests, riparian areas, and aquatic ecosystems for policy and decision-making under the Northwest Forest Plan and beyond.

A LOOK AHEAD

The combined density-management and riparian-buffer study is the first experiment in forests managed under the Northwest Forest Plan to simultaneously address riparian and upslope management issues. It is providing researchers and managers with new knowledge about species and habitat before and after applying several different upslope density-management and riparian-buffer treatments. This study is also serving other purposes for researchers and land-management agencies, including:

- demonstration sites for stand-density and riparian-area management options,
- new methods for measuring responses to treatments,
- species and site-specific knowledge, and
- hypotheses for future research.

Knowledge from this and other studies will be useful in designing future experiments to further examine riparian-area function and management. Questions remain about riparian processes and management. No single experiment will provide all of the knowledge needed to understand and manage these important areas. Observational, retrospective, and modeling studies will also provide useful information to help learn about these ecosystems and interactions.

One of the important issues in riparian management in Pacific Northwest forests is related to the response of riparian ecosystems to management activities inside riparian areas. Many riparian areas in the region, managed under the Northwest Forest Plan, are currently dominated by red alder (Minore and Weatherly 1994; Hibbs and Giordano 1996). As these alder stands begin to fall apart, many of them will be replaced by salmonberry, not by conifers (Hibbs and Giordano 1996). If managers want to see conifers develop in these areas for stand structure and wood recruitment, researchers will need to develop knowledge about the responses of riparian ecosystems to the kinds of silvicultural practices that will support conifer development in these areas. Other questions about management activities in riparian areas are also in need of addressing.

CONCLUSION

Much literature exists, and research is continuing, on upland silviculture, riparian vegetation, and wildlife species for the forests managed under the Northwest Forest Plan. Findings from some of the continuing studies are emerging, yet large gaps remain in knowledge about riparian conditions, processes, and species—especially about how they interact with each other. Along with the new findings, new questions are starting to emerge that will direct the next generation of research. As researchers refine the new questions into testable hypotheses, new designs for operational-scale research are needed.

At the same time, land managers are learning how to manage differently than they have in the past, frequently with the help of researchers. Some operational-scale experiments have been designed specifically to help managers learn about the ecosystems that they manage at the same time that these studies are helping researchers better understand complex systems, such as riparian areas. The next generation of experiments will need to continue to strengthen the collaborative relationships between researchers and managers.

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RIPARIAN BUFFERS AND THINNING DESIGNS IN WESTERN OREGON HEADWATERS ACCOMPLISH MULTIPLE RESOURCE OBJECTIVES

Deanna H. Olson[1], Samuel S. Chan[2], and Charles R. Thompson[3]

ABSTRACT

We are investigating headwater riparian and upland forest management to achieve multiple resource objectives, primarily accelerated development of old-growth habitat and rare species management. For stands 40 to 50 yrs old, a control and three density management treatments are under study. Treatments include a mosaic of leave- and clearcut-islands within a matrix of thinning to various densities. Within this template, four no-entry riparian buffer zones also are under investigation. Companion studies utilize these two templates for biota and/or habitat characterizations; in particular, we are examining amphibians, mollusks, fishes, microclimate, and microsite. The balance of resource objectives was apparent during study implementation. For example, >100 species were evaluated by federal field units at the stand scale across 13 study sites, and many became conflicts to study implementation. The common methods of conflict resolution involved leaving unthinned areas, such as the study design elements of various sizes of riparian buffers and unthinned leave islands. The mosaic of stand-scale conditions resulting from such designs effectively addresses sustainability. This is a cooperative study between the U.S. Department of Interior, Bureau of Land Management, and the U.S. Department of Agriculture, Forest Service, with companion projects conducted by Oregon State University and U.S. Geological Survey partners.

KEY WORDS: Density management, riparian, buffer, headwater, microclimate, amphibians.

INTRODUCTION

Our western Oregon density management and riparian buffer studies provide an opportunity for managers and scientists to address the balance of multiple resource objectives in forested headwater subdrainages. These studies were developed in direct response to a change in natural resource management in the Pacific Northwest initiated by the federal Northwest Forest Plan (USDA and USDI 1993, 1994). This regional paradigm for ecosystem management was developed to focus on forest sustainability. On federal lands, sustainability of forest biological resources, such as forest-dependent species and ecosystem functions, became paramount to wood production and its related socioeconomic imperative.

Implementation of forest ecosystem management is ongoing and adaptive. Our joint studies have had several roles in this implementation. Our work initially aided development of regional standards for research and monitoring under the Northwest Forest Plan because it was among the first research projects proposed in the plan area. Our projects also were the first riparian reserves harvested under the plan in many northwestern Oregon field units, again aiding development of procedures for plan implementation. In particular, regional planners and field units implementing our study faced the goal of balancing resource objectives. Numerous key resources were identified and became study “drivers,” “pivots,” or “barriers” to project implementation. As resource conflict resolution occurred, solutions were available to managers as subsequent analogous conflicts arose in their routine projects. Here, we identify multiple resources that were evaluated and managed for sustainability through implementation of density management and riparian buffer designs. We offer this as an approach for across-scale, multiple-resource forest sustainability.

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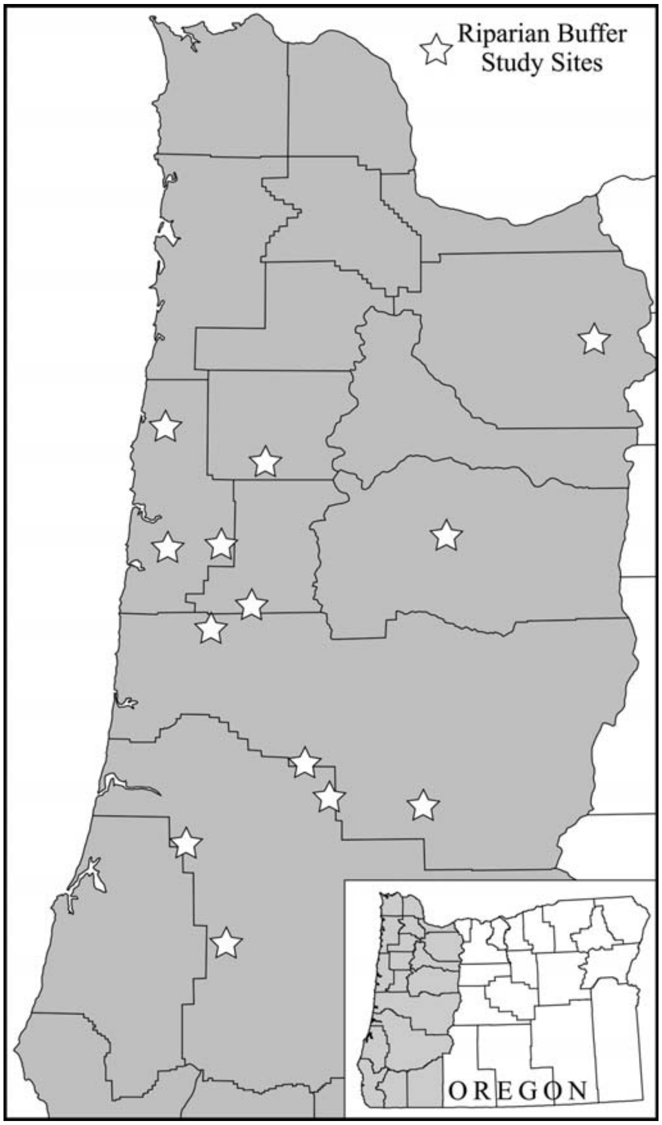

Figure 1—Distribution of 13 sites implementing the riparian buffer and density management studies in western Oregon managed federal forests.

BACKGROUND

Density Management in Headwater Forests

The Oregon density management studies address the utility of various thinning designs to achieve accelerated development of late-successional and old-growth (LSOG) conditions in managed stands (see Tappeiner et al. 1997). These studies were designed by the Bureau of Land Management (BLM; C. Thompson, study coordinator) in cooperation with Dr. John Tappeiner (Principal Investigator, U.S. Geological Survey and Oregon State University) after an assessment of the west-side forest management situation. Much of this forestland was regenerated after intensive clearcut harvest, and now resides in the plan's late-successional reserve (LSR) land allocations. Since the LSR lands are meant to emphasize habitat development over wood volume production, the need to develop effective methods to accelerate development of LSOG conditions was warranted. The thinning treatments were designed to generate results to contribute to the dominant forest management decisions expected for this region in the next one-to-three decades. In addition to monitoring the development of stand structure and composition over time in the various silvicultural treatments, evaluation of the wood production, operational and economic constraints of variable thinning designs, and biodiversity assessments were integral components of this work.

Two age classes of young stands were included in investigations. Nine of 12 study sites implemented with both density management and riparian buffer designs (Figure 1) were young stands 30-50 years old: six on Oregon BLM lands and three on the Siuslaw National Forest. In the six BLM younger stands, three thinning treatments and a control were implemented (Figure 2). These density management treatments included thinning to 80 trees per acre (TPA; 1 acre = 0.405 ha; "moderate density treatment"), 120 TPA ("high density treatment," and a mix of 40, 80 and 120 TPA ("variable density treatment"). Patch cuts, leave islands, and underplanted areas were distributed in the thinned areas, and harvest layout and tree marking guidelines were meant to protect stand structural features known to contribute to biodiversity. Three BLM sites were in older managed stands, 60-70 years old. One of these had never been thinned. This site represents a case study of a first-entry thinning at an older stand age. Two others were previously thinned, with a second entry implemented with a single treatment and two controls (never-thinned and once-thinned). These two sites conceptually represent a look into the future towards a possible management direction for the previously described younger stands in one-to-two decades, when a second entry thinning may be appropriate. Although there are additional BLM density management study sites in each age class, they did not have sufficient streams within them to implement a riparian buffer component for our study.

Riparian Management

Stream networks radiate throughout the west-side forest landscapes of the Pacific Northwest, with headwater streams present in most proposed timber sale areas. Despite their frequency, research focusing on the ecological roles of zero to second-order streams and subdrainages is scarce. In particular, the importance of headwaters to elements of the Aquatic Conservation Strategy Objectives (USDA and

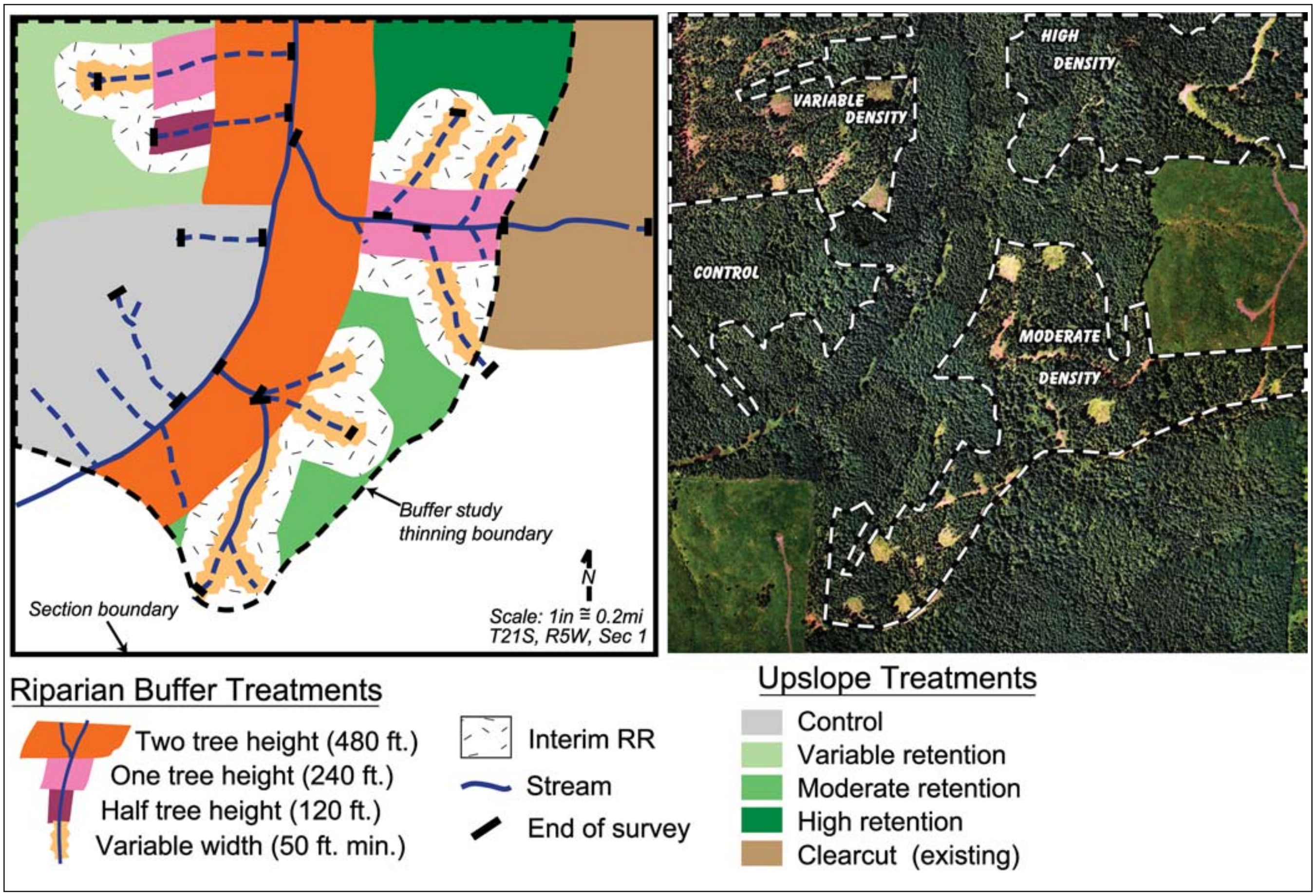

Figure 2—Schematic diagram and aerial photograph of one Bureau of Land Management density management study site ("Bottom Line") showing four upslope treatments: unthinned control; high retention (density) thinning (120 trees per acre [TPA]); moderate retention thinning (80 TPA); and variable retention thinning (with 40, 80, and 120 TPA areas). These views also depict the interim riparian reserve (RR, left) of the Northwest Forest Plan, the portion of those reserves that were planned for thinning (speckling, left figure), and the implemented unthinned riparian buffer (right, aerial photograph).

USDI 1994; Sedell et al. 1994) is unclear. For example, are there critical resources or processes associated with headwaters? If so, what are they and how are they spatially distributed in the headwater aquatic network? Are there risks to the integrity of these values with timber harvest, and what management approaches are appropriate to attain critical resource objectives? Upland forest riparian management approaches vary widely, including: (1) no protection; (2) restoration via stand conversion, thinning and underplanting; (3) streamside protection zones of various widths; and (4) patch reserves (e.g., Cissel et al. 1998). Unfortunately few data are available to address the effectiveness of various headwater riparian management actions in protecting aquatic resources. Additionally, most riparian forest management approaches along larger streams were developed within a regeneration harvest context. Limited information is available for the effects of density management thinning designs on riparian values.

Streams at many sites in the Oregon density management studies worked well for exploring riparian management options within a forest thinning context. Four widths for unthinned riparian "buffers" were chosen for study (Figure 3). Two of these stem from the guidance in the Northwest Forest Plan (one and two site-potential tree height buffers; range 200 to 480 ft; 1 ft = 0.305 m), while the other two stem from less conservative guidance matched to site conditions (a 50 ft minimum variable-width buffer which changes with topographic or vegetative conditions, relevant to state forestry approaches, and about a 20 ft streamside-retention buffer which retains the first streamside tree to provide bank stability from rooting strength, referenced in the Augusta Creek Landscape Management Plan utilizing extensive density management treatments, Cissel et al. 1998).

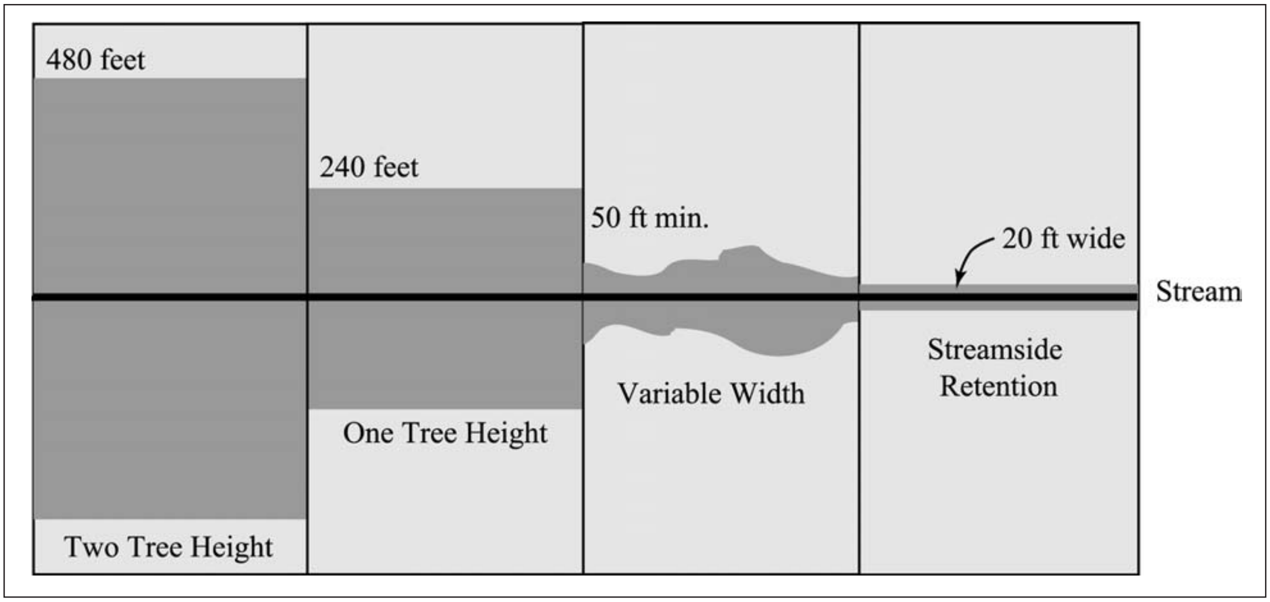

Figure 3—The four unthinned streamside zones under investigation in our joint riparian buffer and density management studies.

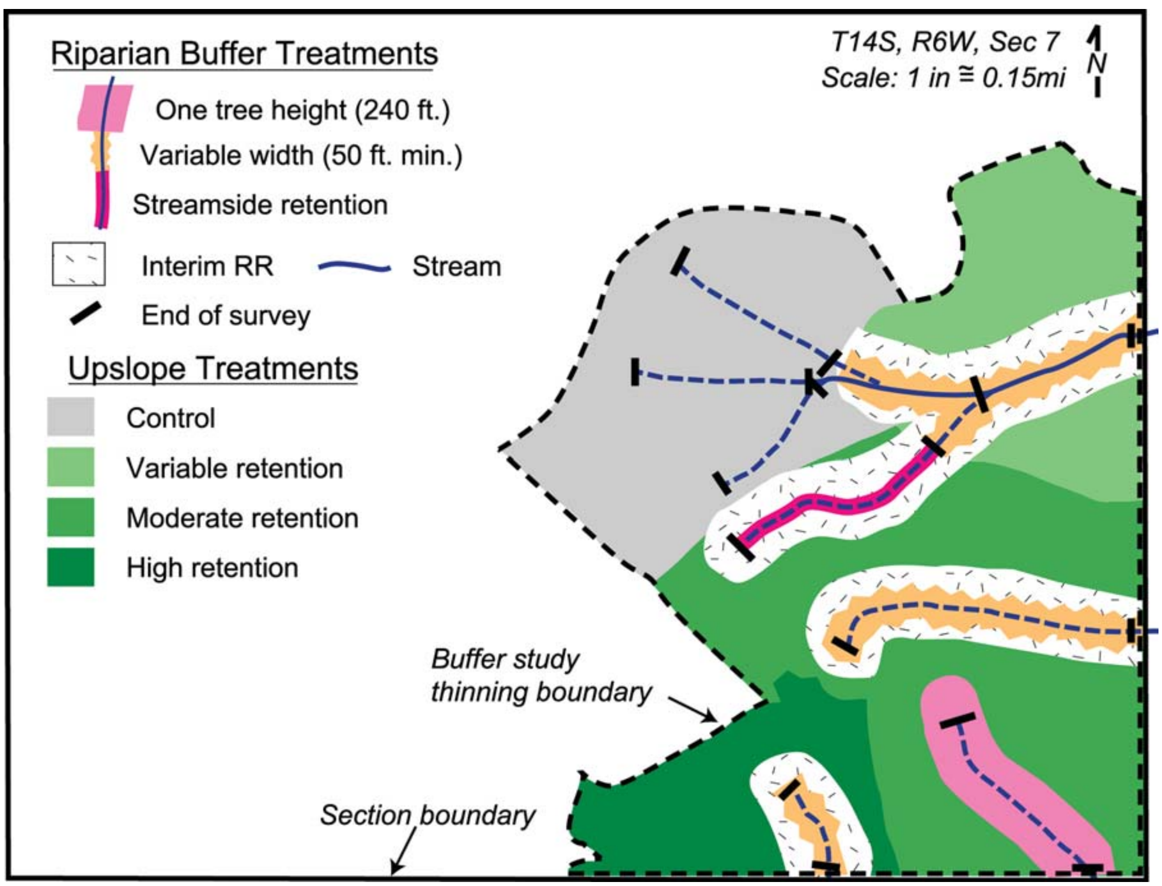

Figure 4—The riparian buffer study is being implemented within the moderate retention thinning treatment (80 trees per acre) at sites that had sufficient stream lengths and upslope forest areas to allow a minimum of two buffer treatments. At this particular site ("Green Peak"), three headwater streams permitted buffer treatments in the moderate retention unit (a one site-potential tree height buffer, a variable width buffer and a streamside retention buffer).

Table 1—Key findings of companion studies implementing research at the western Oregon density management and riparian buffer study sites (from Neitlich and McCune 1997; Olson et al. 2000)

Project	Key Findings
Microclimate and microsite - S. Chan	• Most of the change in microclimate from the stream to the upland forest occurs within the first 45 ft from the stream. • Soil and water temperatures within the riparian buffer are similar between thinned and unthinned stands. • Thinning to 80 TPA resulted in about a 2-6 C increase in air temperature, and about a 15-20% decrease in relative humidity, during the warmest and driest period of the year. • Riparian areas had the most heterogeneous site conditions. • Stands now contain limited large down wood in early stages of decay.
Aquatic vertebrates and habitats - D. Olson	• Headwater vertebrate assemblages differ both longitudinally with stream flow gradients and latitudinally from streams (distinct bank and upslope assemblages). • Several sensitive species and LSOG associated species occur in these managed headwaters; some may be considered critical resources with persistence concerns; one, in particular, associated with discontinuous flow of uppermost stream network. • Faunal responses to treatments are undergoing analysis. • Upslope fauna appears reliant on legacy down wood.
Macroinvertebrates - A. Moldenke and R. Progar	• Headwater invertebrate assemblages differ both longitudinally with stream flow gradients and latitudinally from streams. • Near stream riparian zone arthropod assemblage contained all upslope biota. • Small bodied Chironomidae and Mycetophiliidae dominated emergence from temporary streams. • Larger Ephemeroptera, Plecoptera, and trichoptera dominated emergence in perennial streams.
Lichens and bryophytes - P. Muir and B. McCune	• Diversity and abundance hotspots are associated with gaps, hardwood trees, old remnant trees, and wolf trees. • Relictual species are associated with legacy features, and feature retention can retain such biodiversity

Application of four alternative stream buffers within the three young stand density management treatments plus control unit posed logistical problems due to restrictions on stream length and configuration within a site (often composed of a square mile of BLM-administered land). Hence, we focused the riparian buffer component within one upslope thinning treatment (80 TPA), with matched control stream reaches (Figure 4). Additional criteria for the riparian buffer study included: a minimum of 3 stream reaches, each with a minimum stream length of 2½ site-potential tree heights (approx. 500 ft) to implement a control and two buffer treatments; at least 200 ft of treatment area was needed adjacent to the buffer; and matched stream sizes and conditions among treatment and control reaches.

Several companion studies are using the joint density and riparian management components as templates to examine specific questions. These include pretreatment characterizations and post-treatment responses of: (1) microclimate and microsite conditions - S. Chan, six sites; (2) aquatic dependent vertebrates and habitats - D. Olson, 12 sites; (3) macro-invertebrates - A. Moldenke, Oregon State University [OSU] and R. Progar, U.S. Department of Agriculture, Forest Service, Boise, ID, selected sites; (4)

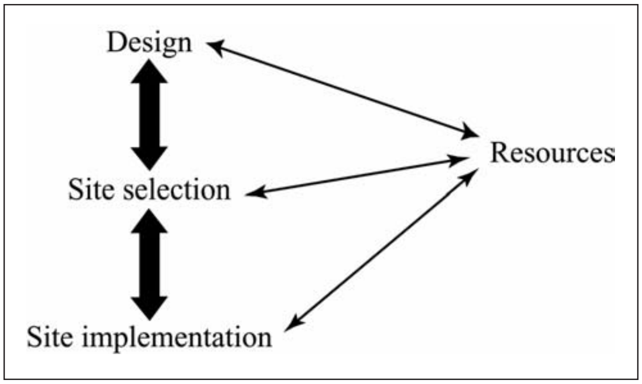

Figure 5—Iterative resource evaluations occurred during project planning and implementation.

lichens and bryophytes - P. Muir and B. McCune, OSU, selected sites. Also a new study, initiated in 2001, examines the role of leave islands for diversity of vascular plants, amphibians, mollusks, arthropods and related microclimate and microhabitat features - S. Wessell and D. Olson, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, OR, and R. Schmitz, OSU, four sites. Most of these projects are biologically focused because we lack information on headwater biota and habitats, their unknown response to a mosaic of thinned and unthinned areas, and the management need to balance timber harvest approaches with species protection and maintenance of ecosystem functions. Many key findings on the headwater forest characteristics, dynamics, flora, and fauna are emerging in these studies (Table 1), and likely will contribute to the adaptive management process for headwater forest management.

MULTIPLE RESOURCES: FROM CONFLICTS TO DRIVERS, PIVOTS, AND BARRIERS

Although we were involved in these projects as researchers to implement our various studies, our role is often greater. Our studies are part of an active interagency adaptive management process that integrates the joint production and protection of multiple resources. As the thinning and riparian buffer experiments were proposed and implemented in western Oregon, the multiple resources that were addressed spanned wood production, species of concern, habitats, and the politico-socioeconomic. Integration of these multiple resource objectives often were translated into proposed tradeoffs of concerns as single considerations conflicted with others and subsequently became a "driver," "pivot," or "barrier" to implementation.

We found that whether a resource conflict resulted in a resource becoming a driver, pivot, or barrier was often contingent upon when in the process (Figure 5) it was recognized as an issue. Conflicts first arose during planning, in 1993-1995, as the study design intersected the path of the Northwest Forest Plan. At the landscape level, the role of federal land-use allocations was questioned. Which allocations were appropriate for study sites; for example, could we implement sites in Late Successional Reserves (LSR's) because we were working to improve LSOG conditions? Initially, sites in Tier 1 Key Watersheds and LSR's were deferred from eligibility due to the early "hands-off" view of these lands under the Northwest Forest Plan. Later, it was decided that research objectives were consistent with management objectives for these allocations. One potential Matrix site was disqualified because the timeframe of the study and its proposed 30-year monitoring might have affected later entry to the site. Thus, LSR and Matrix allocations were perceived as both study "drivers" and "barriers" in different contexts.

Resource conflicts that were considered barriers to implementation generally were recognized at the larger spatial scales during the screening of the landscape for potential sites. Landscape screening criteria were primarily species and habitat concerns. They reflected precautionary principles applied during the early implementation of the Northwest Forest Plan. For example, the following conditions were identified and often avoided for site selection: key watersheds for listed fish, the zone of the marbled murrelet, known activity areas of northern spotted owls, and areas with extensive root rot, likely wind damage, soil erosion and landslide potential. Serious concerns sometimes resulted in the honing of study objectives, or a pivot in study implementation. Potential sites in the Coast Range and western Cascade Range with extensive riparian reserves also were initially perceived as potential conflicts to site selection before they were recognized as research opportunities.

Once landscapes were screened for potential eligibility for site selection and individual sites were assessed, a new set of issues arose. For example, while areas with known northern spotted owl or marbled murrelet nests generally were avoided during landscape screening, dispersal habitats for owls and murrelets emerged as a concern for other sites. Socioeconomics of sites also were projected relative to operational constraints and implementation costs; marketability of sales units were affected by the complex harvest design, need for new road construction, and the potential logging system impacts (e.g., helicopter, suspension). To make a density management site marketable, the

Table 2—Species evaluated during study site implementation

Taxonomic Group (no. species or taxa)	Species (common or scientific names)
Birds (13)	northern spotted owl, marbled murrelet, bald eagle, northern goshawk, raven, pileated woodpecker, saw whet owl, American kestrel, western bluebird, peregrine falcon, snowy plover, brown pelican, Aleutian Canada goose
Mammals (12)	Bats: Townsends big eared bat, pallid bat, fringed bat, long eared myotis, Yuma myotis, long legged myotis, Pacific western big eared bat Others: red tree vole, white footed vole, American marten, deer, elk
Amphibians (5)	red legged frog, southern torrent salamander, Oregon slender salamander, clouded salamander, tailed frog
Fishes (5)	coho salmon, steelhead trout, cutthroat trout, resident cutthroat trout, sculpin spp.
Mollusks (2)	blue gray tail dropper, papillose tail dropper
Lichens (20)	*Hypogymnia oceanica, Lobaria oregana, L. pulmonaria, L. scrobiculatea, Nephroma bellum, N. helveticum, N. laevigatum, N. resupinatum, Pannaria leucostichtoides, P. saubinetii, Parmotrema chinense, Peltigera collina, P. pacifica, Plastimatia lacunosa, Pseudocyphellaria anomala, P. anthraspis, P. crocata, Ramalina thrausta, Sticta fulginosa, S. limbata.*
Mosses (2)	*Buxbaumia piperi, Antitrichia curtipendula*
Fungi (17)	*Gymnopilus punctifolius, Aphaeocollybia sp., Ramaria aurantiisiccescens, Otidea leporina, Sarcosoma mexicana, Cantharellus formaosus, C. subalbidus, C. ciberius, Clavariadelphus liqula, Phaeocollybia sp., Ramaria cyaneigranosa, Gomphus clavatus, G. floccosus, Hydnum repandum, Phaeocollybia attenuata, Canthatellus tubaeformis, Helvella compressa*
Vascular plants (9)	*Orobanche pinorum, Monotropa uniflora, Hypopitys monotropa, Pityopus californica, Pleuricospora fimbriolata, Hemitomes congestum, Sparassis crispa, Botrychium virginianum, B. multifidum*
Minority tree species (8)	Pacific yew, western hemlock, western redcedar, red alder, bigleaf maple, myrtlewood, cherry, tanoak
Tree diseases/pests (4)	laminated root rot, black stain root disease, Douglas-fir bark beetle, swiss needle cast
Noxious weeds (6)	scotch broom, bull thistle, Klamath weed, tansy ragwort, Canadian thistle, hemlock dwarf mistletoe
Other (1)	Oregon silverspot butterfly

economics of patch openings and inclusion of neighboring parcels became important as mechanisms to increase yield and market value. One site harvested primarily via helicopter methods may not have been purchased under later market conditions. Two other sites did not sell when first offered, again due to market values of timber and the cost of implementing the complex study design. They later sold to a single bidder at the government-appraised price.

A preliminary assessment of the wood production in these project areas is compiled in Table 2. Implementation of the density management prescriptions resulted in greater volume removed when compared to traditional thinnings, largely due to the patch cuts ranging in size from ¼ to 1 acre. At one site, the environmental assessment stated that lumber was provided to the public while maintaining or increasing the vigor and volume growth of the stand through time. An increased timber benefit to the economy of the county was projected. These increased timber benefits would apply to all study sites.

Stand- or project-scale implementation was the finest scale at which the balance of resources was addressed. This scale was much more involved, adaptive, and instructive for the resource balancing act. Field units implementing study sites evaluated a myriad of site conditions and concern topics for their environmental assessments. Across all study sites, these included evaluations of species (n=103 species of 13 taxa; Table 3) and specialized habitats (e.g., wetlands, downed wood, snags, soil conditions, meadows). Many of these conflicted with the study, some serving as barriers to proceeding until an adequate resolution was determined.

Application of the study's various design elements was the dominant mode of stand-level conflict resolution. In particular, unthinned areas were used to mitigate for many sensitive species and special habitats; protection was provided with unthinned riparian buffers, leave islands, and control areas (Table 4). For example, protection of lichen diversity "hotspots" (Neitlich and McCune 1997) was implemented at some sites via leave islands. For some potential conflicts, the thinning treatment was expected to be either a relatively benign disturbance, or a short-term risk but a long-term gain in habitat conditions. After site selection, almost all conflicting resource issues were resolved. Interestingly, some of the resource conflicts that were barriers at larger scales were resolved at the fine scale. Development of standard scale-dependent criteria for resource evaluations is warranted. Which resource-management objectives should be attained at the landscape scale, and which objectives are better addressed at finer spatial scales? As we have noted, landscape scale resource attainment could result in precautionary approaches. Alternatively, landscape planning could heighten site-level risks for selected areas.

COMPATIBILITY

Resolving resource conflicts helped achieve the compatibility of multiple resources for joint production and protection. This occurred in similar ways at each spatial scale by either reserving lands for individual resources (in some cases, for combinations of resources) or accepting risk relative to a resource.

At the finest scale, resolving resource conflicts included excising portions of the study site, or allocation of unthinned treatments (control units, no entry riparian reserves, leave islands, tree clumps) to some areas. Conflicts were addressed during site implementation with marking guidelines and operational changes. The complexity of the experimental design, involving various riparian buffer widths, thinning densities of 40, 80, or 120 TPA with patch openings and leave islands of various sizes, and an untreated control, provided flexibility to accommodate potentially conflicting resources. Additionally, the spatial scale of the treatments often were considered small enough to have acceptable risks to some resources.

At the intermediate scale of site selection, the result of resource conflicts also was the reserving of lands. In this case, a site was either categorized as eligible or ineligible for the silvicultural treatments of the study design. During site selection, such eligibility decisions occurred in two spatial units: (1) the project area - often a single section in the BLM checkerboard ownership pattern; or (2) the larger landscape as defined by the distribution of a resource. Exclusion of areas with known resource conflicts was the main resolution of conflicts at this level.

During the early study design, as the objectives were honed and the geographic scope of the study defined, a similar conceptual reserving of the landscape was conducted to restrict the eligibility of lands for site selection. This large scale reserving also was contingent on large scale resource distributions.

MODEL FOR SUSTAINABLE FORESTRY

Implementation of these interagency density management studies can model adaptive forest management and sustainable forestry. Forest managers, resource specialists, and scientists' procedures to resolve conflicting resource

Table 3—Examples of resource conflict resolutions (continued on next page)

Resource	Resolution of Conflict
Northern Spotted Owl	Sites excluded from study if a nest was found. Seasonal restriction of activities to reduce disturbance to foraging and nesting. Majority of treated area > 40% canopy closure.
Marbled murrelet	Seasonal restriction, daily timing restriction to activities, majority of treated area > 40% canopy closure.
General wildlife	Patch cuts positioned to benefit wildlife (1 site), defective trees left (1 site), 2 residual trees per acre topped (1 site), seasonal restrictions, retention of previously topped trees, roads blocked or gated to reduce disturbance, falling/girdling of additional trees, maintain untreated area along main creek for amphibians and mollusks.
Fish	Streamside retention buffer was not placed on streams with fish concerns (1 site), seasonal restriction (2 sites), trees felled into creek for habitat (1 site). Helicopter log instead of 6,300 ft new road construction, build new roads along ridges.
Blue gray tail dropper, Papillose tail dropper, other Mollusks	Helped locate leave islands, untreated riparian area designated.
Douglas fir bark beetle	Seasonal restriction outside the adult beetle flight.
Laminated root rot	Sites with heterogeneous forest condition from this disease were excluded from study, presence at a site was incorporated into patch clearcut islands. Treatment was the same as the rest of the stand in several cases.
Monotrope plants (5 spp)	Unthinned control located to preserve one species, two one-half acre leave islands located for other species, 3-4 trees retained around site centers (maple clumps), some unit boundaries were changed to provide protection.
Orobanche pinorum (Vascular plant)	Reserve island established.
Minority tree species	Retained in study area, patch cuts positioned to assure regeneration of desirable seedlings, reserve patches represent unique characteristics, reserved hardwoods and conifer < 5 in. dbh, retain limby/wolf trees, seasonal restriction and 40 ft max. log length to protect residual stands, minimize landing size.
Buxbaumia piperi, Antitrichia curtipendula (Mosses)	Thirty sites, some protected by control unit, protected by retention of downed logs (1 site). Leave island designated. Mosses located in control and high density thinning treatment.
Fungi (15 spp.); *Sparassis*	Helped locate leave islands, application of density management treatments rather *crispa* than patch cuts where feasible, reserve clumps of trees, if leave islands bisected by logging corridors then they would be < 15 ft wide, protection by stream buffer zones; Retention of 5-6 trees adjacent to or hosting the population.
Lichens	Helped leave island placement, protected by stream buffer zones.

Table 3 (continued)—Examples of resource conflict resolutions

Resource	Resolution of Conflict
Streams and riparian areas	Patch cuts positioned away from stream channels, no yarding in no-cut areas, marshy area protection by one row of conifers around perimeter, yarding away from streams, inner gorge no cut zone, trees felled in leave areas are to be left. Ninety-three trees >15” dbh identified for coarse woody debris and snag creation (1 site), minimize use of riparian zone trees for anchoring or hanging cables, full suspension over streams or wetlands.
Water quality, sedimentation	landing construction > 50 ft from streams, yarding perpendicular to streams, one-end suspension.
Wetlands	Diverted roads, affected riparian reserve boundaries, and affected leave island placement (1 site).
Meadow lithosol	Habitats excluded from treatment (1 site).
Downed wood/snags	Remain on site, damaged trees retained, snags created, trees felled for downed wood after first winter storm season.
Special forest products	Selection of trees to 10 in. dbh made by silviculturist to focus on suppressed trees and intermediate crown classes (1 site). Firewood permits allowed.
Recreation	No harvest uphill of main trail, no harvest within 50 ft of trail where possible, slash piles >100 ft from trail, no marking paint on trail side of trees, flag persons employed during logging.
Fire	Felling away from roads, slash piles burned by U.S. Department of Agriculture, Forest Service, 4 ft wide fuel break along private property boundary (1 site). Slash pulled back 25 ft from roads (1 site), debris burned at landings, patch openings, and within 50 ft of haul roads (1 site).

production and protection goals are noticed and adopted elsewhere. Combined techniques such as leave trees, leave islands, patch openings, multiple thinning densities, and flexible riparian buffers are merged to tier harvests to site and microsite conditions. For example, careful examination of stream channels led to our variable width riparian buffer zones, which bulge or narrow with topographic and vegetative conditions along stream channels. The site quickly becomes a mosaic of conditions, reflecting the normal range of conditions found in a watershed, province, or region. At multiple spatial scales, areas identified for preservation are retained while areas in which risk to various resources is not apparent or appears acceptable, different forest prescriptions are applied.

A challenge for the broad use of this fine-toothed comb approach to “grooming” site-to-landscape conditions is identifying the resources that should be screened per scale and identifying the scale-specific and across-scale approaches for their integrated management. Our combined density management and riparian buffer studies are providing new information relative to unique resources in headwater subdrainages, to contribute new knowledge relevant to this challenge.

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Table 4—Estimated volume of timber harvest (mmbf) and area treated for seven density management study sites (30-50 yrs) and three older "rethin" study sites (70-80 yrs)[1]

Wood Production (mmbf)	Area
8.4 mmbf	389 acres thinned
1.5 mmbf, average 10 mbf/acre	220 acre project area, 163 acres thinned
1.3 mmbf	246 acre project area, 145 acres commercially thinned
1.8 mmbf	380 acre project area, 261 acres thinned
1.6 mmbf	403 acre project area, 135 acres thinned
1.9 mmbf	244 acre project area, 157 acres thinned
3.5 mmbf	312 acres project area, 241 acres thinned
0.94 mmbf	406 acre project area, 94 acres treated (70-80 yrs)
1.6 mmbf	182 acres thinned, 1 acre road clearcut (70-80 yrs)
4 mmbf	230 acre project area, 140 acres thinned (70-80 yrs)

[1] Data come from environmental assessments

nine BLM Resource Areas, the BLM Oregon State Office, the Siuslaw National Forest, and the Pacific Northwest Research Station.

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RESEARCH ON STREAMSIDE ISSUES THROUGH THE WOOD COMPATIBILITY INITIATIVE

Susan Bolton[1] and Cara Berman[2]

ABSTRACT

Through the Wood Compatibility Initiative (WCI), the Center for Streamside Studies (now the Center for Water and Watershed Studies) at the University of Washington has undertaken a series of research efforts addressing production and protection of forest, fish, wildlife, and other aquatic and riparian resources. These efforts consist of micro-habitat and habitat-unit-scale mechanistic studies, trans-scale studies exploring hierarchical linkages of structure and function, as well as the development of a landscape classification model linking physical and biological processes across scales and integrating terrestrial and aquatic ecosystem components. Wood Compatibility Initiative funded projects have involved collaboration with scientists at the Pacific Northwest Research Station, National Marine Fisheries Service, U.S. Fish and Wildlife Service, Weyerhaeuser Company, the City of Seattle, the Lummi Nation and others. The Center for Streamside Studies has addressed the role of large woody debris in streams, including stream input processes and hydraulic and biologic functions. Other studies have investigated freshwater habitat condition and its relation to salmonid productivity and the role of hyporheic flux in redd selection by salmonids. In collaboration with others, historic riparian stand condition, specifically canopy cover related to stream shading, has been investigated as well as the role of geomorphic variability in affecting stream temperatures. This paper summarizes the results from WCI studies initiated over the past four years.

KEY WORDS: Center for Streamside Studies, Center for Water and Watershed Studies, riparian research, rivers.

INTRODUCTION

Through the Wood Compatibility Initiative (WCI), the Center for Streamside Studies (CSS) (now the Center for Water and Watershed Studies) at the University of Washington has undertaken a series of research efforts addressing production and protection of forest, fish, wildlife, and other aquatic and riparian resources. These efforts consist of micro-habitat and habitat unit-scale mechanistic studies, trans-scale studies exploring hierarchical linkages of structure and function, as well as the development of a landscape classification model (Berman[3]) linking physical and biological processes across scales and integrating terrestrial and aquatic ecosystem components. Information derived from these efforts provides information to support natural resource management decision-making. Projects focus on the interactive effects of structures and processes across ecosystem elements and scales and at different places within the stream network. It is these synthetic studies that are necessary to respond to today's complex management landscape.

Center for Streamside Studies projects examined the distribution of large woody debris in streams across various ecoregions in Washington, and hydraulic and biologic functions of natural versus engineered wood. Other studies investigated freshwater habitat condition and its relation to salmonid productivity and the role of hyporheic flux in redd selection by salmonids. In collaboration with Upper Columbia River timber growers and the U.S. Department of Agriculture, Forest Service district forests and supervisor's offices, historic riparian stand condition, specifically canopy cover related to stream shading, was investigated as well as the role of geomorphic variability in affecting

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Table 1—Large woody debris piece quantity: number of pieces per 100 m of channel length (Fox 2001)

Region	BFW Class	Good Condition	Fair Condition	Poor Condition
Western WA	0-6 m	>38	26-38	<26
	>6-30 m	>63	29-63	<29
	>30-100 m	>208	57-208	<57
Alpine	>0-3 m	>28	15-28	<15
	>3-30 m	>56	25-56	<25
	>30-50 m	>63	22-63	<22
DF/PP[a]	0-6 m	>29	5-29	<5
	>6-30 m	>35	5-35	<5

[a]Douglas-Fir/Ponderosa Pine Ecoregion

Table 2—Large woody debris volume: cubic meters per 100 m of channel length (Fox 2001)

Region	BFW Class	Good Condition	Fair Condition	Poor Condition
Western WA	0-30 m	>99	28-99	<28
	>30-100 m	>317	44-317	<44
Alpine	>0-3 m	>10	3-10	<3
	>3-50 m	>30	11-30	<11
DF/PP[a]	0-30 m	>15	2-15	<2

[a]Douglas-fir/Ponderosa pine ecoregion

Table 3—Key piece quantity: number of pieces per 100 m of channel length (Fox 2001)

Region	BFW Class	Good Condition	Fair Condition	Poor Condition
Western WA	0-10 m	>11	4-11	<4
	>10-100 m	>4	1-4	<1
Alpine	>0-15 m	>4	0.5-4	<0.5
	>15-50 m	>1	0.5-1	<0.5
DF/PP[a]	0-30 m	>2	0.5-2	<0.5

[a]Douglas-fir/Ponderosa pine ecoregion

stream temperatures. Wood Compatibility Initiative funded projects have involved collaboration with scientists at the Pacific Northwest Research Station, National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), the city of Seattle, the Weyerhaeuser Company, the Lummi Nation and others. This paper summarizes the results from WCI studies initiated over the past four years.

FINDINGS AND MANAGEMENT IMPLICATIONS

Managers' and regulators' research needs are complex and require a detailed understanding of multi-scalar landscape processes as well as the interactive components of the stream ecosystem. Therefore, it is not unusual for CSS projects to address longitudinal, lateral, and vertical connectivity across multiple spatial and temporal scales. In fact, this approach is required to view the river system holistically and to understand the implications for management decisions

CONCEPTUAL MODEL

The interactive components of a river system form a template on which abiotic and biotic processes unfold. These interactive components exist across spatial and temporal scales and establish a heterogeneous and dynamic system. To conceptualize linkages between stream components, Ward (1989) recognized four dimensions, a longitudinal, lateral, vertical, and temporal dimension. Wood Compatibility Initiative funded projects describe these stream linkages and interactions across spatial and temporal scales allowing managers to better predict the consequences of disturbances (natural and human-induced) on aquatic systems. To the four dimensions we add a fifth, a policy-science-management dimension that assesses and informs attitudes and actions that affect resource protection and recovery.

Longitudinal Dimension (Elements of the Landscape)

The longitudinal dimension reflects upstream-downstream linkages affecting stream processes and patterns. Projects investigating the longitudinal dimension address landscape variability and the distribution and pattern of resources along the longitudinal axis of the stream system.

Large woody debris (LWD) quantity—LWD characteristics in unmanaged basins vary according to climatic, geomorphological, and hydrological differences (Fox 2001; Fox 2002; Fox et al. 2002.). Instream wood is recognized as an important feature linked to channel processes that benefit salmonids and various LWD targets exist to help resource managers assess restoration needs. However, existing wood targets do not adequately account for variations in LWD quantity or volume due to longitudinal differences in geomorphology, ecoregion, or disturbance regime. Data analysis suggests that current wood targets are not appropriate for all streams within Washington state. Data indicate that LWD amounts vary by bankfull width (BFW) class and region (Tables 1-3). Project findings provide a baseline for managers interested in assessing existing conditions and establishing recovery targets. This information is useful for modifying existing wood targets established by Washington state's Watershed Analysis as well as other management and recovery programs within the Pacific Northwest.

Eastside forests and stream temperatures—Riparian forests also vary along the longitudinal axis according to biophysical factors. However, a paucity of information exists on riparian stands and historical shade levels for eastern Washington forests. Johnston (2002) used air photos, field investigation and General Land Office Surveys to characterize historical riparian forest conditions in eastern Washington taking into account the historical fire regime and fire suppression. This project also received funding from a coalition of Upper Columbia River timber growers. Historical riparian conditions are compared to current conditions to evaluate the effects of various management activities (e.g., fire suppression, timber harvest). Findings will allow resource managers and regulators to better understand landscape appropriate strategies for managing eastside riparian forests. Active management within riparian stands raises complex issues, particularly considering the potential reduction of shade along temperature sensitive streams. An understanding of the pre-harvest and pre-fire suppression riparian condition is important for determining appropriate levels of shade and other related riparian forest characteristics.

Longitudinal changes in landform and physical and biological processes also give rise to longitudinal and temporal variation in stream temperature. The natural range of thermal conditions as well as temperature variability at the landscape and watershed scales were examined by Scholz (2001). Findings indicate that temperatures in the Wenatchee National Forest are influenced at the landscape scale by several factors including air temperature, drainage area, elevation, and stream shading. Many of these factors are correlated and these factors affect acute and chronic conditions to different degrees. The physical factors that determine stream temperatures at the landscape scale are not necessarily good predictors of smaller scale temperature regimes. Stream temperatures in several watersheds are perhaps influenced primarily by their high geologic potential for groundwater upwelling, especially in basins with little managed area. This study also received funding from the Wenatchee Supervisor's Office and the U.S. Environmental Protection Agency. (The hyporheic studies discussed under the vertical dimension heading are examining the relative role of groundwater on stream temperature compared to other characteristics such as shade, buffer width and composition, and elevation in urban, agricultural and forested landscapes (Reidy[4]; Monohan[5]) and complement these landscape studies on stream temperature and riparian conditions.)

Understanding system potential and the mechanisms that establish thermal pattern will also assist those designing restoration measures. This research supports and complements work undertaken by the U.S. Department of Agriculture, Forest Service. The Center for Streamside Studies will continue to interact with Pete Bisson on his temperature work in Eastern Washington.

Fish habitat—The interactive components of a river system form a template on which abiotic and biotic processes unfold. The longitudinal dimension is a patchwork of resource availability including habitat for aquatic biota. Physical processes affecting bedload scour, such as flow regime and sediment load as well as behavioral processes, are examined in the context of bull trout spawning habitat development, disturbance, and selection (Shellberg[6]).

Three primary research questions are addressed. First, what general factors influence spawning site selection (substrate, depth, velocity, cover, hyporheic flow) and what are the patterns of scour and fill in these microhabitats? Second, how does the reach scale channel morphology (channel type, sediment transport regime, LWD) affect scour and spawning habitat availability? Finally, what influence does watershed hydrology (runoff timing, frequency, magnitude and duration) have on bedload scour and bull trout distribution? Study results will shed light on the potential influence of physical habitat conditions on bull trout population integrity and distribution and help resource managers identify restoration strategies for this threatened species.

Nutrient dynamics vary longitudinally in river systems as a function of a number of physical and biological processes. In cooperation with NMFS and the City of Seattle, CSS has participated in studies in the Cedar River to investigate the effects of salmon carcasses on nutrient dynamics and resident fish populations (Kiffney et al. 2001). Results from this study will provide information on the rate at which anadromous salmon naturally colonize newly available habitat and the means by which they redistribute themselves into fresh water spawning areas—information currently not available from any research. Water quality information is being collected and components of stream food webs are being sampled for nitrogen and carbon isotopes. Findings will elucidate linkages between anadromous and resident population dynamics and stream productivity.

The Vertical Dimension (Reach Elements)

The vertical dimension reflects interactions between the channel and contiguous groundwater. Projects investigating vertical connectivity address hyporheic flux across variable landscapes and land uses. Hyporheic zones influence chemical, hydrological, zoological, and metabolic functions at various scales and thereby affect channel physiochemical gradients, nutrient availability, and biotic productivity (Brunke and Gonser 1997). Previously, CSS researchers (e.g. Clinton 2001; Coe 2001) investigated hyporheic flux in large alluvial river systems in forested settings. Collaborative research between CSS and USFS scientists Rick Edwards and Steve Wondzell and NMFS scientist Peter Kiffney was initiated to study hyporheic processes in urban and agricultural streams across variable landscapes. This research will focus on hyporheic transient storage in urban and agricultural areas in comparison to forested areas and potential effects on stream temperature and nutrient cycling (Reidy; Monohan; Clinton[7]). These three studies will investigate how transient storage, nutrient retention and invertebrate distribution vary within an array of urban, agricultural, and forested streams. Information derived from this work is important for understanding potential changes in stream temperature and productivity under differing land-use practices.

Temporal and Lateral Connectivity

In addition to longitudinal and vertical connectivity, the above projects incorporate aspects of temporal variability

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and lateral connectivity. The temporal and spatial patchiness of resources structures biotic communities. Temporal fluctuation of process dynamics and resource response variables was investigated in projects addressing LWD delivery (Fox 2001), riparian characterization (Johnston 2002), and thermal patchiness (Scholz 2001). The lateral dimension reflects interactions between the channel and the adjacent riparian/floodplain system. Interactive pathways along this dimension facilitate the exchange of matter and energy. Lateral connectivity was investigated in projects addressing LWD input processes (Fox 2001), groundwater recharge/discharge (Scholz 2001; Reidy[4]; Monohan[5]; Clinton[7]), and habitat-forming processes (Shellberg[6]) including a literature review of riparian soil studies (Mikkelsen and Vesho 2000).

Policy-Science-Management Dimension

The policy-science-management dimension reflects attitudes, behaviors, and actions related to riparian and aquatic protection and recovery. Projects address policy, information transfer, stream restoration and resource management related topics and are designed to assess attitudes, behaviors, and activities related to riparian and aquatic protection and recovery. In 1998, CSS provided organizational help to the Society for Ecological Restoration Northwest Chapter for their annual meetings in Tacoma, Washington. The meeting drew over 600 registered attendees and was a great venue for disseminating information. In addition to the organizational assistance, CSS hosted and developed a concurrent symposium on riparian ecology and management. Abstracts of the symposium are out-of-print but the Center for Water and Watershed Studies will provide copies upon request.

Non-point source (NPS) pollution programs—Successful control of NPS pollution depends in large measure on intervention programs that inform participants and create public awareness in communities where the programs operate. One component of this project (Ryan et al. 2001) identifies the motivations of rural landowners to participate in conservation-oriented land management programs that assist landowners in adopting land management practices. Results of the research (Ise 2001) indicate that (1) self-interest, such as the need for technical assistance and the threat of future regulations, is the strongest motivation for participation; (2) land use decisions are often based on factors related to the land's utility for commodity production or personal aesthetics; and (3) attitudes about upholding private property rights are frequently stronger than attitudes about protecting the environment. This research did not indicate that conservation-oriented programs could instill a conservation ethic or significantly influence change to individual conservation attitudes and behaviors. Findings will assist regulators in devising techniques to improve nonpoint source control.

Extent of monitoring—In addition to research related to behavior and attitudes, monitoring practices of various stream restoration groups and projects was evaluated. Specifically, the perceived shortcoming in the evaluation of stream restoration and fisheries enhancement projects in Washington state was examined (Bash 1999). While project goals include restoring and improving stream health, it was not known to what extent projects were monitored or evaluated to determine if goals are being met.

Findings revealed that monitoring of stream restoration and fisheries enhancement projects may be occurring at higher rates than resource managers thought. However, the level and quality of monitoring activities were highly variable across the sample. Barriers to monitoring included funding, time, personnel, and lack of cooperation from property owners. Monitoring related topics for managers to consider include: appropriateness of objectives and monitoring measures, need for long-term monitoring, development of funding specifically for monitoring, methods for encouraging or requiring monitoring, and implementation and quality of project monitoring. Information from this study may help those managing and funding projects to better understand the current strengths and limitations of project evaluation, and allow them to adjust their policies accordingly.

Restoration projects—Concern for the health of aquatic systems in the Pacific Northwest encouraged research on new methods to enhance freshwater spawning and rearing habitat and to assess habitat related to salmon productivity. Lack of LWD in streams has reduced the complexity and quality of fish habitat. A project designed to compare the hydraulic and biological performance of native LWD and an organic, engineered alternative to LWD (ELWd™ [8]) was undertaken (O'Neal 2000; O'Neal et al. 2000a; O'Neal et al. 2000b; Savery 2000) and received additional support from the Weyerhaeuser Company.

[8] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Fish response was not significantly different for the two types of wood. Values of invertebrate metrics were generally higher for samples collected from ELWd™ surfaces than from traditional LWD. Invertebrate samples were also evaluated in terms of the production of available food resources for salmonids. The results showed greater food availability from the ELWd™ structures. In all sampling, benthic samples did not show a clear difference between the wood types. Therefore, innovative sampling methods were created to assess invertebrate production on LWD.

Savery (2000) compared the hydraulic effects of native LWD and an engineered alternative. The physical differences between the native LWD and the ELWd™ had an effect on the ability of the installed structures to maintain channel position. Engineered LWD did not maintain original bank position as well as native LWD. Although some of the differences between pairs is explained by local hydraulics and bank position, the low mass of engineered wood allows the structure to be moved by the stream. Additionally, engineered roots on the ELWd™ structures improve their stability, but are not as stable as native LWD with attached rootwads. The mean scour produced by the two log types was not statistically significant. However, the engineered structures created a comparatively large amount of turbulence on the upstream side of the log. Research results related to engineered wood performance provide an evaluation of the effectiveness of an engineered alternative compared to traditional LWD for stream enhancement projects before engineered structures are widely placed (O'Neal et al. 2000b).

Management models—Current recovery efforts lack a clear understanding of the relationship between freshwater habitat conditions and salmon response. This information is critical to the successful design of salmon recovery plans. To evaluate the distribution of expected salmon production resulting from alternative restoration strategies in Oregon's Willamette River Basin, CSS, in cooperation with NMFS, is developing a model (Brauner[9]) relating restoration activity to changes in habitat. The resulting model will be linked to a NMFS model relating habitat characteristics to the survival rates of salmon. This project will develop analytical tools to assist resource managers designing or evaluating restoration actions intended to increase salmonid fitness and ultimately productivity.

Riparian forest restoration—In January of 1999, Lummi Natural Resources and the University of Washington Center for Streamside Studies began to analyze the vegetative and environmental data collected in the three years since the Riparian Zone Restoration Project's inception and to evaluate the project's success to data. One of the products of this analysis (Wishnie et al. 1999a; Wishnie et al. 1999b) was the establishment of new data collection protocols, field sheets, and comment and damage codes to improve the accuracy and utility of data collection. These materials are an example of an effective approach to data collection: initial survey protocol, initial data sheet, initial survey codes, damage codes, annual survey protocol, annual survey codes, annual data sheet.

CONCLUSION

WCI funded projects address the following resource management issues and information needs: (1) increase understanding of physical and biological processes across variable landscapes; (2) develop conceptual models allowing inferences within and across regions; (3) explore disturbance processes and implications for management; (4) design multi-scalar monitoring programs; (5) develop linkages between management actions and site-scale alterations; and (6) design and calibrate broad scale monitoring metrics. These projects form the basis for a synthetic approach to understanding and managing complex ecolo-gical systems. A recent WCI grant award to develop a landscape classification model linking physical and biological processes across scales and ecosystem components will allow us to integrate research findings and meet current resource challenges and data needs.

To ensure access to CWWS research, efforts are underway to increase the efficiency and effectiveness of our information transfer activities. Efforts undertaken through the WCI program are important to resource managers throughout the Pacific Northwest. We are committed to ensuring broad dissemination of research results as well as fostering dialogue to address issues important to resource managers.

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PHYSICAL AND CHEMICAL PROCESSES IN HEADWATER CHANNELS WITH RED ALDER

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ABSTRACT

We investigated links between physical disturbance processes, vegetation type (alder or conifer), and stream nitrate concentrations in headwater streams in young-growth stands and old-growth forests within mountainous terrain in southeast Alaska. Alder coverage in upland headwater zones (areas with slopes > 15°, or 27%) associated with landsliding was more extensive within young-growth stands than within old-growth forests. The highest nitrate concentrations occurred in streams within alder dominated young-growth forest. However, some streams with high alder coverage had low nitrate concentrations. These streams were larger and originated within alpine zones on ridge tops, suggesting that landform and source area may also be important factors regulating nutrient concentrations. An understanding of the relationship among disturbance patterns, tree species establishment, and nutrient cycling may help managers better predict the effect of harvest practices on stream productivity.

KEY WORDS: Alder, young-growth forest, headwater channels, landslides, nitrate.

INTRODUCTION

Recent studies of red alder (*Alnus rubra*) were initiated to determine how young-growth ecosystems function and to better understand how alder regrowth influences trophic linkages and processes in managed landscapes of southeast Alaska (Deal et al. 2002; Wipfli et al. 2002; Deal and Orlikowska 2002, in this proceedings; Hennon et al.2002, in this proceedings). Streams in the Pacific Northwest region generally contain low concentrations of nutrients that limit plant growth, particularly nitrogen and phosphorus (Gregory et al. 1987). These low nutrient levels, combined with low light levels beneath dense riparian canopies, limit primary production. Red alder stands have significantly higher soil nitrogen stocks than conifer stands. Nitrogen accretion begins a few years after alder colonization, increases rapidly in the first two decades, and continues until the alder dies and is replaced by more shade-tolerant conifers (Luken and Fonda 1983). Groundwater and hyporheic flows can move alder-derived nitrogen into adjacent streams, dramatically increasing nutrient stocks and, in turn, algal standing stocks in streams with sufficient light levels (Fevold 1998). Alder may also increase the abundance of aquatic, riparian, and terrestrial arthropods, providing more food for fish (Piccolo and Wipfli 2002; Wipfli and Gregovich 2002), bats, and birds. However, these benefits may be outweighed by decreases in large woody debris input (Grette 1985; Andrus et al.1988; McDade et al. 1990), and wood residence times (Anderson et al. 1978; Keim et al. 2000), and increases in sediment loading (Megahan 1982), resulting in overall loss of fish habitat in alder-dominated systems (Hicks 1989; Bilby and Ward 1991; Ralph et al. 1994).

Alder establishment is a response to physical disturbance, both natural and anthropogenic, but conversion to alder forests may alter the subsequent pattern of disturbance with important impacts on sediment input and retention. Thus, management of alder reaches in headwater fish habitat may benefit from an increased understanding of the tradeoffs between positive and negative effects of alder presence. In this paper, we focus on physical disturbance processes associated with alder occurrence in old-growth and young-growth forests and will evaluate trends in nitrate concentration. Our study areas include headwater channels within two watersheds, the Maybeso Experimental Forest

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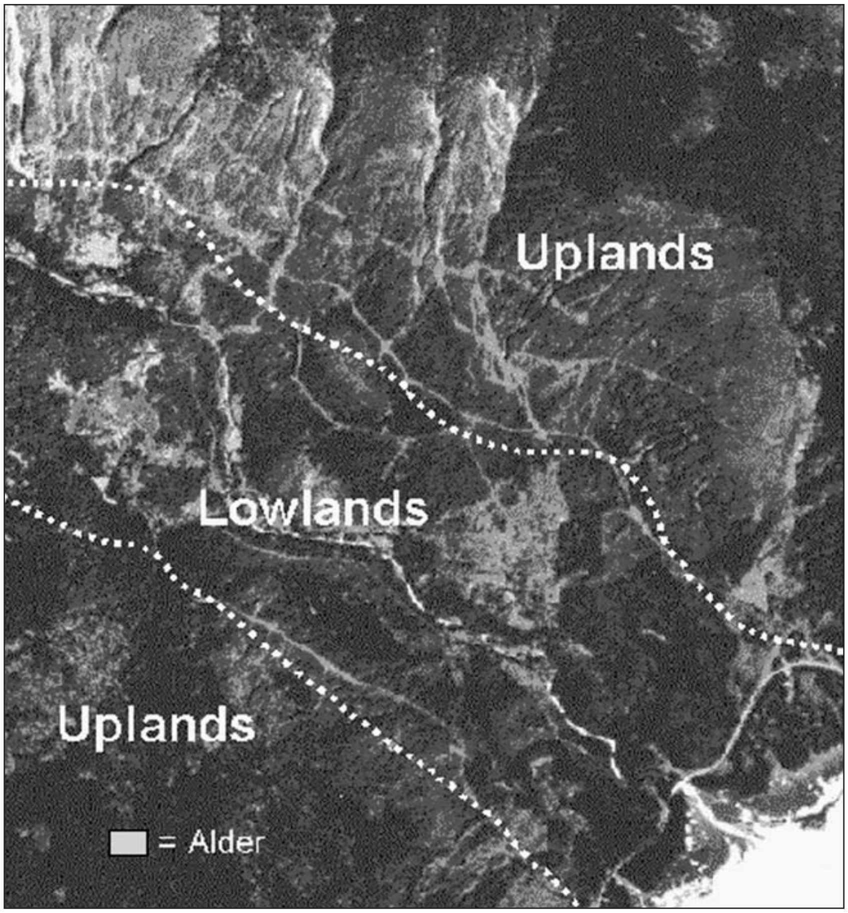

Figure 1—Supervised classification of a false-color infrared image for a portion of the Maybeso watershed. Note: extensive linear patches of alder in the young-growth forests associated with landslides, cable logging, tractor logging, and road building.

and the Karta Wilderness on the eastern coast of Prince of Wales Island, Alaska. These sites have different land use histories, are within a single ecoregion, and have similar geology, topography, landforms, soils, climate, and vegetation (Nowacki et al. 2001). Our specific objectives include:

- Describe the distribution of red alder in forests with different land management histories.
- Describe links between disturbance processes and alder establishment.
- Determine the relationship between alder and stream nitrate concentrations.

A detailed outline of methodology, description of study locations, and technique for determining the proportion of alder coverage can be found in Wipfli et al. (2002).

RESULTS AND DISCUSSION

Distribution of Alder in Young-growth and Old-growth Stands

Aerial photographs dating back to the 1950s and recent field surveys confirm that before timber harvest, red alder was most closely associated with physical disturbances that both created openings in the overstory stand and exposed mineral soil. Natural disturbances included: snow avalanches, landslides, blowdown, and flooding. Distributions of these physical disturbances, and hence, the resulting pattern of alder within the landscape, appeared to be closely associated with landform and climatic regime (precipitation and wind patterns). Timber harvest affected the frequency of disturbance. For example, landslides occurred on steep slopes (> 30°) in conjunction with major rainstorms from the 1960s through the 1990s, primarily within areas clearcut in the late 1950s and 1960s (Helmers 1961-1985; Swanston and Marion 1991; Johnson et al. 2000; Gomi et al. in press). In this study, “landslides” is used as a descriptive term for all rapid soil failures, including debris flows. Human-related disturbances associated with harvest included: broad-scale removal of trees, cable and tractor logging, and road building. In southeast Alaska, where mineral soil is typically covered by an organic horizon, human and natural disturbance processes exposed mineral soils either by removing overlying organic horizons or by burying them under new inorganic sediment.

Table 1—Alder cover and nitrate concentration measurements

	Percent alder	Micrograms nitrate per liter
Young growth		
Lost Bob	0.0	23.1
Good example	1.46	27.9
Cedar 2	3.77	40.4
Good morning	3.90	15.4
Creature	9.94	25.8
Gomi	24.97	35.9
22 mile	29.20	18.6
Gomi Slide*	30.00	110.5
Spruce	31.48	387.8
Next to Guy*	35.00	71.7
Cedar 1	35.56	28.8
W Broken Bridge	38.70	35.3
Guy Cotton	43.15	7.3
E Broken Bridge	47.30	39.2
Mossy	53.28	290.9
Old growth		
Karta Creek*	0.0	18.9
Yeti's View*	40.00	71.1

* In these areas percent alder was estimated, not measured.

Note: sites with over 10% alder (except Cedar 1) have been impacted by landslides.

The Karta and Maybeso watersheds include forests with different land uses (wilderness maintenance versus timber production), but these watersheds have similar landforms, climatic patterns, and are characteristic of many watersheds in southeast Alaska. Glaciers left wide, U-shaped valley walls, steep side slopes, and low-gradient valley floors. We delineated two slope classes for our analysis: (1) upland regions with > 15° slopes and (2) lowland regions with < 15° slopes. This slope threshold separates landslide erosion areas on uplands from deposition areas on lowlands, general patterns observed in southeast Alaska (Johnson et al. 2000; Gomi et al. in press). These slope classes roughly correspond to our field sampling reaches, which were selected above and below transition areas where the slope changes in headwater channels. Transition areas define the upper limit of fish habitat. By combining these slope classes with a supervised classification of a false-color infrared image (we selected certain spectrum, or classes, from the image we knew to be alder from ground observations using ERDAS[3] (1997) to select from an initial unsupervised classification with 25 classes) and landslide inventories (Helmers 1961-1985), we quantified alder occurrence and identified disturbance (Figure 1). This methodology accurately identified patches of alder greater than 20 m in diameter.

Uplands—Within the Maybeso study area, over 58% (75 ha) of the alder component occurs in upland areas. Approximately 90% of this upland alder (68 ha) is on areas disturbed by landslides and 10% is found in areas disturbed only by cable logging and road building. At all sites with documented landslides, red alder established on disturbed mineral soil that bordered stream channels. Conifers, including western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), and western redcedar (*Thuja plicata*), grow along channels without landslide disturbance.

The alder proportion of stand basal area (percent alder) found along upland riparian corridors in young growth was found to be closely related to landslide occurrence (Table 1). We found a significant difference in the mean percent alder

[3] The use of trade or firm names in this publication is for the reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

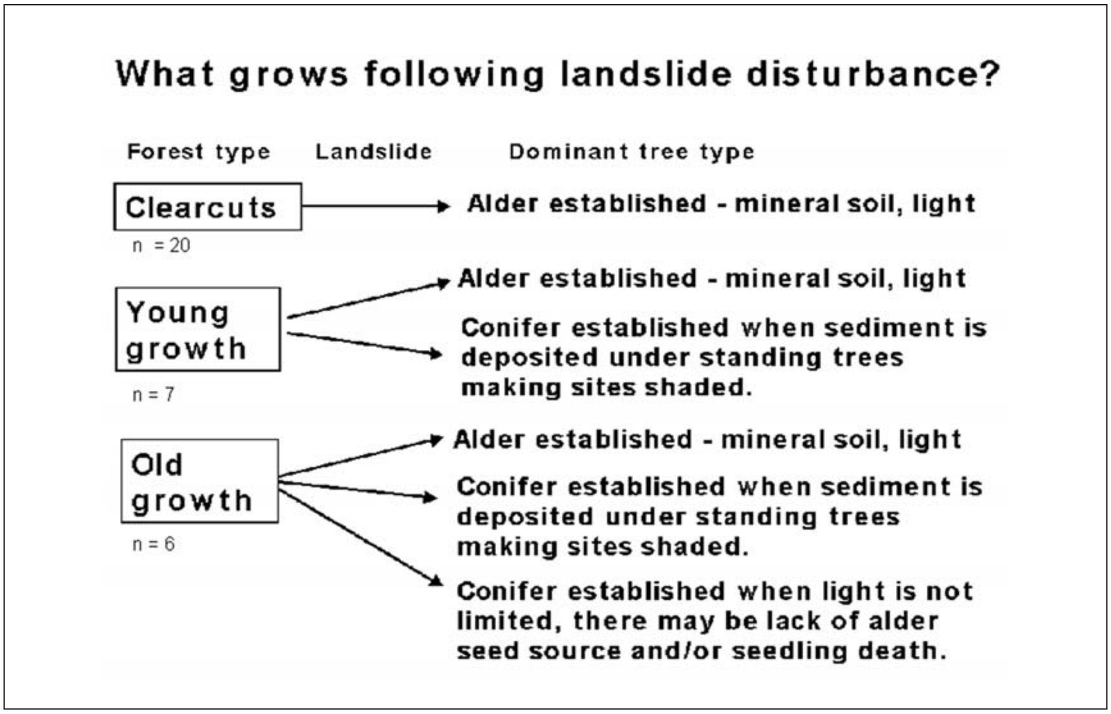

Figure 2—Pattern of alder establishment following landslide occurrence within old growth, young growth, and clearcuts.

found in streams impacted with landslides (mean = 38.3, n = 7) versus those without landslide impacts (mean = 9.1, n = 6; t-test, p = 0.0016). Streams impacted most frequently by landslides were found within deeply incised ravines (> 15 m) with steep banks. All sites with over 10% alder (except Cedar 1) had a history of either multiple landslides or one single landslide that disturbed the majority of the riparian zone adjacent to the stream. Sites with 0 - 10% alder (except Cedar 1) were not disturbed by landslides but were disturbed by cable logging. The Cedar 1 site (36% alder), located below a waterfall, was cable logged (above) and has no history of landslide occurrence. Here, deposition of sands and gravels mobilized within the clear cut zone accumulated at the slope break below a bedrock cliff, providing fresh substrate where alder established.

Within the Karta study area, alder encompassed < 5.0 ha or approximately 0.1% of the study area in contrast to 8% in the Maybeso study area. Within the old-growth forests of the Karta study area, alder was generally found in patches at the initiation sites of landslides too small to be detected on 1:63,360 infrared photographs rather than in the long, easily detectable, linear patches found in young growth. Unlike the Maybeso watershed, some areas disturbed by landslides in the Karta wilderness were vegetated with conifers.

Lowlands—Approximately 42% of the alder (54 ha) in the Maybeso watershed occurs in lowlands. About 37% (20 ha) of this alder is associated with roads, most of which are now abandoned. The remaining lowland red alder (34 ha) grows on landslide deposits, landslide deposits reworked by floods, areas where logs had been dragged, and areas disturbed by tractors (with or without log dragging). Red alder flourished in stream reaches where sediment was deposited behind logs.

It is estimated that < 50% of the alder in the Karta wilderness grew on areas disturbed by a few large landslides. Wood and sediment, associated with landslides, were deposited near the toe slopes of steeper valley side slopes and did not reach the main stem floodplain channels within old growth and young growth. Alder in main stem channels in the Maybeso and Karta watersheds, below our tributary channel study areas, was associated with fluvial processes.

Factors controlling alder growth following landslide disturbance

Following landslide occurrence, either conifer or alder grew back as the dominant species on disturbed sites within clearcuts, young-growth and old-growth forest (Figure 2). Lower alder abundance and greater growth of conifers

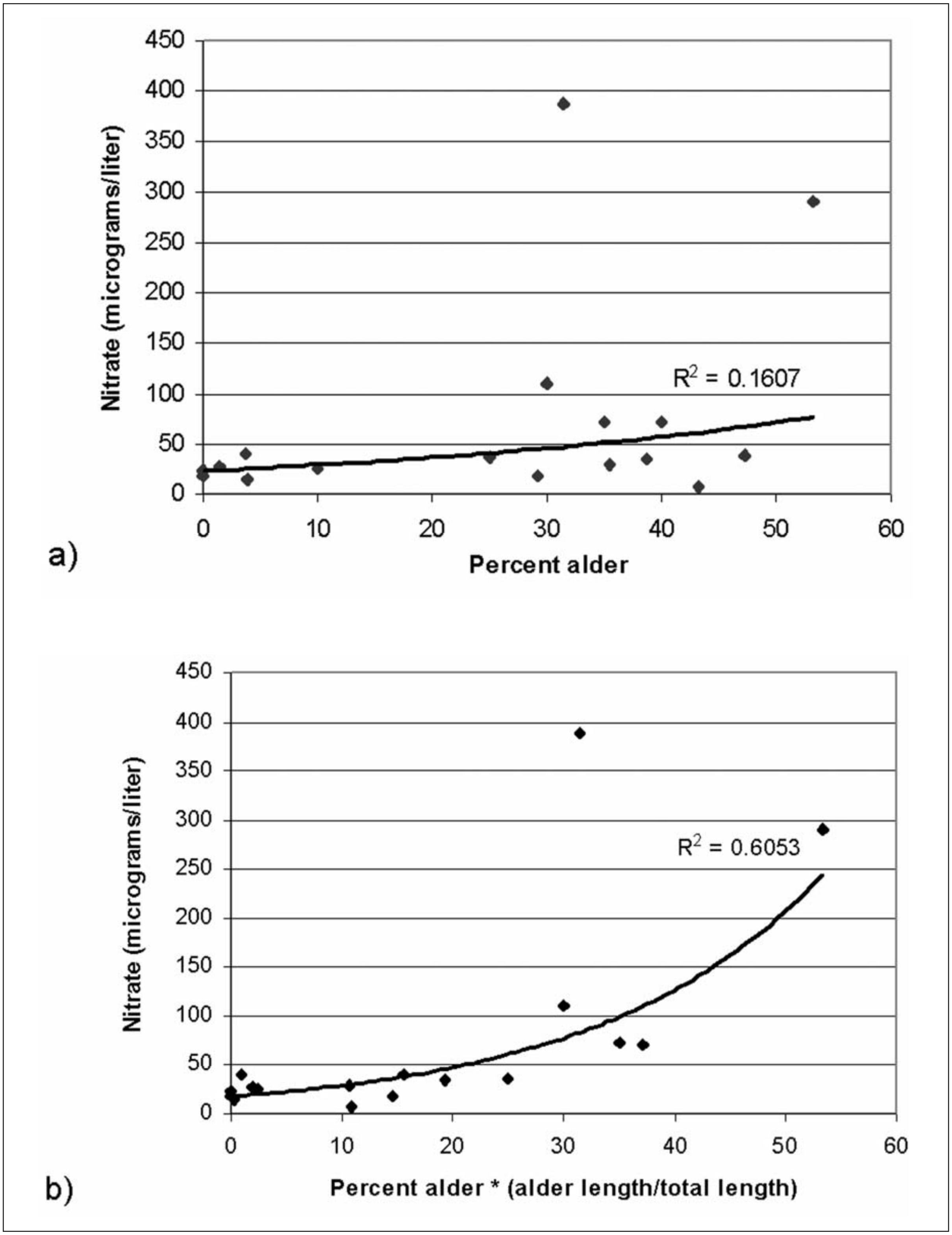

Figure 3—Relationships between nitrate concentration and a) percent alder and b) percent alder multiplied by a factor that accounts for the total length of riparian alder along selected sites.

following landslides in the wilderness area may be attributed to (1) difference in disturbance size and/or shading by large standing trees, and (2) lack of an alder seed source.

The size of the area disturbed by landslides was controlled by the landform that the landslide flowed into, diameter of trees, slope gradient of the stream channel, and location of the deposition zone. Where landslides flowed into unconfined stream channels (generally on slopes gradients > 20°) within old-growth and older young-growth forests, landslide materials knocked over trees, and landslides spread out to widths exceeding 120 m, creating larger disturbed surfaces upon which alder grew. If landslides flowed into confined channels (ravines incised > 15 m) with steep banks, disturbance width was kept narrow (< 25 m) and sites became established with new conifers or remained vegetated with pre-established (residual stand) conifers, not alder. Where landslide materials were deposited within muskegs and clearcuts and an alder seed source was nearby, alder was established regardless of size of the landslide because mineral soil was deposited in an area with no canopy cover and full light.

Large diameter trees (> 30 cm) within forested stands blocked downstream movement of landslide materials, particularly on slope gradients from 9 to 28° (16 to 54%), limiting the size of the sediment deposition area. Alder establishment within these smaller, more heavily shaded deposition zones was limited in comparison to other disturbance locations. At one site within the Karta wilderness, a single conifer tree (diameter > 0.7 m) located along the riparian corridor (with a slope gradient > 16°), stopped the transport of landslide-derived woody debris and split the water flow into two channels. Although flooding subsequently redistributed some sediment downstream at this old-growth site, alder was not found on these reworked deposits. We hypothesize that the existing overstory shaded the exposed mineral soil and inhibited alder establishment in reaches where sediment was transported.

At the location of one very large (> 30 m width, > 600 m length) landslide within the Karta watershed, alder did not establish even though the disturbance was large enough to open the canopy, enabling light to reach the mineral surface. Here, we found a dense stand of shore pine (*Pinus contorta*) growing on an area with slopes ranging from 5 to 25°. Although conditions should have favored alder establishment, it is assumed that a seed source was not near enough to support colonization at this site (no alder were observed in this area).

Association between alder occurrence and nitrate concentrations

We compared the percent alder found along streams with streamwater nitrate concentrations measured during one summer to test whether alder might affect the nitrogen budget of adjacent streams. Nitrate concentrations varied from 7 to 387 mg N/L with the highest nitrate concentrations in streams with > 20% alder (Table 1). All sites with less than 5% alder had low nitrate concentrations < 50 mg N/L. However, some alder-dominated streams also had low concentrations comparable to streams with little alder. Including all sites, no significant relationship between percent alder and nitrate concentration ($r^2 = 0.16$, $p = 0.111$; Figure 3a) was found using linear regression. Because alder basal area was not quantified along the entire upstream length, streams varied in length, and vegetation along the streams was not uniform throughout, the raw survey data do not accurately reflect the true alder abundance that might contribute nitrogen to the stream. To approximate the actual abundance of alder upstream of the sampling sites the following equation was derived:

RAA = (ABA)*(OLA/ELC)

where

RAA is the relative area of alder,
ABA is the measured alder basal area along the study reach,
OLA is the entire length of channel where alder was observed on false-color remote infrared photographs, and
ELC is an estimate of the length of the entire channel.

This calculation assumes the basal area of alder measured along the study reach accurately describes the density along the entire section containing alder. With this correction alder basal area explained 60% of the variation in nitrate concentration among streams ($r^2 = 0.60$, $p = 0.0002$; Figure 3b) suggesting a strong influence by riparian alder.

A proportion of the unexplained variance in nitrate concentration is likely due to differences in discharge and source area, which varied among streams independently of the alder coverage. For example, Guy Cotton and East Fork Broken Bridge were the only streams with sources in alpine areas whereas all others originated in mid-slope positions. Thus, we would not expect alder area alone to explain all of the variation in nitrate concentration. Although the nitrate data are just a snapshot of conditions during one summer, the results suggest that the hypothesis that streamside alder increases stream nitrogen flux is worth more rigorous testing in future studies. Estimating the potential impact of this phenomenon on stream primary production will require year round sampling to understand the seasonality of alder inputs, and *in situ* testing to determine the extent of nitrogen limitation in southeast Alaska streams. Such studies could also incorporate information about the location and area of the hydrologic contributing area, landform type, catchment soil chemistry, and knowledge of groundwater flow pathways to better understand how physical factors, interacting with natural and anthropogenic disturbances, might affect productivity of headwater streams.

SUMMARY

We assessed links among disturbance processes, vegetation type, and nitrate concentrations in the Maybeso and Karta watersheds in southeast Alaska. This information is being used in a collaborative interdisciplinary study that focuses on how young-growth ecosystems function and how red alder influences trophic linkages and processes in managed landscapes (Hennon et al. 2002; in this proceedings; Deal and Orlikowska 2002; in this proceedings).

The majority of alder within steep, U-shaped deglaciated valleys was associated with landslides, road building, tractor logging, and cable logging. On uplands (areas over 15°), over 58% of alder in young-growth forest is associated with landsliding while on lowlands 21% of alder is associated with landslide deposition, cable logging, tractor logging, and road building. Within old-growth, alder was also associated with landslides (approximately 50% of < 5.0 ha of alder observed), but did not appear to be as widespread as in young-growth forest due to the lower frequency of landslides, frictional and shading effects of standing timber, or lack of seed source.

Nitrate concentrations exceeding 300 mg N/L occurred in small channels originating in mid-slope positions along the steep valley side slopes dominated by alder. The lowest nitrate concentrations were found in larger headwater channels draining from alpine areas. Further studies examining the relationship among disturbance patterns, tree species establishment, and nutrient cycling may provide managers with a means to predict the effect of harvest practices on net primary production.

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SECTION C

SCALE ISSUES

AN EVALUATION OF TRADEOFFS BETWEEN WOOD PRODUCTION AND ECOLOGICAL INTEGRITY IN THE OREGON COAST RANGE

Thomas A. Spies[1], K. Norman Johnson[2], Gordon Reeves[3], Pete Bettinger[4], Michael T. McGrath[5], Robert Pabst[6], Kelly Burnett[7], and Keith Olsen[8]

ABSTRACT

Can alternative policies provide greater overall compatibility among wood production and ecological integrity than do current policies? Answering this question requires developing indicators of biodiversity at broad scales and analysis of tradeoffs between measures of biodiversity and wood production. We are developing a suite of indicators based on habitat quality and natural disturbance regimes. A small set of existing wildlife habitat and old-growth forest development indicators was used with a landscape simulator to demonstrate how to create a tradeoff analysis. We compared ecological conditions and timber production at 100 years for four policy alternatives for a large landscape in the central Coast Range. The alternatives differed in ecological condition and timber production, but differences were relatively small. The policy alternative based on retention of large trees in cutting units provided the same ecological conditions as an alternative based on longer rotations with less impact on timber production. One insight from this initial work is that management changes that seem drastic at stand or landscape levels may have small or slow effects on ecological conditions at larger spatial scales.

KEY WORDS: Ecological integrity, timber production, broad scale assessments.

INTRODUCTION

Understanding the tradeoffs between timber production and biodiversity is a complex problem that must be addressed over multiple spatial and temporal scales. At stand scales, timber production can have small to large effects on biodiversity and the natural processes that underpin ecosystem productivity. The potential for mixing different uses of the forest is much greater over broad areas and long time frames. In the 2.02 million hectares Oregon Coast Range Province, for example, a mix of different management objectives exist, ranging from industrial commodity production to wilderness protection. On federal lands, the Northwest Forest Plan (FEMAT 1993) has brought sweeping changes to forest management in this province, dramatically shifting the focus of these forests toward protection of biodiversity through the creation of extensive late-successional and riparian reserves where active management is only allowed for ecological objectives. This shift resulted in a 80-90% reduction of timber harvest from federal lands in the Coast Range compared to the 1980s. In the future, over 75% of the harvest in the Coast Range will come from forest industry lands which operate under the State of Oregon Forest Practices Act.

Current Coast Range policies were put in place owner-by-owner with only a modest attempt to understand their aggregate effect across owners. These policies were based on very different approaches to management: intensive management for commodity production on private lands, and passive, reserved based approaches for biodiversity protection on federal lands. The wide range of forest management strategies in the Coast Range makes it well-suited for a tradeoff analysis.

Many challenges exist to evaluating ecological and timber production tradeoffs at broad scales. Two major challenges are the development of ecological indicators of the status

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Table 1—Examples of general classes of ecological indicators used in CLAMS

Major category of metric		
Species diversity C&I 3.1[1]	**Ecosystem diversity C&I 3.1**	**Ecosystem Dynamics (Forest health and vitality) C&I 3.2**
Species assemblages/habitat groups	Forest structure at patch level	Historical range of variation: Age class distributions Habitat conditions Disturbance regimes
Focal species	Landscape structure and diversity	Ecological processes: Landslides and debris flows
Population viability of key species		

[1] Montreal Process Criterion and Indicator number.

of biodiversity and development of data and tools to evaluate alternative forest management policies. We briefly address both of these challenges. Our objectives are: (1) to describe our general approach to developing indicators of biodiversity at broad scales, (2) to develop a very simple example of a tradeoff analysis using a subset of our indicators. Our example comes from the Oregon Coast Range where we are actively working on policy effects analyses through the Coastal Landscape Analysis and Modeling Study (CLAMS) (Spies et al. 2002a).

ECOLOGICAL INDICATORS

Forestry and ecology have a long history of using ecological indicators. Some of the first indicators were used in Finland to indicate forest productivity (Cajander 1926). More recently in the Montreal Process (1999 revision) a suite of ecological indictors were developed for a broader array of characteristics associated with forest sustainability. The notion of ecological integrity is proposed as a general indicator of the condition of whole communities, ecosystems and even the entire biosphere (Karr 1991; Westra et al. 2000). Karr (1981) has promoted ecological integrity for some time but only recently have efforts been made to incorporate it into regional planning and assessment (Quigley et al. 2001). Ecological integrity ratings based on stand and landscape structure and dynamics, were developed for dry forest ecosystems of the interior Columbia River Basin (Quigley et al. 2001). No whole system measures have been developed in moist coastal ecosystems, although Carey et al. (1999) has developed indices for ecological integrity based on forest floor small mammal communities.

DIMENSIONS OF ECOLOGICAL INTEGRITY

Ecological communities and ecosystems are multidimensional in their spatial and temporal variation. Defining ecological integrity, i.e. the state of biological diversity, with a single variable is not realistic, even if that single variable is an index of several attributes (De Leo and Levin 1997). Species and ecosystems exist in too may forms and vary too much over space and time to be neatly captured in a single number. Many metrics are possible and ultimately the selection is as much an art as it is a science. The number of metrics should be large enough to capture the essential elements of a system but they must not be too numerous to be practical and must be relatively easy to measure. We have attempted to represent the range of biological diversity through three classes of measures: species diversity, ecosystem diversity, and ecosystem dynamics. These classes, which contain several subclasses, correspond to classes of indicators set forth in the Santiago Declaration for sustainable management of forests (Table 1). We do not have the space to discuss these in any detail. Below we briefly describe how we develop a few subclasses of indicators: terrestrial focal species (species diversity), forest structure (ecosystem diversity), historical range of variation (ecosystem dynamics), and aquatic systems (species and ecosystem diversity).

Examples of Selected Ecological Indicators

Terrestrial focal species—We use a focal species approach characterized by Lambeck (1997); Noss et al. (1997); and the Committee of Scientists (1999). The key to focal species

Table 2—Stand characteristics used to construct habitat indice

Ecological metrics	Stand variables	Spatial Extent
Northern Spotted Owl	Trees 10-25 cm dbh Trees 25-50 cm dbh Trees > 75 cm dbh Diameter diversity index Quadratic mean diam stand	Nesting/roosting: 0.6 ha Foraging: 28 ha; 200 ha; 1,800 ha;
Pileated Woodpecker	Nesting: Snags 50-75 cm d. Snags >75 cm d. Foraging: Trees >50 cm d. Vol CWD	Nesting: 0.6 ha Foraging: 452 ha
Western Blue Bird	Snags > 50 cm d. and 5 m t. Snags 25-50 cm d. & 5 m t. Canopy cover (%)	Territory: 0.6 ha
Old Growth	Trees > 100 cm d. Diameter diversity index Snags > 50 cm d. & 15 m t. Large logs m^3/ha Age/Time since last disturbance	0.6 ha

is that the status and time trend of selected species provides insights to the integrity of the larger ecological system. A focal species approach differs from the more widely known indicator species concept because it examines species based on properties that are likely to be overlooked by the coarse filter (e.g., narrow endemism, ecological engineer, large home range, etc.; Lambeck 1997; Noss et al. 1997), rather than species that might represent habitat needs of several species (Thomas 1979). For example, in the Pacific Northwest three small mammal species are used to measure stand biocomplexity (Carey 1995; Carey and Harrington 2001).

We developed a set of criteria and focal species that reflect characteristics of ecological integrity as well as societal concerns (e.g., listed species and game species [Table 1]). For each focal species, we develop models to characterize species occurrences and potential quality of habitat. Because habitat is species-specific, we assumed that no pre-defined vegetation classes could describe habitat suitability for all species. Thus, we developed a habitat suitability modeling approach based on the specific habitat elements as determined from the state of knowledge of the biology of the species (Table 2). Habitat suitability index models are a class of wildlife habitat relationship models specifically developed to facilitate the consideration of wildlife in multidisciplinary natural resource assessments (Schamberger and O'Neil 1986). We extend the HSI approach, developed several decades ago, to a spatially explicit assessment of habitat quality. The models we developed are similar to traditional models because they index habitat quality on a scale from 0 to 1 and they consider life requisites of the organism. They differ from the original approach because multiple spatial scales are represented and observed empirical relationships are considered in model structure.

An example of our approach is the habitat index for the Northern Spotted Owl (McComb et al. 2002). Existing literature and empirical relationships from previous studies were used to construct a habitat capability index:

$$HCI = \sqrt[3]{NCI_f^2 * LCI}$$

Where,

HCI = habitat capability index

f = the focal pixel in GIS grid

NCI = nest stand capability index (based on diversity and density of trees in diameter classes (see Table 1 for list of variables)

LCI = landscape capability index (based on habitat quality within different zones (28 ha, 212 ha, and 1,810 ha) surrounding potential nest sites.

The nest and landscape indices are variously shaped functions (e.g., linear, asymptotic or bell shaped) that range from 0 to 1 as a function of particular stand or landscape characteristics (Table 1). In the case of the Northern Spotted Owl, and for several other species, independent data are available for evaluating the quality of the models or alternative forms of the model. Where independent data do not exist, the models represent untested working hypothesis about habitat relationships.

Forest structure—Structures associated with natural and old-growth forests are typically eliminated in forests managed for timber production (Spies 1998). These include large old trees, large standing and dead trees, and heterogeneous stands composed of a diversity of tree sizes. Using methods similar to the northern spotted owl habitat index, we developed an index of old-growth forest structure that ranges from 0 to 1. A sample of about 40 existing natural young, mature, and old-growth stands from the Oregon Coast Range (Spies and Franklin 1991) was used as a guide to develop a metric that ranged from 0 to 1 for five stand variables (Table 2). While age of stand is not a structural element, it is ecologically important because some species associated with old forests are present because they have low mobility and accumulate slowly with time since last disturbance. These five stand variables were then averaged to produce a single metric for a stand.

Historical Range of Variation—Ecosystems are dynamic in space and time and the notion of the historical range of variation is an attempt to develop ecological reference conditions that take this variation into account. The historical range of variation is simply the range of values that ecosystem or habitat attributes assumed in the past under natural disturbance regimes, such as fire and wind. We estimated the historical range of variation in forest age classes for the Oregon Coast Range over the last several thousand years (Wimberly et al. 2000). We think that the amounts of different successional stages varied considerable over time as a result of large fires that periodically occurred in the area. The variation in amounts of old forest (>200 years) probably ranged between 25 and 75% of the area, while open canopy conditions probably ranged between 10 and 25% of the area. Today the amount of old forest is estimated at around 5% of the Coast Range. Simulations indicate that the range of variation increases with decreasing area. We are still developing the exact form of this metric which we will probably base on a distribution of structure or age classes that would have been expected at province scales.

Aquatic systems—Data limitations and uncertainties are often greater for aquatic systems than for terrestrial systems when assessing ecological integrity over large areas. For example, primary spatial data on aquatic systems were not available for the Coast Range at a resolution fine enough for meaningful tradeoff analyses. Consequently, generating underpinning data layers, such as watershed boundaries and streams, was necessary before we could develop and apply ecological indicators of aquatic system integrity.

Two types of indicators are in the development stage for aquatic systems: (1) one describing the intrinsic potential of streams to provide high quality rearing habitat for salmon and trout (i.e., chinook salmon (*Onchorynchus tshawytscha*), coho salmon (*O. kisutch*), cutthroat trout (*O. clarki*), and steelhead trout (*O. mykiss*); and (2) one describing land management influences on watersheds thought to affect the freshwater habitat for these species. Scores for both types of indicators range from 0 to 1. A composite score for each watershed is calculated by species from intrinsic potential and watershed condition indicator scores using methods analogous to those previously described for modeling the habitat suitability of focal species.

Intrinsic potential for each stream reach is a function of channel gradient, mean annual discharge, and valley constraint. These were modeled from 10m Digital Elevation Models (DEMs) then evaluated with field data. Values of the components associated with high-quality rearing habitat for each species are based on available literature. For example, steelhead and cutthroat trout dominated stream reaches constrained by adjacent hill slopes (Reeves et al. 1998; Burnett 2001). In contrast, chinook and coho salmon were found predominately in unconstrained stream reaches (Reeves et al. 1998; Burnett 2001). The trout also occurred in unconstrained reaches but usually at lower abundances than salmon. Thus, we judge the contribution to intrinsic potential of constrained reaches to be greater for trout than salmon and of unconstrained reaches to be greater for salmon than trout.

The watershed condition indicator is a function of land management-related metrics that can alter streams, including their wood and sediment dynamics, flow patterns, and water temperatures. Some metrics are likely to vary among alternative forest policies (e.g., vegetation age, composition, and structure or road density), but others are not (e.g., presence of dams or percent area of urban land cover). Salmonid habitat quality can change in response to disturbance and succession (Reeves et al. 1995), therefore metric scores are based on the historical range of variability when feasible and available literature otherwise. We consider the watershed condition indices as a working hypotheses

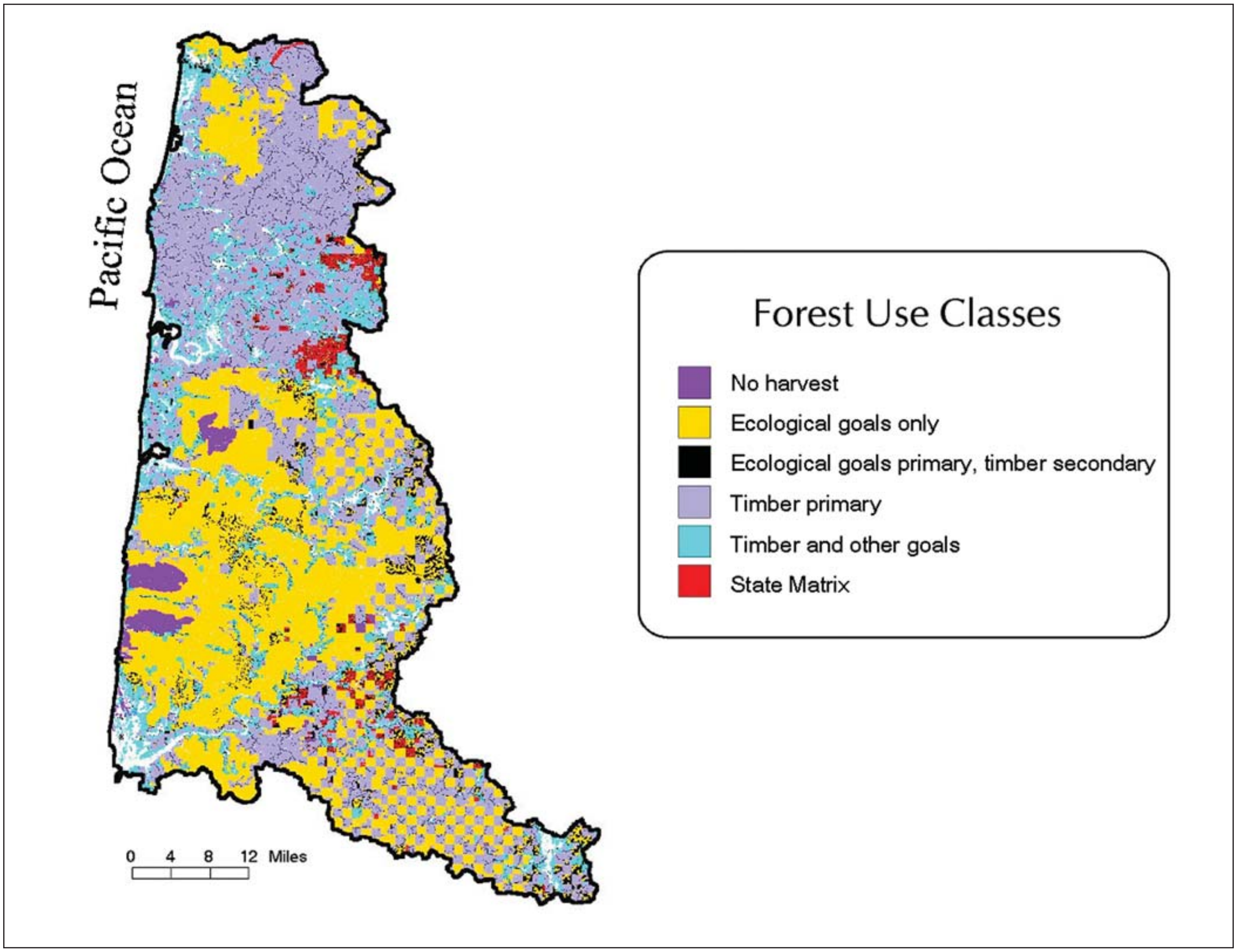

Figure 1—Pattern of forest use classes in central Coast Range of Oregon. No harvest = congressionally designated wilderness; ecological goals only = federal late successional reserves; ecological primary, timber secondary = riparian buffers and federal matrix land; timber primary = private industrial land; timber and other goals = non-industrial private forest land; state matrix = complex weighting of priorities.

Table 3—Characteristics of alternatives used in tradeoff analysis of central Coast Range

Alternative	Land ownerships	Description
Current policy	All	Current policies as indicated in federal and state forest plans and the Oregon Forest Practices Act
Increased retention	Private	Retain 5 conifers/ha > 60 cm dbh and 7 conifers/ha > 30 cm dbh
Increased thinning	Federal	Thin from below to 18 m2/ha in stands less than 40 years of age
Long rotation	Private	80 year rotation

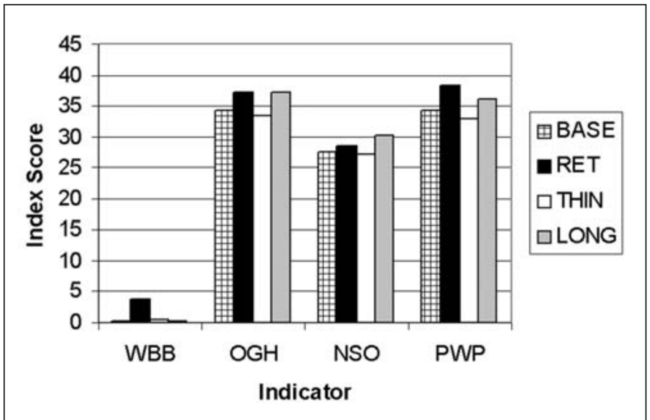

Figure 2—Mean index scores at 100 years for four different ecological indicators and four different scenarios in the central Coast Range. Index scores, which originally ranged from 0 to 1, have been multiplied by 100 to eliminate decimals. Ecological indicators: WBB = western bluebird; OGH = old-growth index; NSO = northern spotted owl; PWP = pileated woodpecker. Scenarios: BASE = base policy; RET = increased retention on private lands; THIN = thinning on federal land; LONG = 80 year minimum rotation on private lands.

based on a limited number of fine- scale and coarse-scale studies in the Coast Range (Reeves et al. 1993; Botkin et al. 1995; Burnett 2001; Reeves et al. in press).

An Example of Tradeoff Analysis for the Central Coast Range

We selected a 537,700 ha area in the central Coast Range of Oregon (Figure 1) with diverse ownership patterns to examine tradeoffs between timber production and biodiversity for a set of alternative management scenarios (Table 3). Boundaries of major watersheds were used to delineate the study area. The LAMPS model (Bettinger and Lennette 2002) was used to simulate 100 years of landscape change under the different alternatives.

The methods used to simulate landowner behavior follow those described in Spies et al. 2002b, (in this proceedings) We utilized timber harvest volume targets from the Northwest Forest Plan for Federal Lands. For state lands, we found the maximum sustainable level (based on current timber volume and expected future growth) subject to achieving goals for representation of different structural conditions and the size distribution of interior habitat patches. For private nonindustrial lands, we used the average harvest level found by Adams et al. (2001) in their analysis of economic behavior of private forest land owners in western Oregon.

For forest industry landowners, we simulated the maximum sustainable level for the management intensities they provided. Timber production was calculated as the average board foot volume of timber produced over the 100 year simulation across all ownerships including volume produced by thinning. Our long-term goal is to utilize the period-by-period harvest targets and management intensities from Adam's et al. (2001) for both private groups. We found that differences in inventories, yields, and other assumptions made it difficult to use Adams' information, especially for the forest industry, but we continue to work with Adams to develop compatible yields and assumptions.

A composite biodiversity index was constructed by averaging the mean scores at 100 years into the simulation of four ecological indices that we have for analysis: (1) old-growth habitat, (2) northern spotted owl (*Strix occidentalis*), (3) pileated woodpecker (*Dryocopus pileatus*), and (4) western blue bird (*Sialia mexicana*) (Table 2). The first three indices are related to closed forest conditions, while the western blue bird is a species representative of open, early successional forest types. Populations of the bluebird in western Oregon are listed as "Sensitive" because of population declines that are possibly related to competition for nest holes from the introduced European starlings (*Sturnus vulgaris*) (Csuti et al. 1997). The composite index is intended only to illustrate a composite ecological index for this simple example of a tradeoff analysis. As our set of ecological indicators develops further, we expect to develop a variety of indices and approaches for applying them at broad scales. For example, we could develop an expected landscape-scale distribution of index scores rather than a single mean score and compare alternatives in terms of how well they fit that distribution. We compared the results of four simulation scenarios (Table 3).

In general, the mean index scores of the individual species differed little among the scenarios (Figure 2). The greatest difference was for western bluebirds, whose mean index score was almost ten times higher for the retention scenario than for any of the other scenarios. This probably resulted from the increase in area of open conditions with snags, which would occur if higher densities of trees were left after clear-cutting on private lands. Some of these trees die during the 50 year rotation and create snags, which are important habitat elements for the species. The retention and long-rotation scenarios resulted in slightly higher mean scores for all the biodiversity metrics when compared with the base policy and the enhanced thinning scenario. This pattern results from increased numbers of large trees and snags that occur with retention and longer rotations on private lands. It was somewhat of a surprise that the thinning scenario did not change the biodiversity indices much over the base scenario. We hypothesized that thinning would increase the rate of development of large trees and

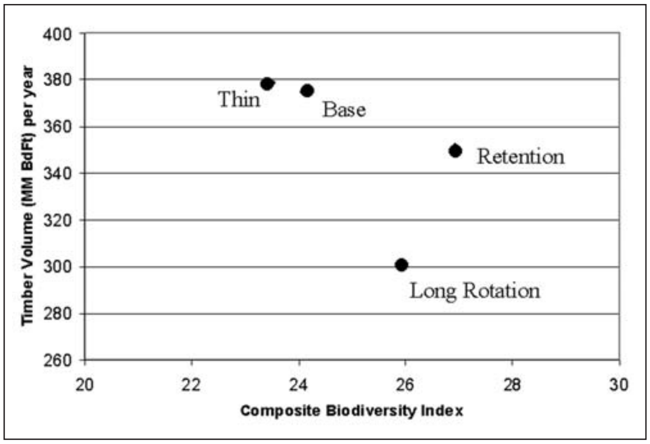

Figure 3—Relationship of timber volume production to the composite biodiversity index at year 100 for four different scenarios (see Figure 2 and Table 2 for explanations).

therefore increase the scores of the ecological indices which are sensitive to this attribute. What we think occurred, however, is that the thinning regime we used reduced amounts of standing dead and down which would reduce the index scores for these attributes. Another hypothesis is that the increases in large trees did not occur within the time frame of the simulation. Finally, perhaps the thinning effect at a landscape scale was not large enough given the acres involved. While over 40,500 ha were thinned in this scenario during the first 40 years on federal lands, this amount is only 24,300 ha more than the base policy or only about 5% of the entire central Coast Range area.

The scenarios differed relatively little among each other in terms of timber production and the composite index of biodiversity (Figure 3). The greatest overall change, compared to the base policy scenario, was in the retention and long rotation scenarios. Of these two, the retention option resulted in the greatest efficiency because the biodiversity index increased while timber production declined only slightly. The thinning option differed little from the base policy scenario, showing a slight decline in biodiversity and a slight increase in timber volume. The long-rotation scenario resulted in the greatest decline in timber volume since during the first few decades there would be little or no timber above 80 years cut. For example, during the first 25 years of the simulation, timber volume production per year from private lands would average 46 million board feet while during the last 25 years it would average 514 million board feet.

The ecological indices are limited in at least two ways. First, they show only trends in habitat quality making it difficult to say what the magnitude of the change means to other ecological criteria. For example, we can not say what the magnitude of the changes means to species viability, a criterion that would require a different type of analysis. However, the indices are useful to indicate direction of trends. A more sophisticated population viability analysis requires much more information (not available for most species) and many more assumptions than the habitat quality analysis we did here. A second limitation is that a single measure of ecological integrity may not change if its components are inversely related to each other. For example, early successional indices will typically change in the opposite direction of late successional indices. Consequently several kinds of ecological integrity measures are needed to provide a more useful characterization of biological diversity.

We have sought a better understanding of tradeoffs between timber production and ecological well being. This information is useful for finding ways to improve the compatibility of timber and other uses at broad scales. Obviously, a key question is how should we measure "timber production" and "ecological well being." We think it is easiest to measure timber production in terms of the total number of board feet harvested over time or per time period as we did. It is questionable, though, whether the landowners, especially the forest industry, are indifferent to the timing of the harvest or the financial attractiveness of the forest schedule. Most authors (Davis et al. 2001; Adams et al. 2001) assume that the forest industry attempts to maximize their wealth (net present value). Activities that increase the projected board foot harvest will not always increase net present value and vice versa. Thus, questions remain about the appropriate way to measure timber production in the tradeoff analysis.

CONCLUSIONS

The tradeoffs between ecological integrity and timber production must be examined at broad spatial scales and across multiple ownerships. The concept of ecological integrity has many dimensions and all are important when evaluating effects of timber production on the state of biological diversity. Quantitative measures of biodiversity and the notion of ecological integrity can be developed but they require much effort and a focus on a variety of measures and multiple spatial and temporal scales. They also must be developed in most cases with little or no empirical information to support them. Consequently, they serve as provisional measures that will change as new information becomes available. We demonstrate the evaluation of tradeoffs using landscape simulation models and indicators of biological diversity. Our study in the central Coast Range indicates that although differences exist in tradeoffs among alternative management approaches, the magnitude is apparently small for this particular set of scenarios. This analysis suggests that over large areas the impact of relatively small differences in management approaches applied to portions of ownerships may not result in major changes to our aggregate measure of ecological integrity within a 100-year time frame. Changes that may seem drastic at stand or landscape levels may have little impact or occur only slowly at province and larger scales. The implications of this inertia, or tendency for broad areas to change slowly, will depend on policy goals and the expectations of the policy makers and the public.

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FRAMING THE DISCUSSION OF FUTURE FORESTRY IN THE PACIFIC NORTHWEST

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ABSTRACT

Planning future management of forests and watersheds in the Pacific Northwest can lead to fruitful outcomes when the planning effort is placed in broad time and space contexts, considers multiple goods and services from these natural resource systems, and is based on effective communication with people representing the many relevant interests. A broad temporal perspective includes reference to historical disturbance regimes from wildfire and other processes. Landscape management plans examined from diverse viewpoints, such as watershed processes, biological diversity, and commodity production, provide a useful medium for balancing management objectives and approaches. Work described in this paper provides examples of some of these approaches for parts of the Oregon Cascade Range.

KEY WORDS: Forestry, landscape management, silviculture, sustainable management.

INTRODUCTION

Federal forestry in the Pacific Northwest is at an impasse. Forest management decisions are now often framed in the context of, "May I cut this tree at this site tomorrow, even if there is a chance of killing that bug?". Recently in the Pacific Northwest the answer is usually, "no." In a fire-prone ecosystem "no" is often a decision with undesirable outcomes in terms of risk to ecosystems and human systems. The management dilemma has many dimensions and at times seems intolerably complex (Holling 2001).

Land management objectives are the basis for planning and potential disagreement. We assume that at the scale of an area such as the Oregon Cascade Range, society seeks a blending of uses and values of natural resources – water, wood, aesthetics, recreation, protection and harvest of selected species. Managing a landscape to provide a widely-accepted mix of these and other benefits of natural resource systems is complicated by the diversity of views of the optimal balance, complexities of ownership patterns and land capability, and limits of our knowledge and of tradeoff analysis itself. A role of describing and analyzing alternative management futures is to make the options and uncertainties clearer in order to inform public decisions.

To plan for the future, it is helpful to see the past and future in relevant contexts. We argue that sound decisions about the ecological and social dimensions of forest management are most appropriately framed in the context of extended time scales, over broad spatial scales, and with consideration of multiple goods and services. The scientific community has wrestled with these issues in several ways. Work on the relevance of the historical (natural) range of variability (Landres et al. 1999 and other papers in that series) indicates the value of framing management decisions using ecosystem conditions of past centuries for taking a "coarse-filter approach" to management of habitat and species (Hunter et al. 1988). Development of the fields of landscape ecology and conservation biology over the past few decades represents a response to the need to consider broad spatial scales of ecosystem behaviors when addressing certain management issues. Studies in the context of the Wood Compatibility Initiative indicate the value of examining tradeoffs among varied good and services of

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forest ecosystems and watersheds in order to best meet societal needs. Finally, perceptions of ecosystems and approaches to managing them for any objectives on the spectrum from wilderness to intensive plantation forestry are as much social as technical matters. Therefore, communication and a significant level of shared understanding are important ingredients in finding a path to sustainable management.

The purpose of this paper is to explore the following four dimensions of a framework for making forest management decisions in the coming decades.

1. Placing near-term decisions and policies in a long-term perspective, both past and future.

2. Placing decisions about specific places in a broad spatial perspective.

3. Considering and integrating multiple ecosystem components, goods, and services, which may involve tough tradeoff decisions.

4. Widely sharing understanding and values.

5. These four elements can be integrated in regional conservation strategies and landscape management analyses and plans.

This paper draws on technical lessons from field and modeling studies of the development of young, managed stands; retrospective analysis of forest disturbance history and landscape dynamics; modeling and analysis of alternative landscape change scenarios; and preliminary analysis of tradeoffs among different management emphases. We also draw on lessons from experience of the Willamette National Forest in development, implementation, and communication of two landscape management plans through an adaptive management process, including work in the Central Cascades Adaptive Management Area (Cissel et al. 1998, 1999).

LONG-TERM PERSPECTIVE

There are arguments for and against using history in planning for future forest landscape management (Morgan et al. 1994; Swanson et al. 1994; Landres et al. 1999). Historic landscape conditions do not give a sharp blueprint for future management. However, attention to the past helps managers avoid attempting the impossible, and can help them meet the direction in regulations for implementing the National Forest Management Act that calls for Forest Service lands to sustain native species throughout their range. The term "native" connotes historical occupancy of a landscape and adaptation to the environment. Hence, reference to historical conditions is used as part of a coarse-filter approach to habitat management (Hunter et al. 1988) and as an indicator of sustainable ecosystem management as defined in the Montreal protocols. Projections of landscape conditions into the future are important in revealing aggregate, sometimes surprising consequences of particular management schemes, such as dispersed patch clearcutting (Franklin and Forman 1987) and the Northwest Forest Plan (Cissel et al. 1999).

A variety of techniques is employed to reconstruct major dimensions of the historical dynamics of Pacific Northwest forests (Garman et al. 1999), including fire history reconstruction studies based on tree-ring analysis. Weisberg and Swanson (in press) and Berkley (2000) have analyzed ten tree-ring, fire history studies in western Oregon and Washington to help unravel temporal and geographic patterns of fire occurrence over the past 600 years. Key findings include: fire historically has been an integral element of the forest landscape of the central Cascade Range of Oregon, periodically resetting succession in large and small patches of landscape; suppression of fire over long periods is itself a form of disturbance to the ecosystem; in parts of the Pacific Northwest low- and moderate-severity fire sustained old-growth attributes and probably certain fire-dependent species in the landscape; and timing of widespread fire in parts of the region in the 1500's and 1800's appears to have been roughly synchronous, suggesting a climate influence in addition to other factors. The last point argues against systematic recurrence of fire simply in response to fuel dynamics on the multi-century scale.

Collectively, these points argue for selective retention of roles of fire in the ecosystem and in the tool kit of forest management, regardless of management objectives. Despite the great longevity of conifers in the Pacific Northwest, these ecosystems are very dynamic. Effective conservation and management strategies need to accommodate this dynamism.

BROAD SPATIAL PERSPECTIVE

The Northwest Forest Plan and other bioregional assessments are a reaction to inadequacies of our past scales of planning at the individual project and National Forest scales. These scales of analysis were inadequate to reveal some important cumulative management effects, which resulted in environmental issues that triggered natural resource management crises (Gunderson et al. 1995;

Johnson et al. 1999). The bioregional assessments and resulting management plans take spatially hierarchical approaches to management of complex ecosystems. Multi-scale landscape analysis has gained prominence over the past two decades both in planning processes that consider several alternatives and in academic exercises.

A series of modeling exercises has explored consequences of alternative management and wildfire scenarios in the Pacific Northwest (e.g., Franklin and Forman 1987; Spies et al., 2002). With Wood Compatibility Initiative funding we have undertaken landscape change modeling of the 17,000-ha Blue River area (Cissel et al. 1999) and a 17000-km^2 area covering much of the western Cascade Range of Oregon (Pennington 2002). Different modeled drivers and types of landscape change, including historical wildfire, intensive plantation forestry, the Northwest Forest Plan, and designated wilderness without fire produce very different landscape conditions over time. Specific properties of these differences reveal contrasts in the mixtures of goods and services produced by each scenario. Because they differ in age class distributions and arrangements, landscapes produced by different drivers ("landscape scenarios") also differ in their mixes of ecological goods and services. A landscape plan that incorporates some components of the historic disturbance regime produces distributions of forest age classes quite similar to the wildfire regime and quite different from the other management scenarios simulated. The other management scenarios potentially eliminate some forest age classes from the landscape, including early (pre-conifer canopy closure) and mature (80-200 yr) classes, which may have important ecological consequences. This suggests that balancing the current policy focus on old-growth forests with attention to other age classes is worthy of consideration. It is also interesting to note the high temporal variability of the historical wildfire system, which contrasts strongly with the orderly design of most managed systems. It is important to also note that management systems, when implemented, are often less orderly than designed. Major sources of uncertainty include the changing social context of management; climate change; and the effects of natural disturbance processes on managed landscapes, regardless of fire suppression and salvage operations.

MULTIPLE GOODS AND SERVICES

Interactions among different components and functions of ecosystems are the subject matter of ecosystem science. The parallel notion in social and economic terms is analysis of tradeoffs among goods, services, and economic costs and benefits in natural resource management. Economists and others in the social dimension have long thought in terms of goods and services derived from natural resource systems. Ecologists have been rather recent arrivals at this point of view, but have picked up the notion of ecological services with some enthusiasm (Daily 1997), in part to promote environmental protection.

Consideration of the multiple goods and services derived from ecosystems helps us recognize the diversity of values we have in forests and watersheds and the competing forces at work among them. Tradeoffs and interactions may be strong or weak, positive or negative; and the interpretations of tradeoffs depend substantially on the scale, spatial extent, and especially the components and functions of the system analyzed. For example, under some conditions, carbon sequestration in forests is strongly and negatively linked with human consumption of wood, because carbon in solid form is directly traded off between the two components of this goods vs. services pair (i.e., wood products vs. carbon sequestration). If wood products are used in solid form for long periods of time (centuries), carbon sequestration in non-forest pools may be increased. More intensive forest management for wood production, on the other hand, may benefit species favored by young, conifer habitat, while reducing habitat for species that fare better in late seral habitat. However, very intensive silviculture may severely limit the duration of this early seral habitat. A somewhat weaker coupling occurs in tradeoffs between wood production and water yield, which, as a first approximation, is sensitive to changes in leaf area. Leaf area recovers much more rapidly in regenerating stands than does carbon accumulation in woody biomass, so the coupling between hydrology and wood removal is weaker than the carbon sequestration - wood removal link. Thus, interactions of wood production with other goods and services from forest systems are complex and multifaceted. To manage for only one outcome may leave others at substantially less than desirable levels.

Tradeoff and interaction terms are evident in analysis of effects of thinning on rate of development of old-growth attributes in plantations previously managed for Douglas-fir production as the primary objective. Support from the Wood Compatibility Initiative helped fund modeling analysis built on the Young Stand Thinning and Diversity Silviculture Study, involving thinning in 40-year old plantations on the Willamette National Forest. Garman et al. (in press) observed that certain thinning practices (heavy thinnings from below at ages 40, 60, 80 years) could produce live-tree attributes meeting standards for old-growth stand structure (Spies and Franklin 1991) early in the second century of stand development. In the absence of management, these stands took nearly an additional century to reach these conditions. Busing and Garman (2002) extended this work to consider quality of wood (e.g., extent of clear-bole wood) produced from these thinning treatments. Generally, their modeling analysis found that thinning from below on longer rotations can promote large live and dead trees and canopy height diversity of old-growth forests while yielding high quality (clear bole) wood. This work indicates that wood production, especially large diameter, clear wood, can be compatible with achieving certain ecological objectives, including development of some old-growth forest attributes. Efforts are now underway to extend these stand modeling capabilities to the landscape scale.

INTEGRATION OVER TIME, SPACE, AND MULTIPLE GOODS AND SERVICES

Landscape management plans can be a medium for synthesis, even science synthesis. They embody ideas derived, in part, from science tested in the course of management application. Management plans are also useful media for communication with diverse groups about alternative courses of future management. We are developing, implementing, and monitoring a landscape management plan through an adaptive management process (Cissel et al. 1999). This process has proven useful as a synthesis of ideas concerning taking long time, broad space, and multiresource approaches to forest and watershed management. Modeling alternative scenarios of landscape change has helped reveal difficulties of using management schemes that take a narrower scope, such as the species protection and recovery focus of the Northwest Forest Plan.

THE HUMAN DIMENSION —COMMUNICATIONS

A continuing, critical step is communication. Over several decades of work associated with the H.J. Andrews Experimental Forest, we have learned that continuing dialogue among land managers and scientists with a constant stream of visitors on field tours has shaped our view of the potential futures of forestry. Partly in response to these field discussions we have taken research and land management action to help test and shape that forestry in the real world. Five essential elements of this continuing discourse are: treat it as a continuing, open discussion; do it in the field where difficulties with language and personalities are less likely to intrude on good communication; present real examples of science-management connections and of alternative approaches to stand and landscape management; share and test ideas among local researchers and managers and visitors to the area; and engage visitors with a broad mixture of political, social, and disciplinary perspectives. We have no good name for this discourse in the woods. It is not "technology transfer" because it is not about technology and it is not about transfer, but rather about sharing ideas and views on the future of forest and watershed management.

CONCLUSIONS

As with many natural resource issues, the future of forestry on federal lands will undergo change which is often difficult (Gunderson et al. 1995; Holling 2001). In a period of dramatic change, such as the transition of the Pacific Northwest federal forestry from the 1980s to the 21st century, it is important to capitalize on opportunities for creativity and adaptation without becoming overwhelmed with the complexity of the situation (Holling 2001). Despite the complexity it may impose, we argue that consideration of specific, broad time and space scales and of tradeoffs provides essential context for charting the future. Repeated discussions in the contexts of the forest and of real examples of management approaches are an important venue for deliberating the future of forestry.

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DEVELOPMENT OF MIXED RED ALDER-CONIFER STANDS IN SOUTHEAST ALASKA

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ABSTRACT

Overstory stand structure and growth, and understory plant diversity and abundance were assessed in nine 38- to 42-year-old mixed red alder-conifer stands on Prince of Wales Island, Alaska. Tree species composition ranged from 100% conifer to 79% alder as a proportion of stand basal area. Tree height growth patterns for overstory trees were reconstructed using dominant red alder, Sitka spruce and western hemlock trees at each site. Height growth of alder was initially much greater than for conifers, but conifers emerged from alder overstory after 20-30 years and are now 4-9 m above the alder canopy. Understory species richness was greatest in mixed stands containing 18-51% alder and was lower in pure conifer and predominantly alder stands. Total understory plant cover and herbaceous cover increased with increasing proportions of red alder. Understory plant communities appeared to be more diverse and abundant in mixed alder-conifer stands than in pure conifer stands. Results suggest that mixed red alder-conifer stands may increase understory plant production and availability for deer forage and improve habitat for small mammals.

KEY WORDS: Silviculture, stand development, red alder, understory plants, overstory-understory interactions, southeast Alaska.

INTRODUCTION

Red alder (*Alnus rubra* Bong.) is a relatively short-lived, shade-intolerant tree with rapid juvenile height growth. In Alaska, alder usually occurs as a pioneer species with Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) on exposed mineral soils (Harris and Farr 1974; Ruth and Harris 1979). Recent logging has increased the amount of alder in the forests of Southeast Alaska, particularly in upland areas with heavy soil disturbance. However, little information is available about the growth and ecological role of red alder in Southeast Alaska and basic information on silvics, stand growth and yield, tree species mixtures, succession, tree mortality and decay, and understory vegetation in alder stands is lacking. This study uses a broadly integrated approach to examine the role of alder in young-growth forest ecosystems and the influence that alder has on different forest resources.

In Southeast Alaska, even-age forest management has been used almost exclusively in the region for wood production, and stands have been regenerated through clearcutting and natural reproduction. However, the dense, uniform, even-aged conifer stands that quickly develop are recognized as having broadly negative consequences for wildlife and fish (Wallmo and Schoen 1980; Schoen et al. 1981,1988; Thedinga et al. 1989; Hanley 1993; Dellasala et al. 1996). Canopy closure generally occurs 25 to 35 years after cutting followed by a nearly complete elimination of understory vegetation for 100 years or longer (Alaback 1982a, 1984; Tappeiner and Alaback 1989). Attempts to reestablish understory herbs and shrubs through thinning young-growth conifer stands have led to mostly conifer regeneration with little new herbaceous colonization (Deal and Farr 1994). However, recent studies of mixed red alder-conifer stands have indicated that different successional pathways are possible following clearcutting in Southeast Alaska. These alder-conifer stands have both species-rich and highly productive understory vegetation with biomass similar to that of old-growth stands of the

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region (Hanley and Hoel 1996; Deal 1997; Hanley and Barnard 1998). Habitat quality for some small mammals in even-aged, alder-conifer stands may be equal to that of old-growth forests (Hanley 1996). Although inclusion of alder will not provide mitigation for all wildlife-habitat problems (e.g., lack of snow interception for deer winter range), it may accomplish more than is possible by thinning even-aged conifer stands.

In this paper, we examine the structure of mixed red alder-conifer forests and present preliminary information on stand development of overstory alder and conifer trees. We also assess understory plant diversity and abundance in mixed alder-conifer stands and discuss implications of this research for wildlife. These preliminary results will be used to further develop investigations on the role of alder in young-growth forest ecosystems and to assess the potential tradeoffs and compatibility of different forest resources in mixed alder-conifer stands. This information may also be used to help develop regional adaptive management practices.

APPROACH

To assess the role of red alder in young-growth forests and to evaluate potential tradeoffs in wood production and biodiversity between alder-dominated and conifer-dominated forests we sampled stands containing a range of alder-conifer mixtures. The proportion of alder basal area was the major criterion for stand selection with increasing alder composition sampled across a continuum from pure conifer to predominantly alder. To reduce the variability among stands we limited our sites to the Maybeso and Harris watersheds, Prince of Wales Island. These watersheds contain large areas that were logged about 40 years ago and have stands of relatively similar age with a wide range of alder/conifer composition. Nine forest stands were intensively sampled during the summer of 2000.

METHODS

We used a combination of variable-radius and fixed-area plots to sample and describe stand structure and composition. Variable-radius plots were used to assess stand density, alder frequency, distribution and proportion of basal area in each stand, and understory vegetation. Larger fixed-area plots were used to determine stand and tree growth, tree mortality, and tree height growth patterns. Plot data were combined by stand. Tree height growth was reconstructed using stem sections from 90 overstory alders and conifers to determine patterns of stand development.

Understory plant vegetation was sampled in seventy 1-m^2 vegetation quadrats and 2-m radius shrub plots systematically located throughout the stand. Vegetation cover was measured on quadrats and shrub plots located at both the overstory variable-radius and fixed-area plots. Vegetation cover was estimated for all vascular and commonly found non-vascular plants. Cover data were combined by stand.

PRELIMINARY RESULTS

Stand History, Composition and Structure

Stand reconstruction showed that all of the sites were harvested between 1958 and 1962. Sites were selected on the basis of preliminary estimates of overstory alder and conifer composition but actual stand compositions were not determined until after stand data were summarized. Most of the sites had less alder than the original estimates indicated, and only two sites contained more than 50% alder as a proportion of stand basal area. The pattern of alder was usually linear, was found along streams or on logging roads, and was closely associated with disturbances including landsliding, log dragging, tractor logging, or road building (Johnson and Edwards 2002, in this proceedings).

Overall, the proportion of alder varied from 0% in a pure conifer site to almost 80% alder in another site. Most sites had approximately 20-50% alder with Sitka spruce and western hemlock comprising the majority of other species in the stand. Some sites also had a minor component of western red cedar. Stand density was generally inversely related to the proportion of alder either as a function of basal area or as a function of tree stocking. The most open site with the lowest basal area and tree stocking was the site that had the highest proportion of alder.

Most sites were relatively well stocked with abundant small-diameter conifer trees and stand basal areas were only slightly less than comparable even-aged pure conifer stands in the region. The site with the highest proportion of alder had considerably fewer trees and lower basal area than the other sites. The average diameter of alder trees was much larger than the average diameter of spruce or hemlock trees. However, the biggest diameter and tallest trees in almost all sites were conifers. Most mortality occurred in small-diameter conifers and alders.

Reconstruction of Red Alder and Conifer Height Growth

The height growth of dominant and codominant alders and conifers were compared at two sites. These sites were chosen to show two different patterns of height growth in a mostly alder overstory stand (Alluvial Fan site, Figure

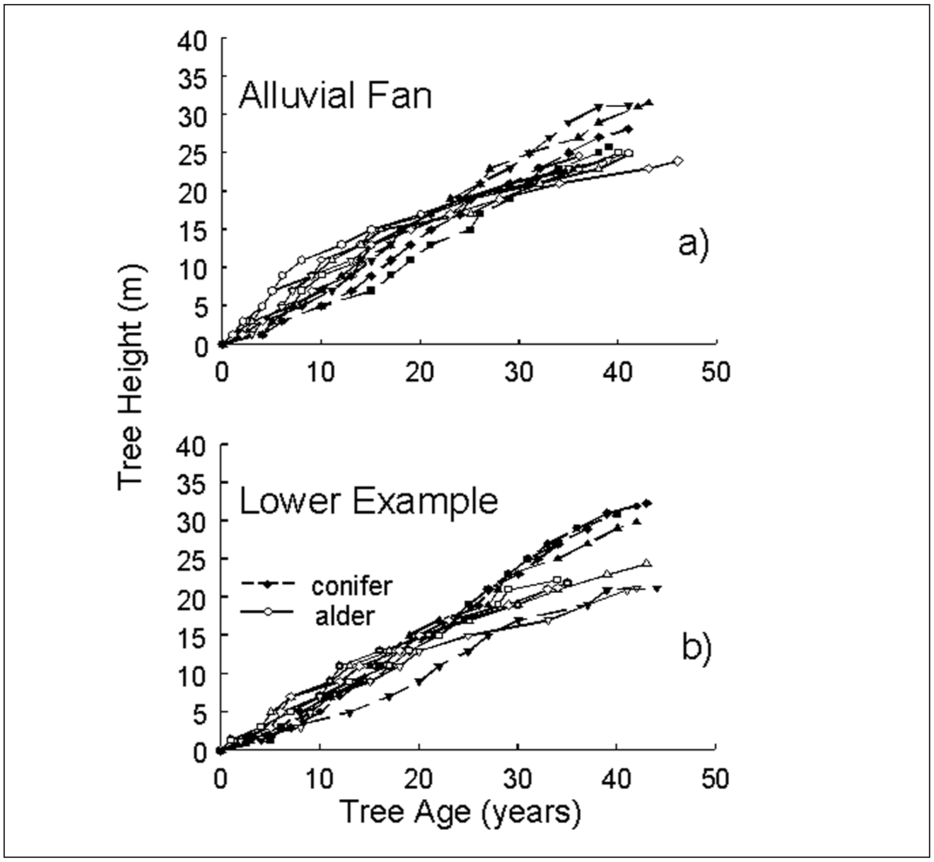

Figure 1—Tree height growth reconstructions for dominant red alders and conifers (Sitka spruce and western hemlock) at two of our research sites. The Alluvial Fan site (a) is a predominantly alder overstory stand, and the Lower Example site (b) is a conifer-dominated stand.

1a) and a conifer-dominated stand (Lower Example site, Figure 1b). These sites illustrate general growth trends for alder and conifers but also show different potential stand development patterns.

At the Alluvial Fan site, alders exhibited rapid early height growth but then slowed down after 20-30 years (Figure 1a). Initially, conifers grew slowly but during last 20-30 years they have consistently had greater height growth than associated alders in the stand. Alders at 10, 20 and 30 years old averaged +4.0, +1.5, and -2.0 m taller than conifers of the same age. Dominant conifers emerged from the alder overstory between 20-30 years after cutting (Figure 1a), and in the current stand (year 2000), conifers average about 4.6 m taller than the overstory alders. Height growth of alders was very uniform with all of the alders currently about 24 m tall. Conifers are continuing to grow rapidly in height while the alders have shown a consistent slow down in height growth.

At the Lower Example site (Figure 1b), this same general height growth pattern for alders was apparent with rapid early height growth followed by declining growth. The slow down of height growth in alder at the Lower Example site was more pronounced than at the Alluvial Fan site. Alders at 10, 20 and 30 years old averaged +2.1, -0.5, and -4.6 m taller than conifers of the same age. Dominant conifers emerged from the alder overstory at about 20 years after cutting (Figure 1b), and in the current stand (year 2000), conifers are now more than 9 m taller than the overstory alders. At the Lower Example site, many alders are now being suppressed by the conifer overstory and there is considerable alder mortality.

Understory Plant Diversity and Abundance

The species richness of these mixed alder-conifer stands was fairly high with 112 species of understory plants including 49 herbs and 15 shrubs (Table 1). The lowest species richness was in the pure conifer stand and the stand with the highest proportion of alder. The pure conifer stand in our study had a total of 43 species including only 12

Table 1—Species diversity measures for all plant species, non-vascular and vascular plants, herbaceous plants, and shrubs

	Species Diversity Measures				
Data Set	Richness	Alpha	E	H’	D’
Full	112	52.6	0.60	2.39	0.82
Non vascular	48	25.2	0.45	1.47	0.62
Vascular	64	27.3	0.68	2.23	0.82
Herb	49	17.8	0.67	1.89	0.79
Shrub	15	9.6	0.61	1.39	0.64

Note: Richness is the total number of plant species in the study; Alpha diversity is the average number of species per site; Evenness (E) = H’ / ln (Richness), from (Pielou 1975); Diversity (H’) = $-\Sigma$ (p_i * ln(p_i) where p_i = importance probability in element i, from (Shannon and Weaver 1949); D’ = 1 - Σ (p_i) from (Shannon and Weaver 1949). The herb data set included herbaceous plants and ferns. The shrub data set included woody shrubs and tree seedlings.

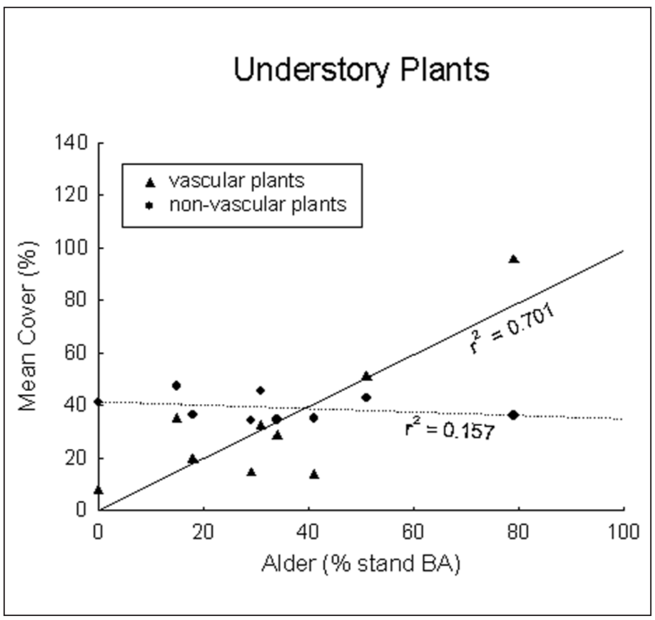

Figure 2—The mean canopy cover of vascular and non-vascular plants as a function of the proportion of alder basal area for all nine of our research sites combined.

herbs and 8 shrubs. The stand with the highest proportion of alder had 49 species including 15 herbs and 10 shrubs. The greatest species richness occurred at the Alluvial Fan site (51% alder) with a total of 62 species including 26 herbs. Overall, the most species rich stands were those stands with more even mixtures of alders and conifers.

Understory canopy coverage appeared to be closely related to the amount of alder in the stand and understory plant cover increased with increasing proportion of alder basal area. The proportion of alder basal area explained about 58% of the variability of total plant cover. Analysis of cover for vascular plants (taller plants with tracheophytes) and non-vascular plants (bryophytes) showed different relationships. The non-vascular plant cover was similar for all of the sites and varied among sites from about 35-45%. There was no significant relationship ($r^2 = 0.157$, $p = 0.291$) between the cover of non-vascular plants and the proportion of alder basal area (Figure 2). In contrast, the vascular plants showed a strong correlation ($r^2 = 0.701$, $p = 0.005$) between increasing vascular plant cover and increasing proportion of alder basal area.

DISCUSSION

These mixed red alder-conifer stands contained variable stand structures including large overstory conifers, medium sized red alders and a moderate stocking of understory conifers. Typical well-stocked hemlock/spruce stands in Southeast Alaska at similar sites and ages have slightly higher basal areas (50-80 m^2 ha^{-1}) than our sites (37-63 m^2 ha^{-1}) and much higher tree stocking than the mixed alder-conifer stands we studied. These lighter stocked alder-conifer stands had higher understory plant diversity and much greater abundance of vascular plants compared with typical, heavily stocked conifer stands of the same age. Alaback (1982a) reported that understory biomass in hemlock/spruce stands in Southeast Alaska peaked at a stand age of 15 to 25 years, and rapidly declined once the canopy closed. After canopy closure, these stands enter an intense stem-exclusion stage, with the least diverse understories occurring in stands between 40 and 90 years of age (Alaback 1982b). Young-growth conifer stands of the same age as our sites (40 years) typically contain dense, uniform overstories of hemlock and spruce that severely suppress understory development. In contrast, our 40-year-old mixed alder-conifer stands currently provide relatively abundant and diverse understory plant communities.

It is unclear how long red alder will remain in these stands. Red alder is replaced in stands by longer lived conifers that sustain growth rates longer than associated alders but the time required for alder senescence has not been well documented (Harrington et al. 1994). In pure alder stands in the Pacific Northwest, alder mortality increases rapidly in stands over 90 years old (Worthington et al. 1962) and little alder remains by the age of 130 years (Newton and Cole 1994). In the stands we studied, it appears that alder is being suppressed and may die soon in some sites, but in other sites, alder is thriving and will persist for much longer. The conifer-dominated site at Lower Example (Figure 1b) shows that the tallest alder are now 9 m shorter than associated overstory conifer trees. Many smaller suppressed alder have already died in these stands and we expect that the alder in this stand may be almost completely replaced by conifers in 20 years. However, in the evenly mixed alder-conifer stand at Alluviual Fan (Figure 1a), the tallest alder are only 4 m shorter than the overstory conifer trees. Few of the alder appear to be dying and there are still several hundred overstory alder per hectare in this stand and fewer overstory conifers. We expect these alder to survive for several more decades. Information is lacking on the life span of alder, but based on observation (Hennon, personal correspondence), alder can live more than 100 years in Alaska and we expect that some alder in this stand may survive for another 50 years or more.

Understory plant species richness was greatest in the stands with mixtures of alder and conifers. Species richness for vascular plants was greatest in stands containing 18-51% of the stand basal area in alder. Vascular plant abundance also significantly increased with increasing proportion of alder in the stand. Bryophytes (mosses and liverworts) may have biodiversity value but vascular plants are generally more important plants for wildlife and fish. Vascular plants including some important herbs and shrubs provide forage for Sitka black tailed deer and key habitat for small mammals. These larger shrubs also provide greater biomass for invertebrates that in turn provide important trophic resources for songbirds, fish and other insectivores. Based on preliminary results it appears that these mixed alder-conifer stands will provide improved terrestrial and aquatic food resources for wildlife and fish.

It is important to remember that the stands we studied were cut to provide specific wood products for sawmills and pulpmills in the region. Cutting occurred with no effort to encourage alder regeneration, in fact, alder has been considered an undesirable tree species and may have been removed following normal precommercial thinning practices. This study provides some preliminary information on the role of alder in managed young-growth forest ecosystems and the potential tradeoffs and compatibility of different forest resources in mixed alder-conifer stands. Inclusion of alder in a regenerating stand may mitigate some of the effects of clearcutting in areas where purely even-aged conifer stands would compromise wildlife and aquatic resources.

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