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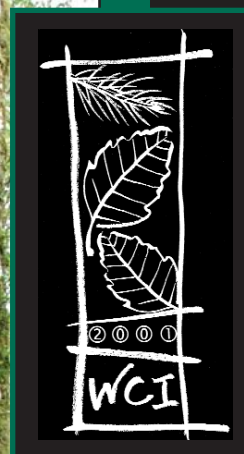
Forest Service

Pacific Northwest  
Research Station

General Technical  
Report  
PNW-GTR-563  
November 2002



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



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



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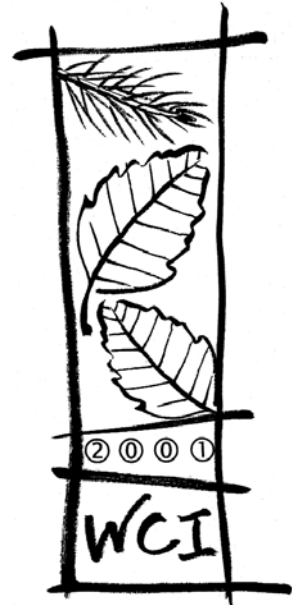
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**CONGRUENT MANAGEMENT  
OF MULTIPLE RESOURCES:  
PROCEEDINGS FROM THE  
WOOD COMPATIBILITY  
INITIATIVE WORKSHOP**

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

Skamania Lodge  
Stevenson, Washington  
December 4-7<sup>th</sup> 2001

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## ABSTRACT

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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 4-7<sup>th</sup> 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

| <b>When you know:</b>           | <b>Multiply by:</b> | <b>To find:</b> |
|---------------------------------|---------------------|-----------------|
| Meters (m)                      | 3.28                | Feet            |
| Square meters (m <sup>2</sup> ) | 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 <sup>2</sup> )  | .093                | Square meters   |
| Inches (in)                     | .394                | Centimeters     |
| Acres                           | .405                | Hectares        |
| Mile                            | 1.609               | Kilometers      |
| Pounds (lbs)                    | .454                | Kilograms       |

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## EMERGENT RESULTS FROM THE WOOD COMPATIBILITY INITIATIVE

Richard W. Haynes<sup>1</sup>, Robert A. Monserud<sup>2</sup>, and Adelaide Johnson<sup>3</sup>

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### 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.

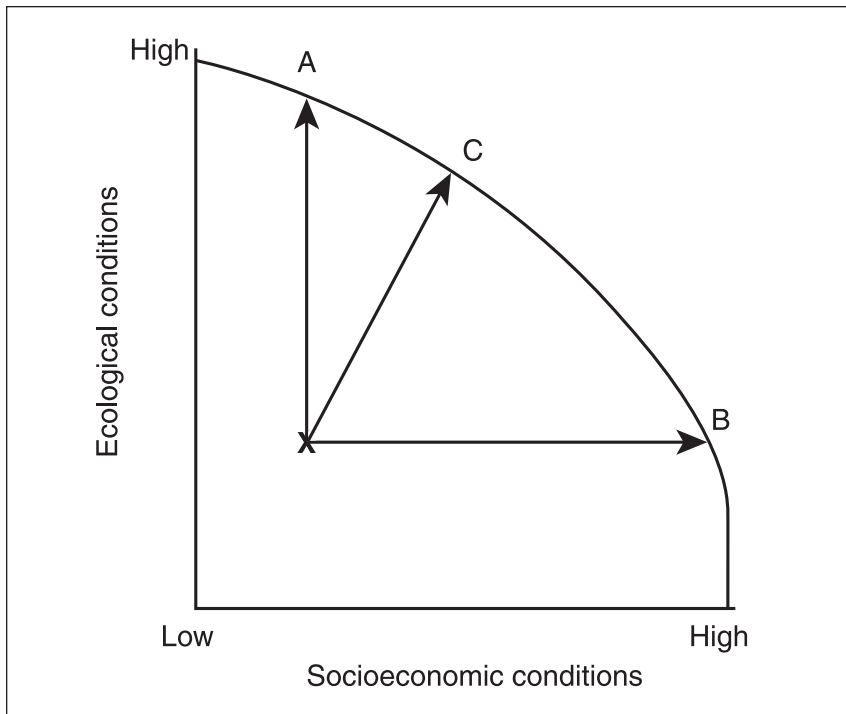


Figure 1—Hypothetical joint production function between ecological and socioeconomic conditions showing opportunities for compatible changes of both.

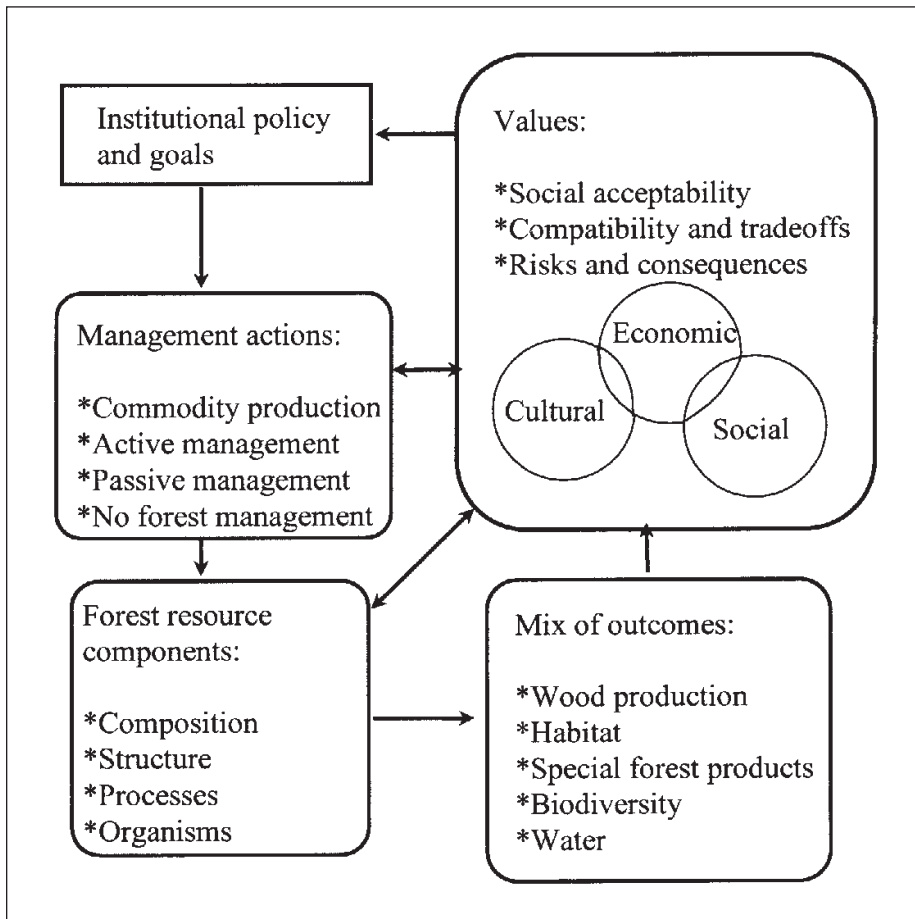


Figure 2—Wood Compatibility Initiative general conceptual model including forest resource components with interactions among social values, institutions, management, and outcomes.

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 non-uniform 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.

## LITERATURE CITED

- Beese, W.J.; Bryant, A.A. 1999. Effect of alternative silvicultural systems on vegetation and bird communities in coastal montane forests of British Columbia, Canada. *Forest Ecology and Management*. 115: 231-242.
- Beese, W.J.; Phillips, E.J. 1997. Harvesting Costs and Impacts of Alternative Silviculture Prescriptions in Old Growth. In: *Forest Management into the Next Century: What Will Make It Work?* Proceedings. Madison, WI: Forest Products Society: 02-110.
- Behan, R. 1990. Multiresource forest management: a paradigmatic challenge to professional forestry. *Journal of Forestry*. 88(4): 12-18.
- Carey, A.B.; Thysell, D.R.; Brodie, A.W. 1999. The Forest Ecosystem Study: background, rationale, implementation, baseline conditions, and silvicultural assessment. Gen. Tech. Rep. PNW-GTR-457. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 129 p.
- Cissel, J.H.; Swanson, F.J.; Weisberg, P.J. 1999. Landscape management using historical fire regimes: Blue River, Oregon. *Ecological Applications*. 9(4): 1217-1231.
- Clayoquot Scientific Panel. 1995. Sustainable ecosystem management in Clayoquot Sound: planning and practices. Victoria, BC: Report 5; Scientific Panel for Sustainable Ecosystem Management in Clayoquot Sound. 296 p.
- Committee of Scientists. 1999 (March 15). Sustaining the People's Lands: Recommendations for Stewardship of the National Forests and Grasslands into the Next Century. Washington, DC: U.S. Department of Agriculture. 193 p.

- Curtis, R.O. 1996. Silvicultural options for harvesting young-growth production forests. Prospectus for DNR/PNW Cooperative Project. Unpublished document. On file with: USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3625-93d Avenue SW, Olympia, WA 98512-9193. 5 p.
- Curtis, R.O. 1998. "Selective cutting" in Douglas-fir: history revisited. *Journal of Forestry*. 96(7): 40-46.
- Curtis, R.O.; DeBell, D.S.; Harrington, C.A. [et al.]. 1998. Silviculture for multiple objectives in the Douglas-fir region. Gen. Tech. Rep. PNW-GTR-435. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 123 p.
- Duncan, S. 2000. Closer to the truth 75 years of discovery in forest & range research. Misc. Pub. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 76 p.
- Everest, F.H.; Swanston, D.N.; Shaw, C.G., III [et al.]. 1997. Evaluation of the use of scientific information in developing the 1997 Forest plan for the Tongass National Forest. Gen. Tech. Rep. PNW-GTR-415. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 69 p.
- Forest Ecosystem Management Assessment Team (FEMAT). 1993. Forest ecosystem management: an ecological, economic, and social assessment. Washington, DC: U.S. Department of the Interior; U.S. Department of Agriculture; U.S. Department of Commerce; U.S. Environmental Protection Agency. 729 p. [plus appendices].
- Forest Practices Code of British Columbia Act, 1994. [Place of publication unknown]. [Publisher unknown]. 41 p.
- Franklin, J.F. 1988. Pacific Northwest forests. In: Barbour, M.G.; Billings, W.D., eds. *North American Terrestrial Vegetation*. New York: Cambridge University Press. 434 p.
- Franklin, J.F.; Dyrness, C.T. 1973. Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW-GTR-8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 417 p.
- Franklin, J.F.; Norris, L.A.; Berg, D.R.; Smith, G.R. 1999. The history of DEMO: an experiment in regeneration harvest of northwestern forest ecosystems. *Northwest Science* 73 (Spec. Issue): 3-11.
- Franklin, J.F.; Waring, R.H. 1981. Distinctive features of the northwestern coniferous forest: development, structure, and function. In: Waring, R.H., ed. *Forests: fresh perspectives from ecosystem research*. Corvallis, OR: Oregon State University Press. 59-86.
- Fujimori, T.; Kawanabe, S.; Saito, H. [et al.]. 1976. Biomass and primary production in forests of three major vegetation zones of the northwestern United States. *Journal of Japan Forestry Society*. 58: 360-373.
- Gregory, R.G. 1972. *Forest Resource Economics*. New York: John Wiley and Sons. 254 p. Chapter 13.
- Halpern, C.B. 1995. Response of forest communities to green-tree retention harvest: a study plan for the vegetation component of the Demonstration of Ecosystem Management Options (DEMO) study. [Seattle, WA]: [University of Washington, College Forest Resources]. 36 p. [plus appendix].
- Halpern, C.B.; Raphael, M.G., eds. 1999. Retention harvests in Northwestern forest ecosystems: the Demonstration of Ecosystem Management Options (DEMO) study. *Northwest Science* 73 (Spec. Issue). 125 p.
- Isaac, L.A. 1943. Reproductive habits of Douglas-fir. Washington, DC: Charles Lathrop Pack Forestry Foundation.
- Isaac, L.A. 1956. Place of partial cutting in old-growth stands of the Douglas-fir region. Res. Pap. PNW-RP-16. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
- Loucks, D.M.; Knowe, S.A.; Shainsky, L.J.; Pancheco, A.A. 1996. Regenerating coastal forests in Oregon: an annotated bibliography of selected ecological literature. Research Contribution 14. Corvallis, OR: Oregon State University, Forest Research Laboratory. 122 p.

- McClellan, M.H.; Swanston, D.N.; Hennon, P.E. [et al.]. 2000. Alternatives to clearcutting in the old growth forests of southeast Alaska: study plan and establishment report. Gen. Tech. Rep. PNW-GTR-494. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 40 p.
- Meidinger, D.; Pojar, J., eds. 1991. Ecosystems of British Columbia. Special Report Series 6. Victoria, BC: British Columbia Ministry of Forests. 330 p.
- Monserud, R.A. 2002. Large-scale management experiments in the moist maritime forests of the Pacific Northwest. *Landscape and Urban Planning*. 59: 159-180
- Peterson, C.E.; Monserud, R.A. 2002. Compatibility between wood production and other values and uses on forested lands. A Problem Analysis PNW-GTR-564. 50 p.
- Smith, D.M. 1986. The practice of silviculture. 8<sup>th</sup> edition. New York: John Wiley & Sons.
- Smith, J.P.; Gresswell, R.E.; Hayes, J.P. 1997. A research problem analysis in support of the Cooperative Forest Ecosystem Research (CFER) Program. Corvallis, OR: U.S. Department of the Interior, U.S. Geological Society. 92 p.
- Tappeiner, J.C.; Huffman, D.; Marshall, D. [et al.]. 1997a. Density, ages, and growth rates in old-growth and young-growth forests in coastal Oregon. *Canadian Journal of Forest Research*. 27: 638-648.
- Tappeiner, J.C.; Lavender, D.; Walstad, J. [et al.]. 1997b. Silvicultural systems and regeneration methods: current practices and new alternatives. In: Kohm, K.A.; Franklin, J. F., eds. *Creating a Forestry for the 21<sup>st</sup> Century: The Science of Ecosystem Management*. Washington, DC: Island Press. 151-164.
- U.S. Department of Agriculture, Forest Service. 1997a. Land and resource management plan: Tongass National Forest. R10-MB-338d. Juneau, AK.
- U.S. Department of Agriculture, Forest Service. 1997b. Tongass land management plan revision: final environmental impact statement [FEIS]. R10-MB-338b. Juneau, AK. Part 1: Summary, chapters 1 - 3 (physical and biological environment).
- U.S. Department of Agriculture, Forest Service 1997c. Tongass land management plan revision: record of decision [ROD]. R10-MB-338a. Juneau, AK.
- U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management. 1994a. Final supplemental environmental impact statement on management of habitat for late-successional and old-growth forest related species within the range of the northern spotted owl. Washington, DC: Volumes I and II.
- U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management. 1994b. Record of decision for the President's forest plan. Washington, DC: 74 p. [plus appendices].
- Walter, H. 1985. *Vegetation of the Earth and ecological systems of the geobiosphere*, 3d ed. New York: Springer-Verlag. 318 p.
- Waring, R.F.; Franklin, J.F. 1979. Evergreen coniferous forests of the Pacific Northwest. *Science* 204: 1380-1386.
- Williamson, R.L. 1973. Results of shelterwood harvesting of Douglas-fir in the Cascades of western Oregon. Res. Pap. PNW-RP-1161. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 13 p.

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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 some way, 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<sup>a</sup>

| 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<br>Debris Flows<br>Canopy gap dynamics<br>Blowdown<br>Wildfire<br>Forest<br>Pathogens |                                  |                                 |                                                                              |                                   |                                                        |

<sup>a</sup> Elements in bold are included in current version of the approach.

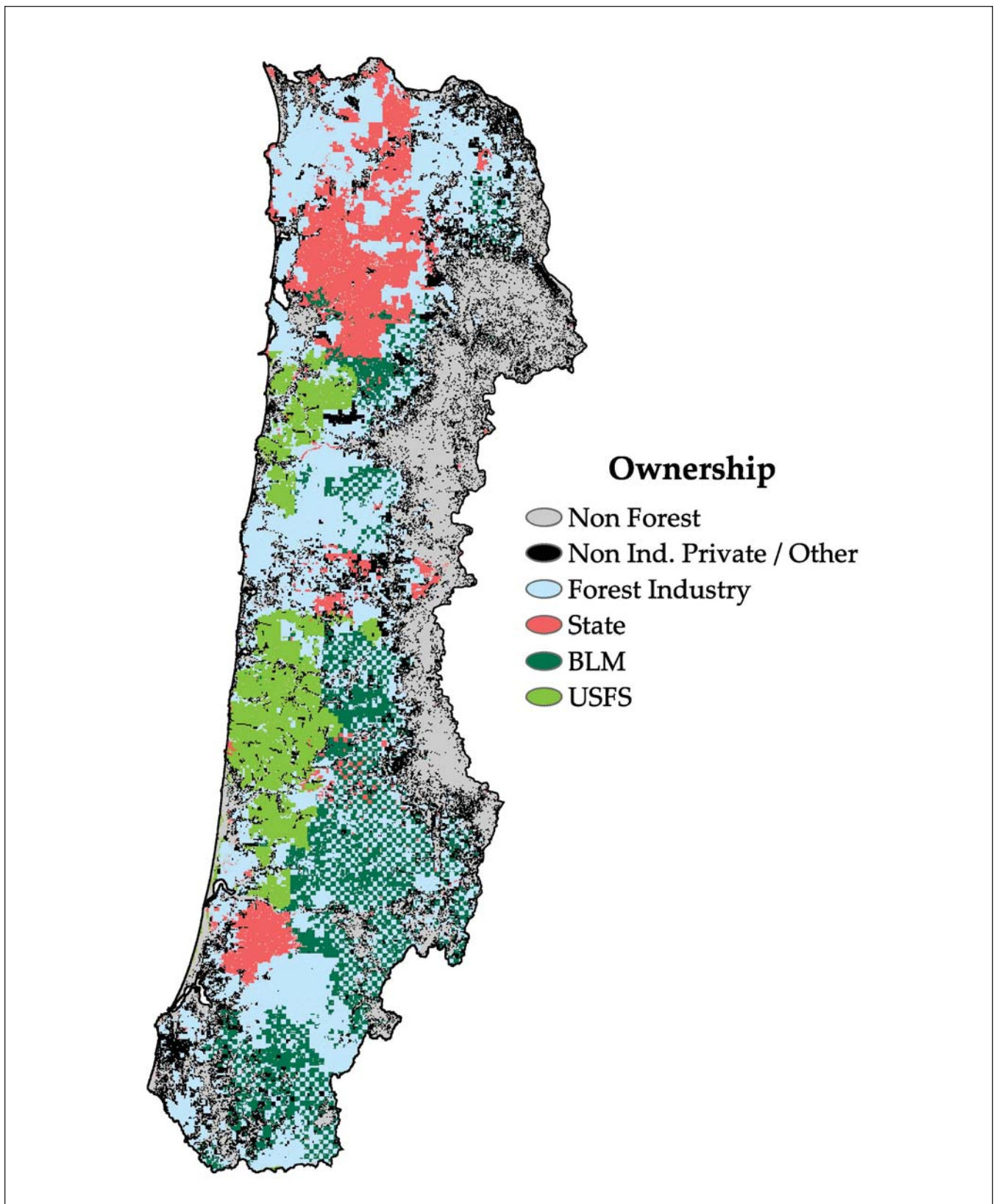


Figure 1—Ownership patterns in the Oregon Coast Range physiographic province.

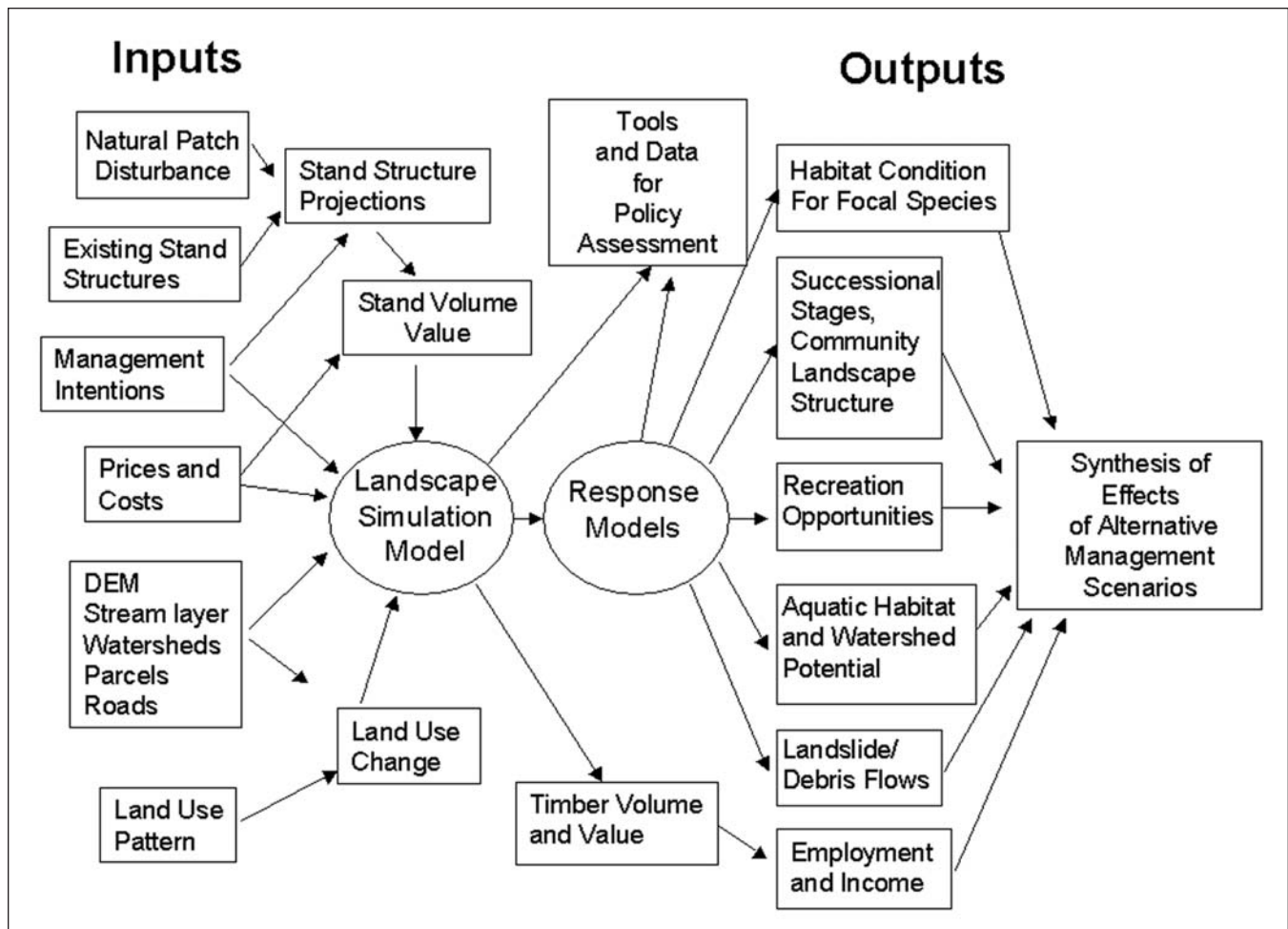


Figure 2—Conceptual model of components and linkages in CLAMS.

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

<sup>a</sup> 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.

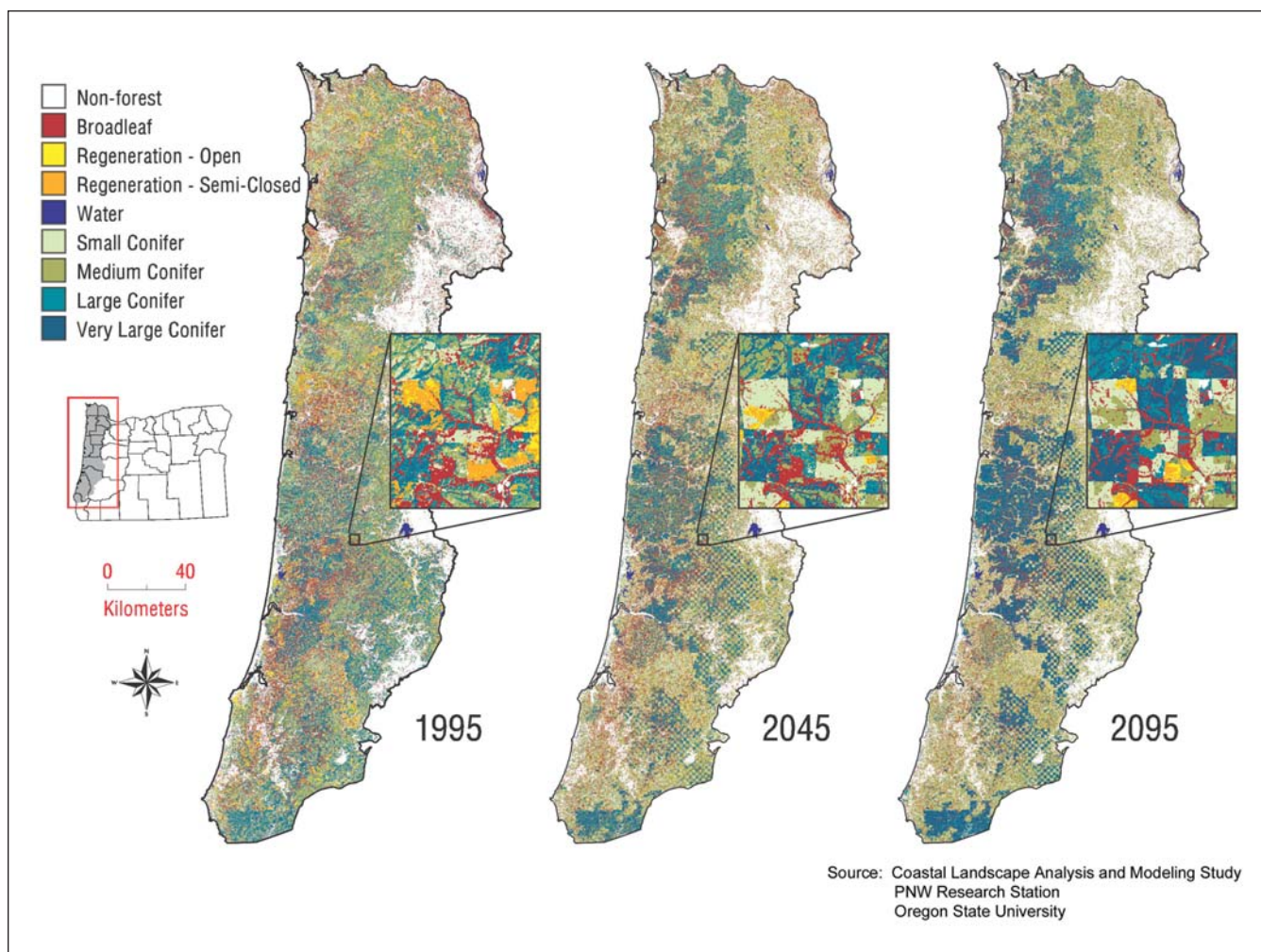


Figure 3—Simulation of changes in forest size classes for 1995-2095 under current policies using the LAMPS model.

**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 goal (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 wild-fires 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**

| <b>Dimension</b>                      | <b>Characteristics and issues</b>                                                                                                                                              |
|---------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 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 silvicultural 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.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Bardwell, L.V. 1991. Problem-framing: a perspective on environmental problem solving. *Environmental Management*. 15(15): 603-612.
- Baskerville, G.L. 1997. Advocacy, science, policy and life in the real world. *Conservation Ecology*. 1(1): 9. <http://www.consecol.org/vol1/iss1/art9>. (5/31/2002)
- Bettinger, P. 1999. Distributing GIS capabilities to forestry field offices: Benefits and challenges. *Journal of Forestry*. 97(6): 22-26.
- Bettinger, P.; Boston, K. 2001. A conceptual model for describing decision-making situations in integrated natural resource planning and modeling projects. *Environmental Management*. 28: 1-7.
- Bettinger, P.; Lennette, M. 2002. *Landscape Management and Policy Simulator (LAMPS). Version 1.1. User's Manual*. Oregon State University, College of Forestry. 98 p.
- Carey, A.B.; Lippke, B.R.; Sessions, J. 1999. Intentional systems management: managing forests for biodiversity. *Journal of Sustainable Forestry*. 9(3/4): 83-125.
- Clark, R.N.; Stankey, G.H.; Brown, P.J. [et al.]. 1999. Toward an ecological approach: integrating social, economic, cultural, biological and physical considerations. In: Johnson, N.C.; Malk, A.J.; Sexton, W.T.; Szaro, R. eds. *Ecological stewardship: a common reference for ecosystem management*. Oxford: Elsevier Science Ltd.: 297-318.
- Cohen, W.B.; Spies, T.A.; Alig, R.J. [et al.]. 2002. Characterizing 23 years (1972-1995) of stand replacement disturbance in western Oregon forests with Landsat imagery. *Ecosystems*. 5: 122-137.
- Cohen, S.G.; Bailey, D.E. 1997. What makes teams work: group effectiveness from the shop floor to the executive suite. *Journal of Management*. 23: 239-290.
- Forest Ecosystem Management Assessment Team [FEMAT]. 1993. *Forest ecosystem management: an ecological, economic, and social assessment*. Portland, OR: U.S. Department of Agriculture; U.S. Department of the Interior [and others]. [Irregular pagination].

- Franklin, J.F. 1993. Preserving biodiversity: species, ecosystems, or landscapes? *Ecological Applications*. 3(2): 202-205.
- Hann, D.W.; Hester, A.S.; Olsen, C.L. 1995. ORGANON user's manual: edition 5.0. Corvallis, OR: Department of Forest Resources, Oregon State University. 127 p.
- Haufler, J.B. 1994. An ecological framework for forest planning for forest health. *Journal of Sustainable Forestry*. 2: 307-316.
- Hunter, M.L. 1990. *Wildlife, forests, and forestry*. Englewood Cliffs. New Jersey: Prentice Hall. 370 p.
- Janssen, W.; Goldsworthy, P. 1996. Multidisciplinary research for natural resource management: conceptual and practical implications. *Agricultural Systems*. 51: 259-279.
- Johnson, K.N.; Franklin, J.F.; Thomas, J.W.; Gordon, J. 1991. Alternatives for management of late-successional forests of the Pacific Northwest. A report to the Agricultural Committee and the Merchant Marine Committee of the U. S. House of Representatives. Corvallis, OR: College of Forestry, Oregon State University. 59 p.
- Kaiser, J. 2000. Ecologists on a mission to save the world. *Science*. 287: 1188-1192.
- Landres, P.B.; Morgan, P.; Swanson, F.J. 1999. Overview of the use of natural variability concepts in managing ecological systems. *Ecological Applications*. 9(4): 1179-1188.
- Lee, K.N. 1993. *Compass and gyroscope: integrating science and politics for the environment*. Washington, DC: Island Press. 255 p.
- Lettman, G. 1998a. Oregon non-industrial private forest management intensity survey. Salem, OR: Oregon Department of Forestry, Resources Planning.
- Lettman, G. 1998b. Oregon industry forest management intensity survey. Salem, OR: Oregon Department of Forestry, Resources Planning.
- Lettman, G.; Campbell, D. 1997. Private forest practices in Western Oregon. Salem, OR: Oregon Department of Forestry, Resources Planning.
- McComb, W.C.; McGrath, M.; Spies, T.A.; Vesely, D. 2002. Models for mapping potential habitat at landscape scales: an example using Northern Spotted Owls. *Forest Science*. 48(2): 203-216.
- McLain, R.; Lee, R.J. 1996. Adaptive management: promises and pitfalls. *Environmental Management*. 20(4): 437-448.
- Meffe, G.K.; Viderman, S. 1995. Combining science and policy in conservation biology. *Wildlife Society Bulletin*. 23(3): 327-332.
- Mills, T.J.; Clark, R.N. 2001. Roles of scientists in natural resource decision-making. *Forest Ecology and Management*. 153(1-3): 189-198.
- Moeur, M.; Stage, A.R. 1995. Most similar neighbor: an improved sampling inference procedure for natural resource planning. *Forest Science*. 41: 337-359.
- Nelson, R.H. 1999. The religion of forestry: scientific management. *Journal of Forestry*. 97(11): 4-8.
- Norton, B.G. 1998. Improving ecological communication: the role of ecologists in environmental policy formation. *Ecological Applications*. 8(2): 350-362.
- Noss, R. 1990. Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology*. 4: 355-364.
- Ohmann, J.L.; Gregory, M.J. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest neighbor imputation in the coastal province of Oregon, USA. *Canadian Journal of Forest Research*. 32: 725-741.
- O'Neil, T.A.; Johnson, D.H.; Barrett, C. [et al.]. 2000. Seven wildlife-habitat relationship matrices for Oregon and Washington. In: Johnson, D.H.; O'Neil, T.A., manag. dirs. *Wildlife-habitat relationships in Oregon and Washington*. Corvallis, OR: Oregon State University Press. 736 p.
- Oregon Department of Forestry. 2001. Northwest Oregon State Forests Management plan. Salem, OR: Oregon Department of Forestry, Resources Planning.
- Silbaugh, J.M.; Betters, D.R. 1995. Quantitative biodiversity measures applied to forest management. *Environmental Reviews*. 3: 277-285.

- Spies, T.A.; Reeves, G.H.; Burnett, K.M. [et al.]. 2002. Assessing the ecological consequences of forest policies in a multi-ownership province in Oregon. In: Liu, J.; Taylor, W.W., eds. Integrating landscape ecology into natural resource management. Cambridge University Press. 179-207.
- State of Oregon. 1999. Oregon revised statutes, chapter 527: Insect and disease control; forest practices. <http://www.leg.state.or.us/ors/527.html>. (5/31/2002)
- Swanson, F.J.; Greene, S. 1999. Perspectives on scientists and science in bioregional assessments. In: Johnson, K.N.; Swanson, F.; Herring, M.; Greene, S., eds. Bioregional assessments: science at the crossroads of management and policy. Washington, DC: Island Press: 55-69.
- Ter Braak, C.J.F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology*. 67: 1167-1179.
- Urban, D.L.; Acevedo, M.F.; Garman, S.L. 1999. Scaling fine-scale processes to large-scale patterns using models derived from models: meta-models. In: Mladenoff, D.J.; Baker, W., eds. Spatial modeling of forest landscape change: approaches and applications. Cambridge University Press: 70-98.
- U.S. Department of Agriculture, Forest Service [USDA]. 1996. Status of the interior Columbia Basin: summary of scientific findings. Gen. Tech. Rep. PNW-GTR-385. Portland, OR: U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management. 144 p.
- Wimberly, M.A.; Spies, T.A.; Long, C.J.; Whitlock, C. 2000. Simulating historical variability in the amount of old forests in the Oregon Coast Range. *Conservation Biology*. 14(1): 167-180.

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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 proceedings) 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 seep-like habitats. The basic method is an intensive search and seine technique (Bury and Corn 1991; Jones and Raphael, in review<sup>5</sup>) 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

<sup>5</sup> 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<sup>2</sup>. 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)<sup>6</sup>, 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.

<sup>6</sup> 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.

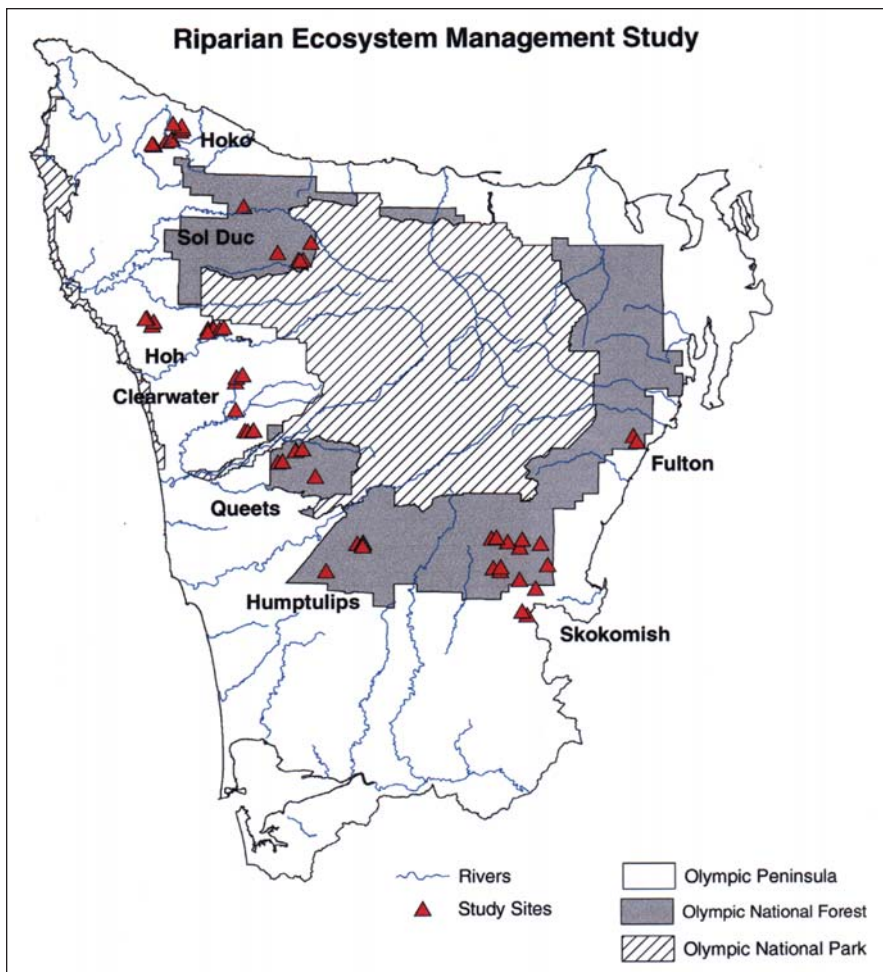


Figure 1—Study sites on the Olympic Peninsula, Washington. Names of major river basins in which study sites occurred are given.

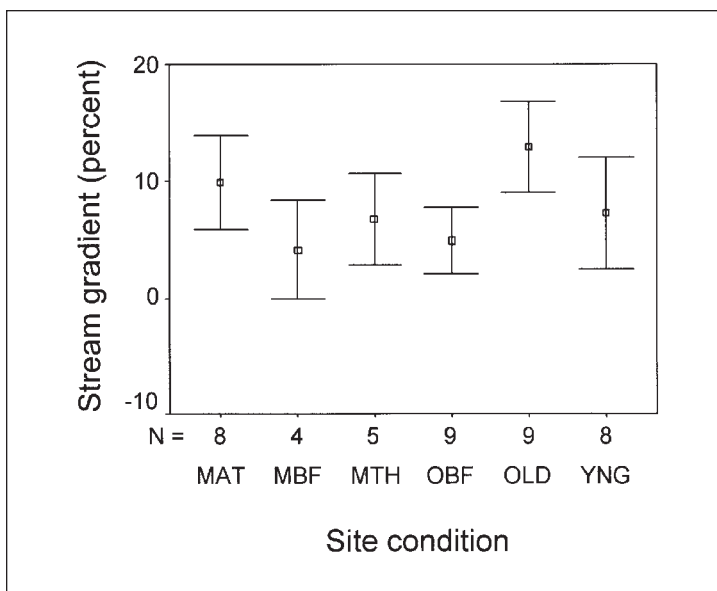


Figure 2—Comparison of stream gradient among site conditions, Olympic Peninsula, Washington, 1996–1999. Values represent means and 95 percent confidence intervals; numbers of sites are indicated on x-axis. Abbreviations are MAT (mature sites), MBF (buffered mature sites), MTH (thinned mature sites), 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 <sup>2</sup> |
| Terrestrial amphibians | 41                    | 11                      | 1,687                | 42 835 m <sup>2</sup> 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 <sup>2</sup> 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  $\chi^2$  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 | $\chi^2$ | P    |
|--------------------------------------------|-------------------|--------------|--------|-----------------|----------------|-------|----------|------|
| Fishes (n = 52 sites):                     | (12) <sup>a</sup> | (10)         | (12)   | (4)             | (5)            | (9)   |          |      |
| Cutthroat trout                            |                   |              |        |                 |                |       |          |      |
| <i>Oncorhynchus clarki clarki</i>          | 1.24              | 9.30         | 6.82   | 7.85            | 7.14           | 5.71  | 8.16     | .15  |
| Coho salmon                                |                   |              |        |                 |                |       |          |      |
| <i>Oncorhynchus kisutch</i>                | 2.91              | .81          | 2.13   | 0               | 0              | 0     | 2.87     | .72  |
| Coastrange sculpin                         |                   |              |        |                 |                |       |          |      |
| <i>Cottus aleuticus</i>                    | 1.92              | 1.55         | 6.00   | 0               | 9.28           | .91   | 6.53     | .26  |
| Torrent sculpin                            |                   |              |        |                 |                |       |          |      |
| <i>Cottus rhotheus</i>                     | 1.13              | .24          | 16.67  | .59             | 10.31          | 2.21  | 2.52     | .77  |
| Amphibians, stream<br>(n = 38 sites):      | (10)              | (4)          | (10)   | (3)             | (4)            | (7)   |          |      |
| Tailed frog                                |                   |              |        |                 |                |       |          |      |
| <i>Ascaphus truei</i>                      | 96.87             | 5.81         | 32.07  | 0               | 0              | 8.90  | 12.79    | .03  |
| Cope's giant salamander                    |                   |              |        |                 |                |       |          |      |
| <i>Dicamptodon copei</i>                   | 59.31             | 9.60         | 38.72  | 5.76            | 0              | 18.97 | 16.70    | .01  |
| Olympic torrent salamander                 |                   |              |        |                 |                |       |          |      |
| <i>Rhyacotriton olympicus</i>              | 22.01             | 0            | 41.17  | 0               | 0              | 5.22  | 13.74    | .02  |
| Amphibians, terrestrial<br>(n = 41 sites): | (11)              | (6)          | (9)    | (4)             | (4)            | (7)   |          |      |
| Olympic torrent salamander                 | .73               | .02          | .11    | .11             | 0              | .06   | 14.08    | .02  |
| Ensatina                                   |                   |              |        |                 |                |       |          |      |
| <i>Ensatina eschscholtzii</i>              | .13               | .07          | .09    | .23             | .20            | 0     | 6.37     | .27  |
| Van Dyke's salamander                      |                   |              |        |                 |                |       |          |      |
| <i>Plethodon vandykei</i>                  | .56               | .09          | 0      | 0               | 0              | 0     | 18.50    | <.01 |
| Western red-backed salamander              |                   |              |        |                 |                |       |          |      |
| <i>Plethodon vehiculum</i>                 | 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                                |                   |              |        |                 |                |       |          |      |
| <i>Dendragapus obscurus</i>                | 0                 | .09          | .08    | .16             | .14            | .05   | 1.57     | .90  |
| Band-tailed pigeon                         |                   |              |        |                 |                |       |          |      |
| <i>Columba fasciata</i>                    | .08               | 0            | 0      | .16             | 0              | .05   | 9.44     | .09  |
| Vaux's swift                               |                   |              |        |                 |                |       |          |      |
| <i>Columba fasciata</i>                    | .29               | .32          | 0      | .21             | .14            | .07   | 4.58     | .47  |
| Rufous hummingbird                         |                   |              |        |                 |                |       |          |      |
| <i>Selasphorus rufus</i>                   | .46               | .05          | .37    | 1.30            | .28            | .27   | 11.31    | .05  |
| Hairy woodpecker                           |                   |              |        |                 |                |       |          |      |
| <i>Picoides villosus</i>                   | .21               | .28          | .19    | .63             | 1.25           | .10   | 10.43    | .06  |
| Northern flicker                           |                   |              |        |                 |                |       |          |      |
| <i>Colaptes auratus</i>                    | .04               | 0            | .04    | .05             | 0              | 0     | 2.58     | .77  |
| Willow flycatcher                          |                   |              |        |                 |                |       |          |      |
| <i>Empidonax traillii</i>                  | 0                 | 0            | 0      | .05             | 0              | 0     | 5.50     | .36  |
| Hammond's flycatcher                       |                   |              |        |                 |                |       |          |      |
| <i>Empidonax hammondi</i>                  | .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  $\chi^2$  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 | $\chi^2$ | P    |
|----------------------------------|------|--------------|--------|-----------------|----------------|-------|----------|------|
| Pacific-slope flycatcher         |      |              |        |                 |                |       |          |      |
| <i>Empidonax difficilis</i>      | 5.31 | 5.32         | 4.95   | 5.89            | 5.90           | 3.01  | 4.94     | .42  |
| Gray jay                         |      |              |        |                 |                |       |          |      |
| <i>Perisoreus canadensis</i>     | 0    | .09          | .04    | 0               | .28            | 0     | 3.64     | .60  |
| Steller's jay                    |      |              |        |                 |                |       |          |      |
| <i>Cyanocitta stelleri</i>       | .17  | .56          | .16    | 1.00            | .07            | .45   | 9.88     | .08  |
| Chestnut-backed chickadee        |      |              |        |                 |                |       |          |      |
| <i>Poecile rufescens</i>         | 1.86 | 2.45         | 3.48   | 2.14            | 5.97           | .83   | 6.72     | .24  |
| Brown creeper                    |      |              |        |                 |                |       |          |      |
| <i>Certhia americana</i>         | .42  | .65          | .11    | .10             | .14            | 0     | 11.12    | .05  |
| Winter wren                      |      |              |        |                 |                |       |          |      |
| <i>Troglodytes troglodytes</i>   | 7.82 | 7.08         | 7.77   | 6.35            | 10.49          | 3.96  | 9.57     | .09  |
| American dipper                  |      |              |        |                 |                |       |          |      |
| <i>Cinclus mexicanus</i>         | .07  | .37          | 0      | .21             | 0              | .78   | 15.4     | .01  |
| Golden-crowned kinglet           |      |              |        |                 |                |       |          |      |
| <i>Regulus satrapa</i>           | 1.78 | 2.64         | 3.70   | .63             | 10.63          | .98   | 23.66    | <.01 |
| Swainson's thrush                |      |              |        |                 |                |       |          |      |
| <i>Catharus ustulatus</i>        | .13  | .51          | .57    | 1.61            | .35            | 1.16  | 16.60    | .01  |
| American robin                   |      |              |        |                 |                |       |          |      |
| <i>Turdus migratorius</i>        | .25  | .51          | .15    | 1.35            | .63            | .87   | 9.70     | .08  |
| Varied thrush                    |      |              |        |                 |                |       |          |      |
| <i>Ixoreus naevius</i>           | 1.01 | .69          | .38    | .63             | .14            | .78   | 7.517    | .19  |
| Cedar waxwing                    |      |              |        |                 |                |       |          |      |
| <i>Bombycilla cedrorum</i>       | 0    | .14          | .08    | .89             | 0              | .21   | 7.22     | .21  |
| Warbling vireo                   |      |              |        |                 |                |       |          |      |
| <i>Vireo gilvus</i>              | 0    | .19          | 0      | .31             | 0              | .69   | 11.54    | .04  |
| Hutton's vireo                   |      |              |        |                 |                |       |          |      |
| <i>Vireo huttoni</i>             | 0    | .09          | .19    | .47             | .49            | .37   | 6.81     | .24  |
| Orange-crowned warbler           |      |              |        |                 |                |       |          |      |
| <i>Vermivora celata</i>          | 0    | 0            | 0      | .26             | 0              | 0     | 23.35    | <.01 |
| Black-throated gray warbler      |      |              |        |                 |                |       |          |      |
| <i>Dendroica nigrescens</i>      | 0    | 0            | .27    | .05             | .56            | .10   | 6.32     | .27  |
| Hermit warbler                   |      |              |        |                 |                |       |          |      |
| <i>Dendroica occidentalis</i>    | 0    | .09          | .11    | 0               | .07            | 0     | 4.55     | .47  |
| MacGillivray's warbler           |      |              |        |                 |                |       |          |      |
| <i>Oporornis tolmiei</i>         | 0    | .09          | 0      | .73             | .21            | .16   | 16.67    | .01  |
| Wilson's warbler                 |      |              |        |                 |                |       |          |      |
| <i>Wilsonia pusilla</i>          | 0    | .37          | .42    | 2.19            | .14            | 1.13  | 29.24    | <.01 |
| Western tanager                  |      |              |        |                 |                |       |          |      |
| <i>Piranga ludoviciana</i>       | 0    | .28          | .14    | 1.04            | .21            | .05   | 10.53    | .06  |
| Black-headed grosbeak            |      |              |        |                 |                |       |          |      |
| <i>Pheucticus melanocephalus</i> | .10  | .09          | 0      | .31             | 0              | .10   | 14.23    | .01  |
| Spotted towhee                   |      |              |        |                 |                |       |          |      |
| <i>Pipilo maculatus</i>          | 0    | 0            | 0      | .68             | .07            | .05   | 21.37    | <.01 |
| Song sparrow                     |      |              |        |                 |                |       |          |      |
| <i>Melospiza melodia</i>         | 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  $\chi^2$  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 | $\chi^2$ | P   |
|-------------------------------|------|--------------|--------|-----------------|----------------|-------|----------|-----|
| White-crowned sparrow         |      |              |        |                 |                |       |          |     |
| <i>Zonotrichia leucophrys</i> | 0    | 0            | 0      | .16             | 0              | 0     | 11.22    | .05 |
| Dark-eyed junco               |      |              |        |                 |                |       |          |     |
| <i>Junco hyemalis</i>         | .04  | .46          | .18    | .63             | .28            | 1.04  | 16.30    | .01 |
| Red crossbill                 |      |              |        |                 |                |       |          |     |
| <i>Loxia curvirostra</i>      | .04  | .28          | .06    | .21             | 0              | .10   | 6.26     | .28 |
| Mammals (n = 49 sites):       | (10) | (8)          | (10)   | (8)             | (5)            | (8)   |          |     |
| Montane (dusky) shrew         |      |              |        |                 |                |       |          |     |
| <i>Sorex monticolus</i>       | .28  | 0            | .44    | .06             | .25            | .27   | 7.809    | .17 |
| Trowbridge's shrew            |      |              |        |                 |                |       |          |     |
| <i>Sorex trowbridgii</i>      | .43  | .31          | .66    | .43             | .72            | .63   | 2.68     | .75 |
| Deer mouse                    |      |              |        |                 |                |       |          |     |
| <i>Peromyscus maniculatus</i> | .86  | .31          | 1.26   | .69             | .41            | .40   | 2.07     | .84 |
| Forest deer mouse             |      |              |        |                 |                |       |          |     |
| <i>Peromyscus keeni</i>       | 3.45 | 3.23         | 5.11   | 3.42            | 5.06           | 2.05  | 3.88     | .57 |
| Pacific jumping mouse         |      |              |        |                 |                |       |          |     |
| <i>Zapus trinotatus</i>       | .04  | .11          | .23    | .17             | .21            | .58   | 10.95    | .05 |

<sup>a</sup> 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  $\chi^2$  ( $P \leq 0.10$ ) for relation of relative abundance to stream and site attributes, Olympic Peninsula, Washington, 1996–1999**

| Species class | Attribute      |              |          |             |           |                       |
|---------------|----------------|--------------|----------|-------------|-----------|-----------------------|
|               | 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  $\chi^2$  analysis, Olympic Peninsula, Washington, 1996–1999 (continued on next page)**

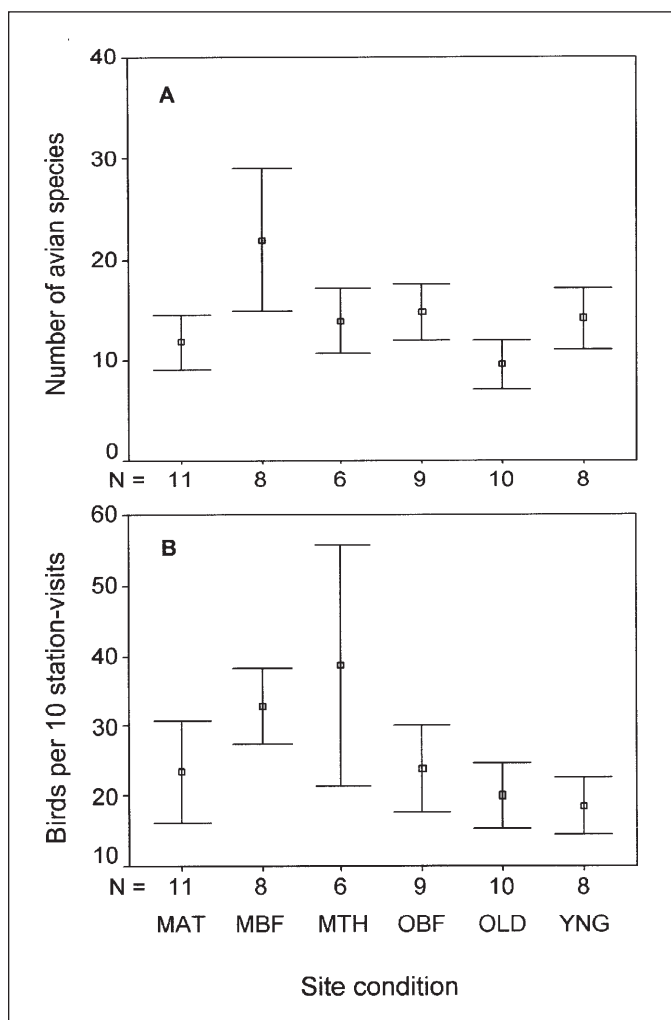
| Class and species <sup>a</sup>          | Elevation                | Stream width | Stream gradient | Stream classification | Parent rock |
|-----------------------------------------|--------------------------|--------------|-----------------|-----------------------|-------------|
| Fishes (n = 52 sites):                  |                          |              |                 |                       |             |
| Cutthroat trout                         | -.29 (0.04) <sup>b</sup> |              | -.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  $\chi^2$  analysis, Olympic Peninsula, Washington, 1996–1999**

| Class and species <sup>a</sup> | 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                     | -.51 (<.01) | -.55 (<.01)  | .29 (.07)       | 8.64 (.03)            | 6.75 (.04)  |
| Forest deer mouse              |             | -.54 (<.01)  |                 |                       |             |
| Pacific jumping mouse          |             | -.26 (.07)   |                 |                       |             |

<sup>a</sup> Only species with at least one significant association ( $P \leq 0.10$ ) are listed.

<sup>b</sup> 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).**

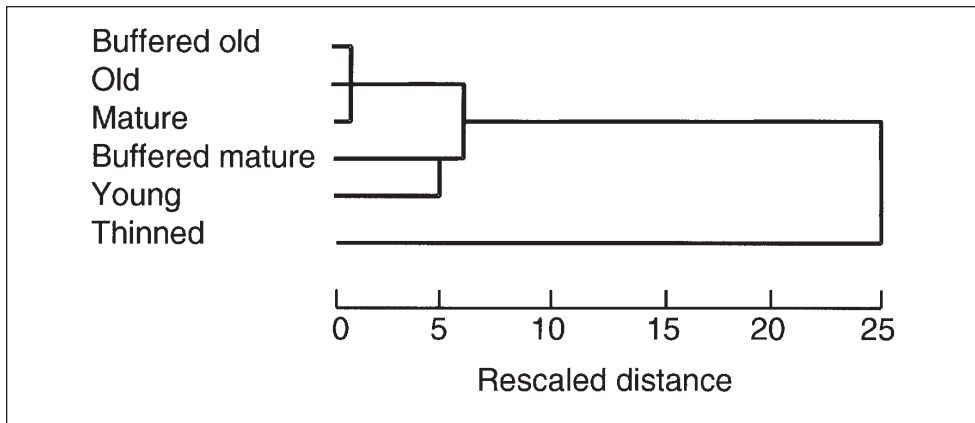


Figure 4—Dendrogram showing relative similarity of site conditions based on mean abundance of common birds, Olympic Peninsula, Washington, 1996–1999.

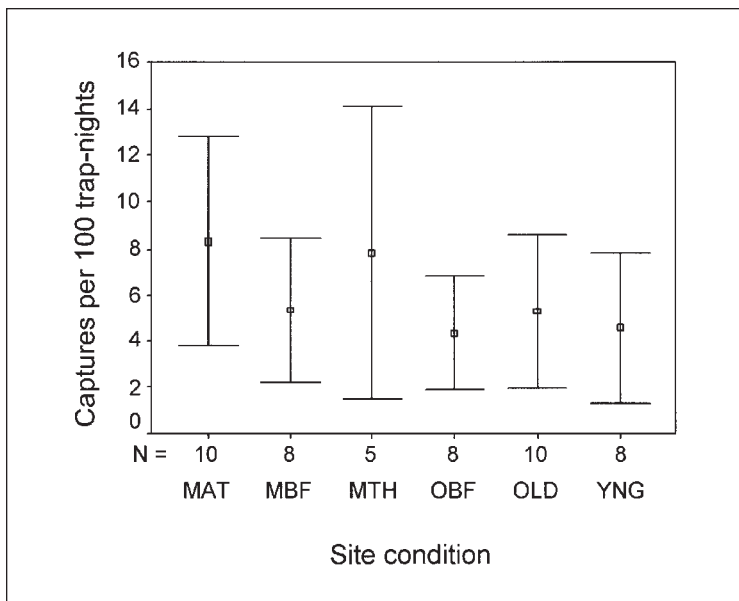


Figure 5—Mean total abundance (captures per 100 trap-nights) of small mammals among site conditions, Olympic Peninsula, Washington, 1996–1999. Values represent means and 95 percent confidence intervals. Abbreviations are MAT (mature sites), MBF (buffered mature sites), MTH (thinned mature sites), OBF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

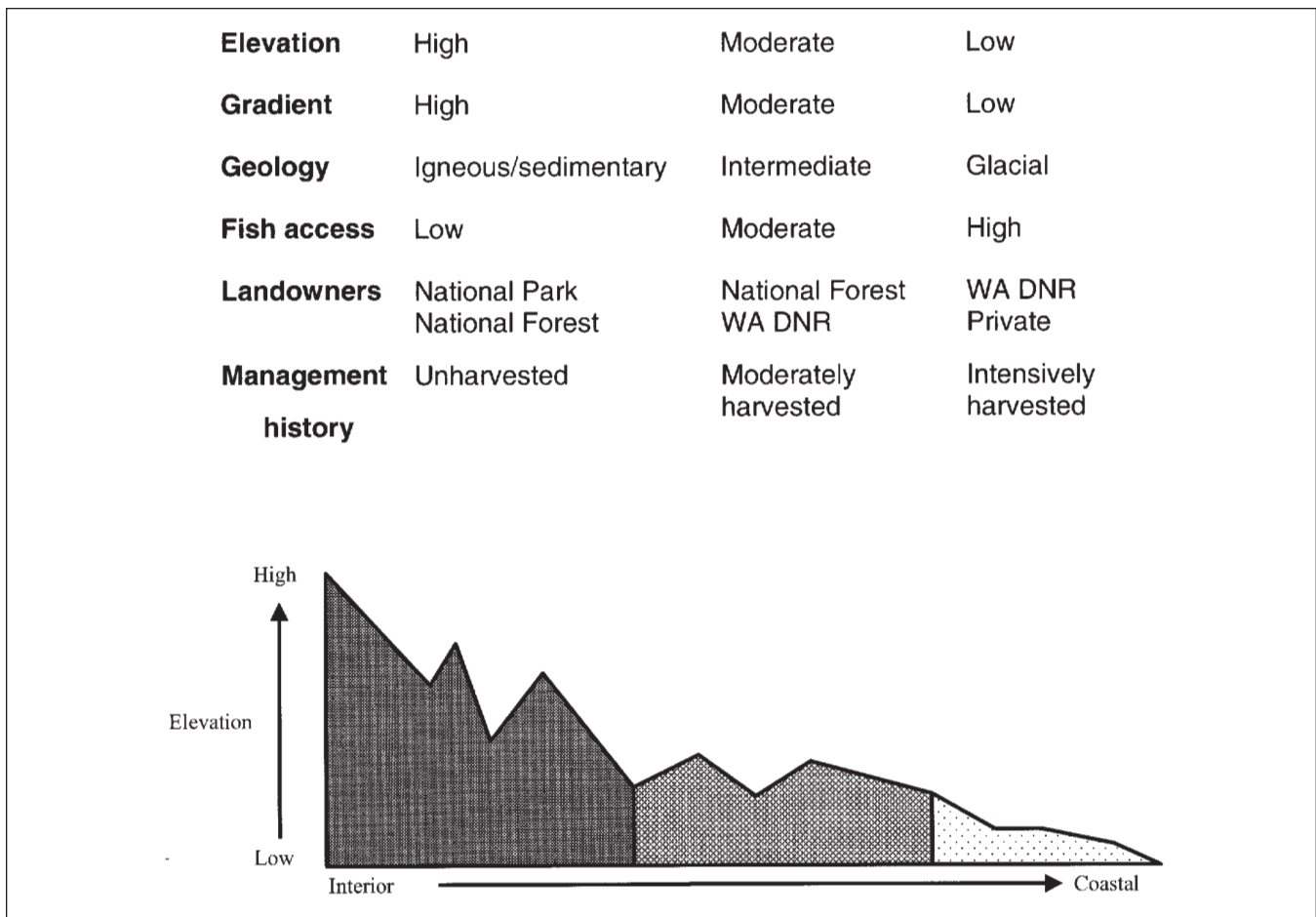


Figure 6—Diagrammatic cross section of the western Olympic Peninsula, Washington, 1996–1999, showing generalized differences in physical and management history attributes. WA DNR = Washington State Department of Natural Resources

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.

## ACKNOWLEDGEMENTS

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## LITERATURE CITED

- Allard, M.W.; Gunn, S.J.; Greenbaum, I.F. 1987. Mensural discrimination of chromosomally characterized *Peromyscus oreas* and *P. maniculatus*. *Journal of Mammalogy*. 68: 402-406.
- Bisson, P.A.; Raphael, M.G.; Foster, A.D.; Jones, L.L.C. 2002. Influence of site and landscape features on vertebrate assemblages in headwater streams of the Olympic Peninsula. In: Johnson, A.C.; Haynes, R.W.; Monserud, R.A.; eds. *Congruent Management of Multiple Resources: Proceedings from the Wood Compatibility Workshop*. Gen. Tech. Rep. PNW-GTR-563. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 61-72.
- Blessing, B.J.; Phenix, E.P.; Jones, L.L.C.; Raphael, M.G. 1999. Nests of Van Dyke's salamander (*Plethodon vandykei*) from the Olympic Peninsula, Washington. *Northwestern Naturalist*. 80: 77-81.
- Bury, R.B.; Corn, P.S. 1991. Sampling methods for amphibians in streams in the Pacific Northwest. Gen. Tech. Rep. PNW-GTR-275. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 29 p.
- Conaway, C.H. 1952. Life history of the water shrew (*Sorex palustris navigator*). *The American Midland Naturalist*. 48: 219-248.
- Forest Ecosystem Management Assessment Team [FEMAT]. 1993. Forest ecosystem management: an ecological, economic, and social assessment. Portland, OR: U.S. Department of Agriculture; U.S. Department of the Interior [et al.]. [Irregular pagination].

- Montgomery, D.R.; Buffington, J.M. 1993. Channel classification, prediction of channel response, and assessment of channel condition. Seattle: University of Washington; final report; Timber Fish and Wildlife Report TFW-SH10-93-002. 84 p.
- O'Connell, M.A.; Hallett, J.G.; West, S.D. [et al.]. 2000. Effectiveness of riparian management zones in providing habitat for wildlife. Seattle: University of Washington; final report; Timber Fish and Wildlife TFW-LWAG1-00-001. 459 p.
- Pearson, S.F.; Manuwal, D.A. 2001. Breeding bird response to riparian buffer width in managed Pacific Northwest Douglas-fir forests. *Ecological Applications*. 11: 840-853.
- Reynolds, R.T.; Scott, J.M.; Nussbaum, R.A. 1980. A variable circular-plot method for estimating bird numbers. *Condor*. 82: 309-313.
- Thomas, J.W.; Raphael, M.G.; Anthony, R. [et al.]. 1993. Viability assessments and management considerations for species associated with late-successional and old-growth forests of the Pacific Northwest. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 523 p.
- U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management. 1994. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl. [Place of publication unknown]. 74 p. [plus Attachment A: standards and guidelines].
- Verts, B.J.; Carraway, L.N. 1998. Land mammals of Oregon. Berkeley, CA: University of California Press. 668 p.
- Washington Department of Natural Resources (WDNR). 1997. Final Habitat Conservation Plan. Washington State Department of Natural Resources, Olympia, Washington.

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

Ralph J. Alig<sup>1</sup> and Jeffrey D. Kline<sup>2</sup>

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### **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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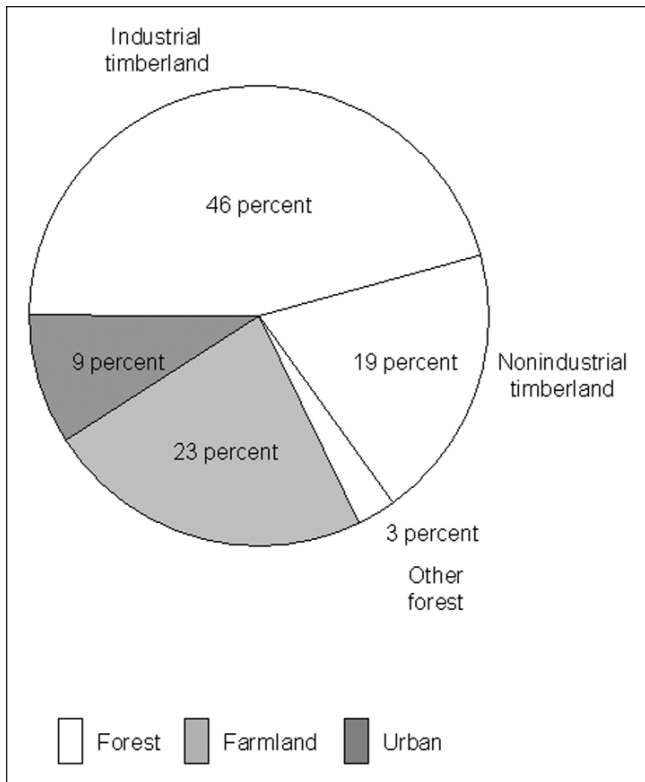


Figure 1a—Current composition of land uses on private land, western Oregon.

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

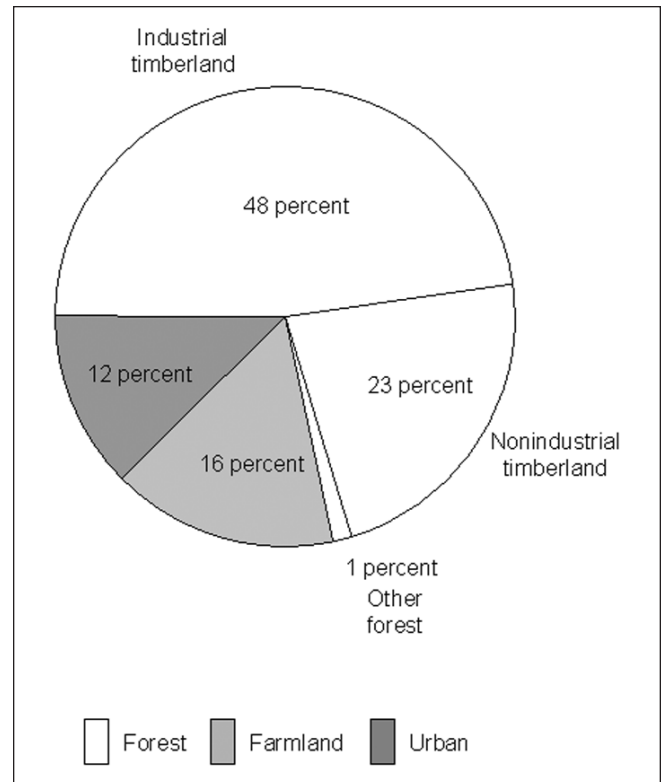


Figure 1b—Current composition of land uses on private land, western Washington.

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

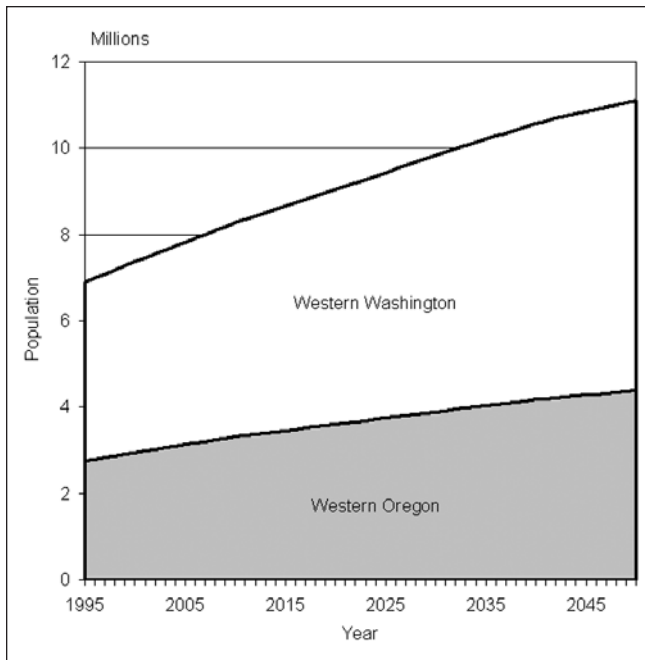


Figure 2—Projected population, Pacific Northwest, Westside.

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 pro-

ductivity 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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## LITERATURE CITED

- Alig, R.J. 1986. Econometric analysis of the factors influencing forest acreage trends in the Southeast. *Forest Science*. 32(1): 119-134.
- Alig, R.J.; Healy, R. 1987. Urban and built-up land area changes in the United States: An empirical investigation of determinants. *Land Economics* 63: 215-226.
- Alig, R.J.; Benford, F.; Moulton, R.; Lee, L. 1999a. Long-term projections of urban and developed land area in the United States. In: *Proceedings Philadelphia, PA “Balancing Working Lands and Development,”* CD-ROM produced by American Farmland Trust and Land Trust Alliance; Karl Otte, ed. Philad., PA. June.
- Alig, R.J.; Adams, D.; Chmelik, J.; Bettinger, P. 1999b. Private forest investment and long-run sustainable harvest volumes. *New Forests* 17: 307-327.
- Azuma, D.; Birch, K.; Herstrom, A.; Kline, J.; Lettman, G. 2002. Land use change on non-federal land in western Oregon, 1973-2000. Oregon Department of Forestry, Salem, Oregon. Unnumbered publication. 48 p.
- Alig, R.J.; Zheng, D.; Spies, T.; Butler, B. 2000. Forest cover dynamics in the Pacific Northwest West Side: Regional Trends and Projections. PNW-RP-522. Portland, OR: U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.

- Barlow, S.A.; Munn, I.; Cleaves, D.; Evans, D. 1998. The effect of urban sprawl on timber harvesting. *Journal of Forestry*. 96: 10-14.
- Bettinger, P.; Alig, R.J. 1996. Timber availability on non-federal land in western Washington: Implications based on physical characteristics of the timberland base. *Forest Product Journal* 46: 30-38.
- Bockstael, N.E. 1996. Modeling economics and ecology: the importance of a spatial perspective. *American Journal of Agricultural Economics*. 78: 1168-1180.
- Capozza, D.; Helsley, R.W. 1989. The fundamentals of land prices and urban growth. *Journal of Urban Economics*. 26: 295-306.
- Cho, S.; Wu, J.; Alig, R.J. 2001. Land development under uncertainty: a comparison between the west and east sides of the Cascade range. Review Draft. Oregon State University, Dept. of Ag. and Resource Economics. On file with Dr. J. Wu, Oregon State University, Dept. of Ag. and Resource Economics.
- Hardie, I.; Parks, P.J. 1997. Land use with heterogeneous land quality: an application of an area base model. *American Journal of Agricultural Economics*. 79: 299-310.
- Haynes, K.; Fotheringham, A. 1984. Gravity and spatial interaction models. Beverly Hills, CA: Sage Publications. 88 p.
- Kingsbury, L. 1999. Oregon's Conservation Reserve Enhancement Program: Likely participation and recommendations for implementation. Oregon State Univ., Masters thesis. Corvallis. 112 p.
- Kline, J.; Alig, R.J. 1999. Does land use planning slow the conversion of forest and farm land? *Growth and Change*. 30(1): 3-22.
- Kline, J.; Alig, R. 2000. "Research Report 3: Forest Impacts." Prepared for Willamette Valley Alternative Futures, for EcoNorthwest, Inc., Eugene, OR. 35 p.
- Kline, J.; Alig, R.J.; Johnson, R. 2000a. Forest owner incentives to protect riparian habitat. *Ecological Economics* 33(1): 29-43.
- Kline, J.; Alig, R.J.; Johnson, R. 2000b. Fostering the production of nontimber services among forest owners with heterogeneous objectives. *Forest Science*. 46(2): 302-311.
- Kline, J.; Alig, R. 2001. A spatial model of land use change in western Oregon and western Washington. Res. Pap. PNW-RP-528. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 24 p.
- Kline, J.; Moses, A.; Alig, R. 2001. Integrating urbanization into landscape-level ecological assessments. *Ecosystems*. 4: 3-18.
- Kuuluvainen, J.; Karppinen, H.; Ovaskainen, V. 1996. Landowner objectives and nonindustrial private timber supply. *Forest Science* 42: 300-308.
- Lorensen, T.; Birch, K.; Lettman, G. 1993. Wildfire prevention and control in areas of residential forest land development: an analysis of fire data. Tech. Bulletin, Public Affairs Office, Oregon Department of Forestry, Salem, Oregon.
- Matthews, S.; O'Connor, R.; Plantinga, A. 2002. Quantifying the impacts on biodiversity of policies for carbon sequestration in forests. *Ecological Economics* 40: 71-87.
- Mills, E.S. 1980. Urban economics. Glenview, IL: Scott, Foresman and Co. 241 p.
- Nelson, G.C.; Hellerstein, D. 1997. Do roads cause deforestation? Using satellite images in econometric analysis of land use. *American Journal of Agricultural Economics*. 79(1): 80-88.
- Parks, P.J.; Murray, B.C. 1994. Land attributes and land allocation: nonindustrial forest use in the Pacific Northwest. *Forest Science* 40(3): 558-575.
- Plantinga, A.J.; Buongiorno, J.; Alig, R.J. 1990. Determinants of changes in non-industrial private timberland ownership in the United States. *Journal of World Forest Resource Management*. 5: 29-46.
- Plantinga, A.J.; Mauldin, T.; Alig, R. 1999. Land use in Maine: determinants of past trends and projections of future changes. Res. Pap. PNW-RP-511. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 20 p.

Smith, W.B.; Vissage, J.S.; Darr, D.R. Sheffield, R. 2001. Forest resources of the United States, 1997. Gen. Tech. Rep. NC-219. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 190 p.

United Nations Population Division. 2002. The state of the world population 2001. New York. 198 p.

United States Census Bureau. 2000. Population estimates. Washington, DC.

U.S. Department of Agriculture, Forest Service. 2002. An analysis of the timber situation in the United States:1997-2050. Draft. Richard Haynes, ed. Gen. Tech. Rep. PNW-GTR-560. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2001. The National Resources Inventory, 1997. Unnumbered NRCS Report, Washington, DC.

Wear, D.N.; Bolstad, P. 1998. Land use changes in southern Appalachian landscapes: spatial analysis and forecast evaluation. *Ecosystems*. 1: 575-594.

Wear, D.N.; Liu, R.; Foreman, J.M.; Sheffield, R.M. 1999. The effects of population growth on timber management and inventories in Virginia. *Forest Ecology and Management*. 118: 107-115.

Zheng, D.; Alig, R. 1999. Changes in the non-federal land base involving forestry in western Oregon, 1961-1994. Res. Pap. PNW-RP-518. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 22 p.

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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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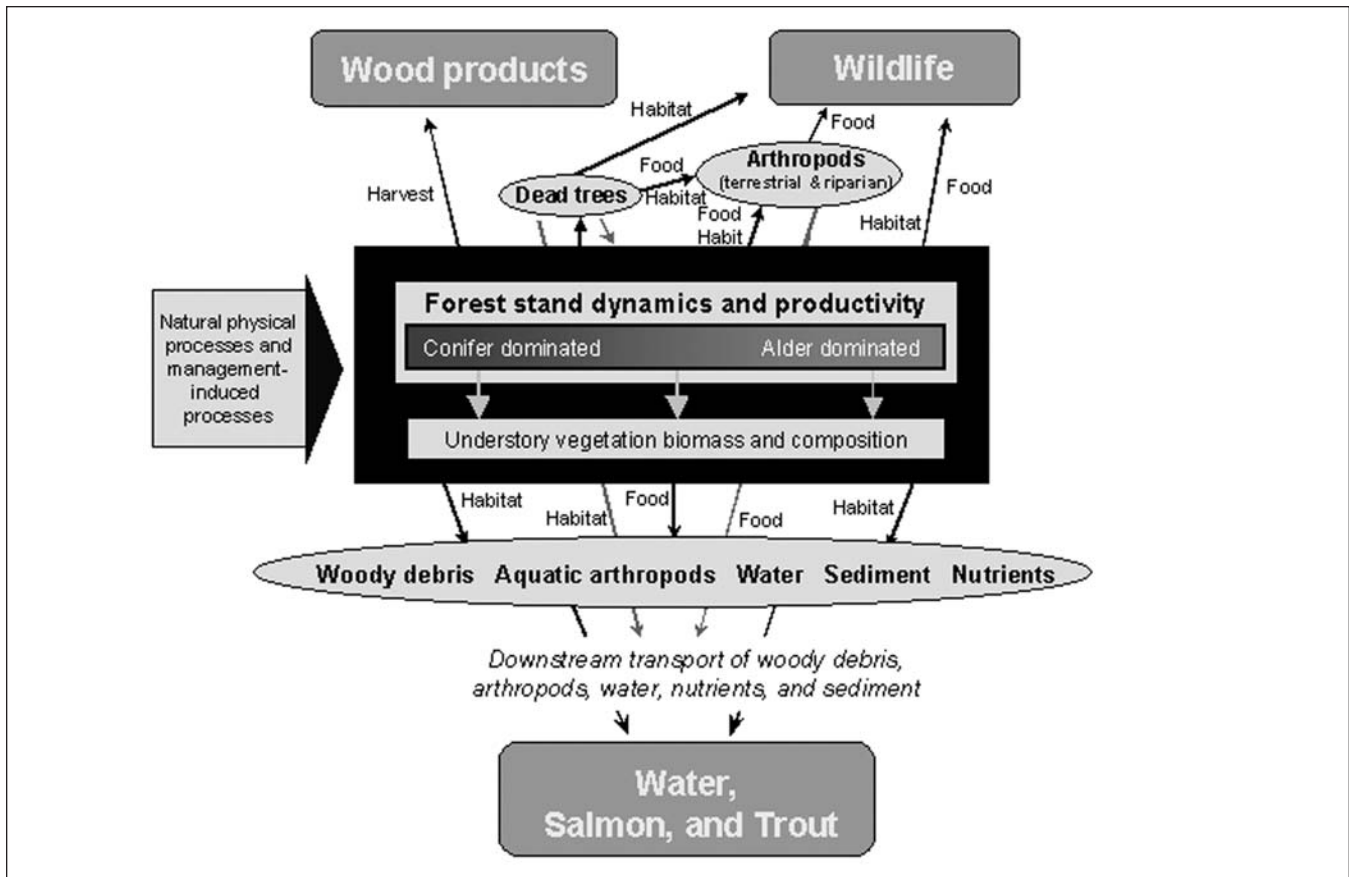


Figure 1—Conceptual diagram illustrating how red alder influences wood, wildlife, and fish productivity. This diagram indicates how each discipline links with others to build an integrated study.

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.

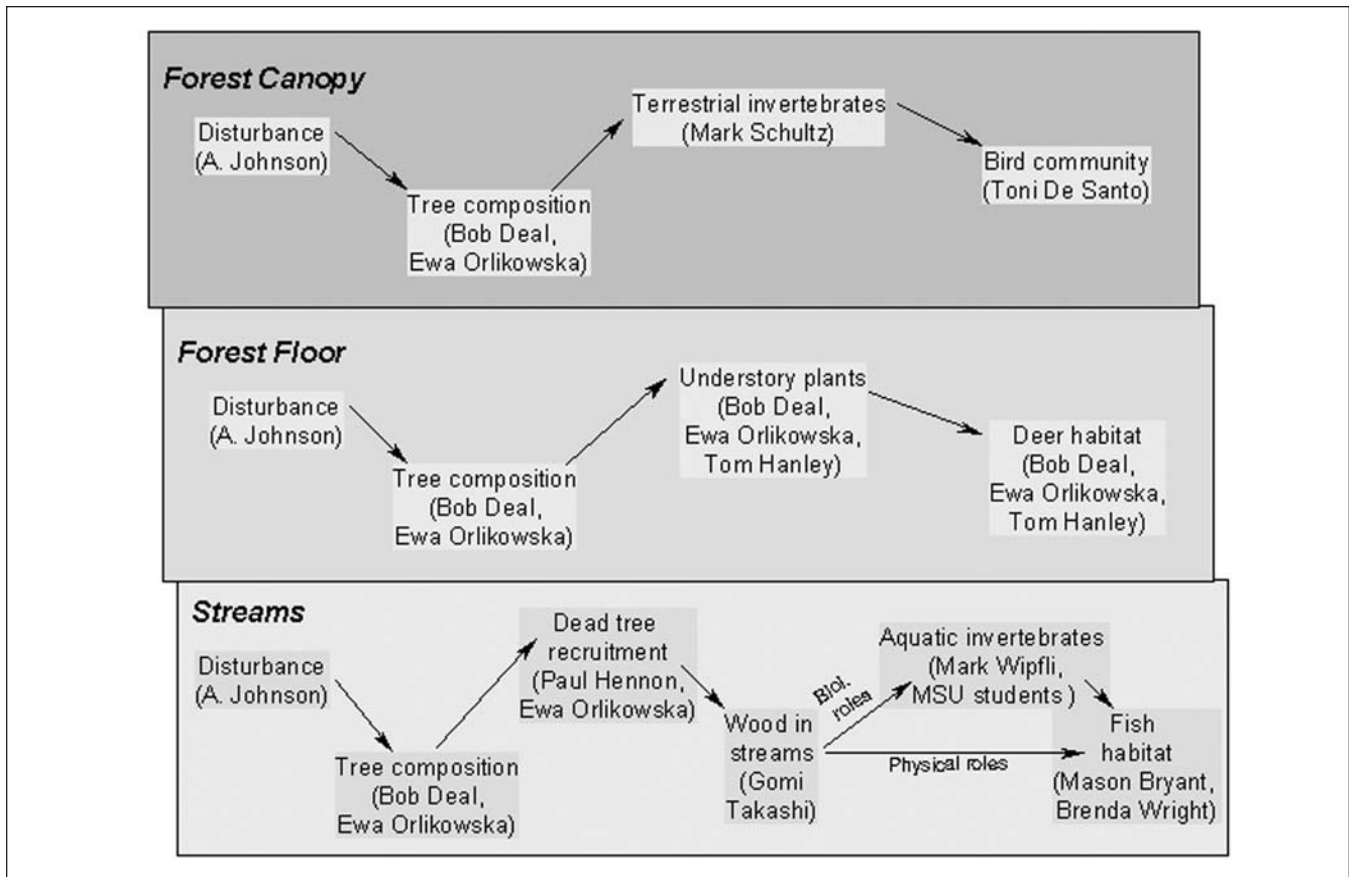


Figure 2—Several key ecological themes in the wood compatibility research on the role of red alder in young-growth forests of Southeast Alaska. Note that these themes do not capture all aspects of our study (e.g., wood production); they highlight areas where we attempted to track an important resource 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 streams 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

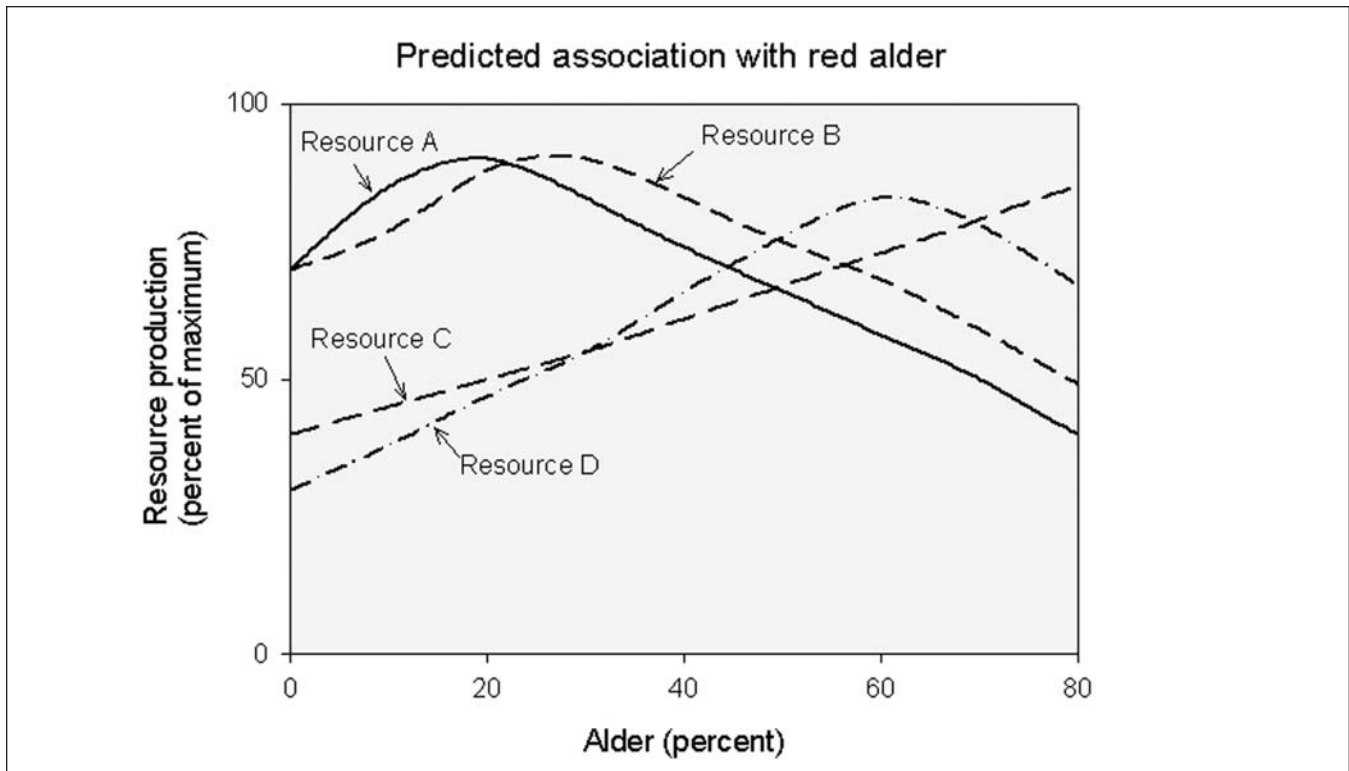


Figure 3—Conceptual depiction of how various resources may vary across the gradient of tree composition (e.g., percentage of basal area of red alder) in young-growth forests from pure conifer to nearly pure red alder. Once supported by data from our sampling, we will use this approach to simultaneously 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<sup>12</sup>. 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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## LITERATURE CITED

- Alaback, P.B. 1982. Dynamics of understory biomass in Sitka spruce-western hemlock forests of southeast Alaska. *Ecology*. 63(6): 1932-1948.
- Bryant, M.D. 1985. Changes 30 years after logging in large woody debris, and its use by salmonids. In: *Riparian ecosystems and their management: reconciling conflicting uses*. Johnson, C.D.; Ziebell, D.R.; Patton, P.F. [et al.], eds. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 329-334.

<sup>12</sup> Russell, Jim. 2001. Personal Communication. Supervisory Silviculturist, Sitka Office, Tongass National Forest, USDA Forest Service, Sitka, AK.

- Bisson, P.A., Bilby, R.E.; Bryant, M.D. [et al.]. 1987. Large woody debris in the Pacific Northwest: past, present, and future. In: Proceedings of the Symposium Streamside Management: Forestry and Fishery Interactions. Feb. 12-14, 1986. Seattle, WA: University of Washington: 143-190.
- Deal, R.L. 1997. Understory plant diversity in riparian alder-conifer stands after logging in southeast Alaska. Research Note PNW-RN-523. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station.
- Dellasala, D.A.; Hagar, J.C.; Engel, K.A. [et al.]. 1996. Effects of silvicultural modifications of temperate rain-forest on breeding and wintering bird communities, Prince of Wales Island, Southeast Alaska. *Condor*. 98: 706-721.
- Eglitis, A.; Hennon, P.E. 1997. Porcupine feeding damage in precommercially thinned conifer stands of central southeast Alaska. *Western Journal of Applied Forestry*. 12: 115-121.
- Hanley, T.A. 1993. Balancing economic development, biological conservation, and human culture: the Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) as an ecological indicator. *Biological Conservation*. 66: 61-67.
- Hanley, T.A. 1996. Small mammals of even-aged, red alder-conifer forests in southeastern Alaska. *Canadian Field Naturalist*. 110(4): 626-629.
- Hanley, T.A.; Bernard, J.C. 1998. Red alder, *Alnus rubra*, as a potential mitigating factor for wildlife habitat following clearcut logging in southeastern Alaska. *Canadian Field Naturalist*. 112(4): 647-652.
- Hanley, T.A.; Hoel, T. 1996. Species composition of old-growth and riparian Sitka spruce-western hemlock forests in southeastern Alaska. *Canadian Journal of Forest Research*. 26: 1703-1708.
- Hetrick, N.J.; Brusven, M.A.; Meehan, W.R.; Bjornn, T.C. 1998a. Changes in solar input, water temperature, periphyton accumulation, and allochthonous input and storage after canopy removal along two small salmon streams in southeast Alaska. *Transactions of the American Fisheries Society*. 127: 859-875.
- Hetrick, N.J.; Brusven, M.A.; Bjornn, T.C. [et al.]. 1998b. Effects of canopy removal on invertebrates and diet of juvenile coho in a small stream in Southeast Alaska. *Trans. Am. Fish. Soc.* 127: 876-888.
- Newton, M.; Cole, E.C. 1994. Stand development and successional implications: pure and mixed stands. In: the biology and management of red alder. Hibbs, D.E.; DeBell, D.S.; Tarrant, R.F., eds. Corvallis, OR: Oregon State Univ. Press.
- Sedell, J.R.; Swanson, F.J. 1984. Ecological characteristics of streams in old-growth forests of the Pacific Northwest. In: Fish and wildlife relationships in old-growth forests. Meehan, W.R.; Merrell, T.R.; Hanley, T.A., eds. Proceedings of a symposium. Alaska District, American Institute of Fishery Research Biologists; Northwest section. Juneau, Alaska: Wildlife Society; Alaska Council on Science and Technology: 9-16.
- Schoen, J.W.; Kirchhoff, M.D.; Hughes, J. H. 1988. Wildlife and old-growth forests in southeastern Alaska. *Natural Areas Journal*. 8: 138-145.
- Schoen, J.W.; Wallmo, O.C.; Kirchhoff, M.D. 1981. Wildlife-forest relationships: is a reevaluation necessary? *Transactions of the North American Wildlife and Natural Resources Conference*. 46: 531-544.
- Tappeiner, J.C. II; Alaback, P.B. 1989. Early establishment and vegetative growth of understory species in the western hemlock-Sitka spruce forests of Southeast Alaska. *Canadian Journal of Botany*. 67: 318-326.
- Wallmo, O.C.; Schoen, J.W. 1980. Response of deer to secondary forest succession in southeast Alaska. *Ecology*. 26(3): 448-462.
- Wipfli, M.S. 1997. Terrestrial invertebrates as salmonid prey and nitrogen sources in streams: contrasting old-growth and young-growth riparian forests in southeastern Alaska, USA. *Canadian Journal of Fisheries Aquatic Science* 54: 1259-1269.
- Wipfli, M.S.; Gregovich, D.P. 2002. Export of invertebrate and detritus from fishless headwater streams in Southeast Alaska: implications for downstream fish-bearing food webs. *Freshwater Biology*. In press.



*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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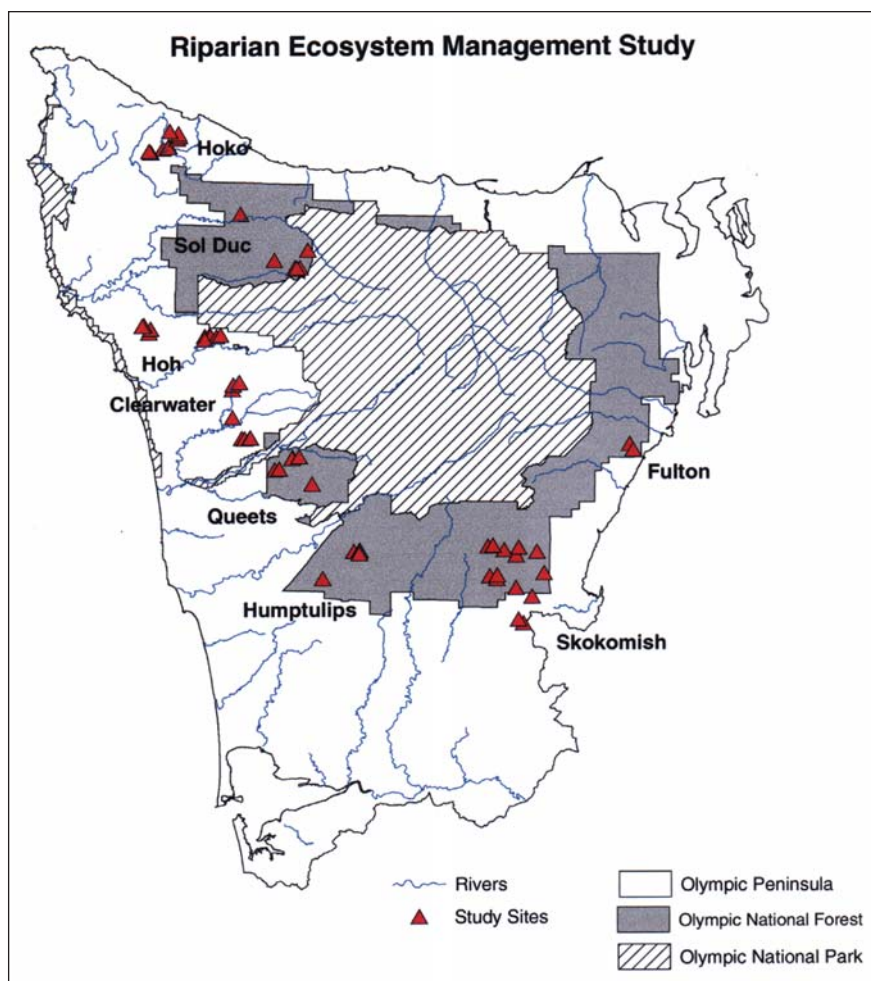


Figure 1—Location of study sites on the Olympic Peninsula, Washington state. Names of major river basins in which study sites occurred are given. The crosshatched area bounds Olympic National Forest and Olympic National Park.

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<sup>5</sup>, 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?*

<sup>5</sup> COPE Report, Vol. 9, No. 3, Aug. 1996.

**Table 1—Top: common names of headwater stream vertebrates<sup>a</sup>. 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               |
| % channel in glides                                  | % riparian late-seral forest  | Road density                                   |
| % channel in silt and sand substrate                 |                               | Drainage density                               |
| % channel in gravel and pebble substrate             |                               | Watershed area                                 |
| % channel in large and small cobble substrate        |                               | Elevation at base                              |
| % channel in boulder and bedrock substrate           |                               | % watershed area in recently active landslides |
|                                                      |                               | % watershed area in southerly aspect           |
|                                                      |                               | % watershed area with steep slopes (>60%)      |

<sup>a</sup> 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                                                                                                                         |
|-----------------------------------------------|---------------|-------------------------------------------------------------------------------------------------------------------------------------|
| <i>Site variables</i>                         |               |                                                                                                                                     |
| 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.                    |
| <i>Landscape variables</i>                    |               |                                                                                                                                     |
| % 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 <sup>2</sup> .                                                            |
| Drainage density                              | Watershed     | Ratio of the length of streams to the total watershed area, expressed as km/km <sup>2</sup> .                                       |
| 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 orthoimagery. 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 orthoimagery. Stream networks were derived from a hydrography cover created in 1992 by the ONF and updated with 1997 orthoimagery 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<sup>a</sup>**

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

<sup>a</sup> 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<sup>6</sup> 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

<sup>6</sup> 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.

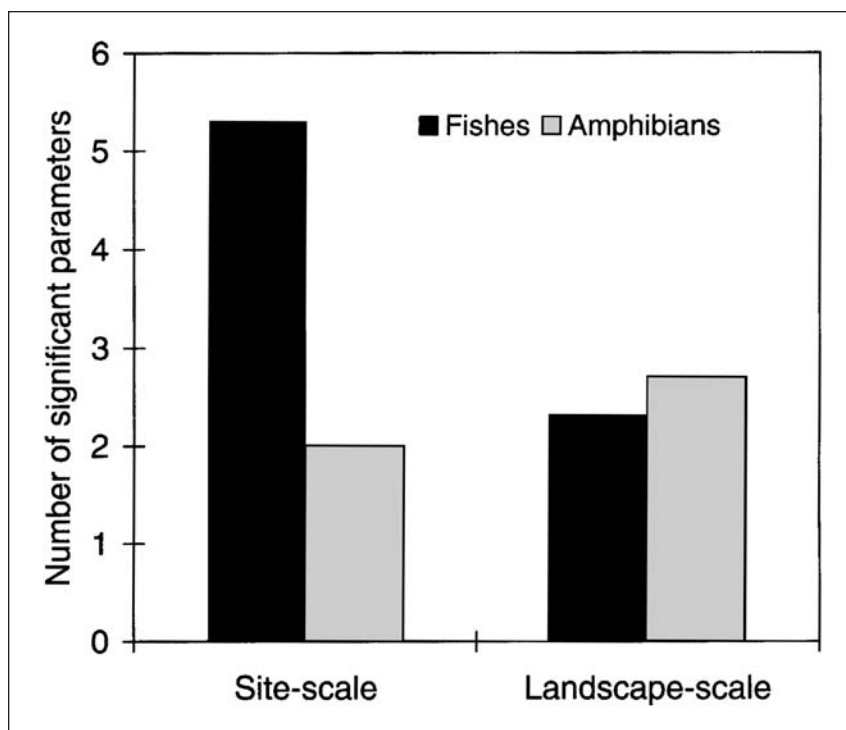


Figure 2—Comparison of the average number of site-scale and landscape-scale variables (Table 1) significantly influencing fish and amphibian species in headwater streams on the Olympic Peninsula.

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-

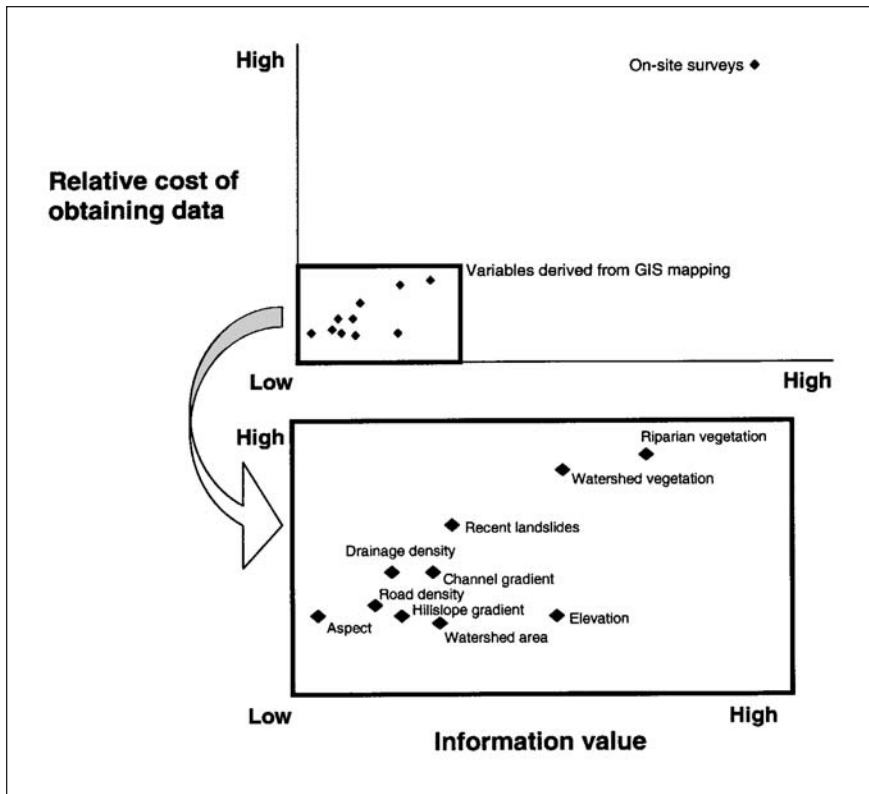


Figure 3—Cost-benefit comparison of various landscape-scale parameters. Information value is the relative influence of each parameter on headwater vertebrates.

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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## LITERATURE CITED

- Agee, J.K. 1988. Successional dynamics on forest riparian zones. In: Raedeke, K.J., ed. Streamside management: riparian wildlife and forestry interactions. Contribution Number 59, Institute of Forest Resources. Seattle: University of Washington: 31-43.
- Berg, D.R. 1995. Riparian silvicultural system design and assessment in the Pacific Northwest Cascade Mountains, USA. *Ecological Applications*. 5(1): 87-96.
- Corkran, C.C.; Thoms, C. 1996. Amphibians of Oregon, Washington, and British Columbia. Edmonton, AB: Lone Pine Publishing: 175 p.
- Fausch, K.D.; Young, M.K. 1995. Evolutionarily significant units and movement of resident stream fishes: a cautionary tale. *American Fisheries Society Symposium*. 17: 360-370.
- Forest Ecosystem Management Assessment Team [FEMAT]. 1993. Forest ecosystem management: an ecological, economic, and social assessment. Portland, OR: U.S. Department of Agriculture: U.S. Department of the Interior [and others].
- Gregory, S.V.; Lamberti, G.A.; Erman, D.C. [et al]. 1987. Influence of forest practices on aquatic production. In: Salo, E.O.; Cundy T.W., eds. Streamside management: forestry and fishery interactions. Contribution Number 57. Seattle: University of Washington, Institute of Forest Resources: 233-255.
- Gregory, S.V.; Swanson F.J.; McKee W.A. [et al]. 1991. An ecosystem perspective of riparian zones. *BioScience*. 41(8): 540-551.
- Hawkins, C.P.; Kershner, J.L.; Bisson, P.A. [et al]. 1993. A hierarchical approach to classifying stream habitat features. *Fisheries*. 18(6): 3-12.
- Hayes, J.P.; Adam, M.D.; Bateman, D. [et al]. 1996. Integrating research and forest management in riparian areas of the Oregon Coast Range. *Western Journal of Applied Forestry*. 11(3): 85-89.
- Naiman, R.J.; Bilby, R.E.; Bisson, P.A. 2000. Riparian ecology and management in the Pacific coastal rain forest. *BioScience*. 50(11): 996-1011.

- Naiman, R.J.; Magnuson, J.J.; McKnight, D.M.; Stanford, J.A. 1995. *The freshwater imperative: a research agenda*. Washington, D.C.: Island Press: 165 p.
- Quigley, T.M.; Haynes, R.W.; Graham, R.T., tech. eds. 1996. Integrated scientific assessment for ecosystem management in the interior Columbia Basin and portions of the Klamath and Great Basins. Gen. Tech. Rep. PNW-GTR-382. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. [irregular pagination].
- Raphael, M.G.; Bisson, P.A.; Foster, A.D.; Jones, L.L.C. 2002. Effects of streamside forest management on the composition and abundance of stream and riparian fauna of the Olympic Peninsula. In: Johnson, A.C.; Haynes, R.W.; Monserud, R.A.; eds. *Congruent Management of Multiple Resources: Proceedings from the Wood Compatibility Workshop*. Gen. Tech. Rep. PNW-GTR-563. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 27-40.
- Reeves, G.H.; Everest, F.H.; Sedell, J.R. 1993. Diversity of juvenile anadromous salmonid assemblages in coastal Oregon basins with different levels of timber harvest. *Transactions of the American Fisheries Society*. 122: 309-317.
- Reeves, G.H.; Bisson, P.A.; Dambacher, J.M. 1998. Fish Communities. In: Naiman, R.J.; Bilby R.E., eds. *River ecology and management*. New York: Springer-Verlag: 200-234.
- Schlosser, I.J.; Angermeier, P.L. 1995. Spatial variation in demographic processes of lotic fishes: conceptual models, empirical evidence, and implications for conservation. *American Fisheries Society Symposium*. 17: 392-401.
- Thomas, J.W.; Maser, C.; Rodiek, J.E. 1979. Riparian zones. In: Thomas, J.W., ed. *Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington*. Agriculture Handbook 553. Washington, D.C.: U.S. Department of Agriculture, Forest Service, with U.S. Department of the Interior, Bureau of Land Management and the Wildlife Management Institute: 40-47.
- Thomas, J.W.; Raphael, M.G.; Anthony, R. [et al]. 1993. Viability assessments and management considerations for species associated with late-successional and old-growth forests of the Pacific Northwest. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 523 p.
- Zalewski, M.; Naiman, R.J. 1985. The regulation of riverine fish communities by a continuum of abiotic-biotic factors. In: Alabaster, J.S., ed. *Habitat modifications and freshwater fisheries*. London, England: Butterworth: 6-9.

## **A SURVEY OF RESEARCH ON RIPARIAN RESPONSES TO SILVICULTURE**

Patrick G. Cunningham<sup>1</sup>

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### **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 (Brososke et al. 1997; Danehy and Kirpes 2000<sup>2</sup>; 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 streambanks when clearcutting is done near streams (Brososke 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 Brososke et al. (1997); Dong et al. (1998); Hagar (1999); and O'Connell et al. (2000) suggest installing buffers between streams and timber harvest units. Brososke et al. (1997) and Dong et al. (1998) use information from Chen

<sup>2</sup> Danehy 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 (Broszofsky 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<sup>3, 4</sup>, 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 effects 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<sup>3</sup>.

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

<sup>3</sup> 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].

<sup>4</sup> 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.

<sup>5</sup> 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.

## LITERATURE CITED

- Beschta, R.L. 1991. Stream habitat management for fish in the northwestern United States: the role of riparian vegetation. *American Fisheries Society Symposium*. 10: 53-58.
- Brosofske, K.D.; Chen, J.; Naiman, R.J.; Franklin, J.F. 1997. Harvesting effects on microclimatic gradients from small streams to uplands in western Washington. *Ecological Applications*. 7(4): 1188-1200.
- Bury R.B.; Corn, P.S. 1988. Responses of aquatic and streamside amphibians to timber harvest: a review. In: Raedeke, K.J. ed. *Streamside management: riparian wildlife and forestry interactions*. Contribution Number 59. Seattle, WA: Institute of Forest Resources, University of Washington: 165-181.

- Carey, A.B.; Thysell, D.R.; Brodie, A.W. 1999. The forest ecosystem study: background, rationale, implementation, baseline conditions, and silvicultural assessment. Gen. Tech. Rep. PNW-GTR-457. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 129 p.
- Chan, S.S.; Bailey, M.D.; Karnes, D. [et al.]. 1997. The role of silviculture in the active management of riparian zone vegetation in the Oregon Coast Range: a partnership between researchers and managers. In: Communicating the role of silviculture in managing national forests: proceedings of the National Silviculture Workshop. Gen. Tech. Rep. NE-GTR-238. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 205 p.
- Chen, J.; Franklin, J.F.; Spies, T.A. 1995. Growing-season microclimate gradients from clearcut edges into old-growth Douglas-fir forests. *Ecological Applications*. 5: 74-86.
- Cissel, J.H.; Swanson, F.J.; Grant, G.E. [et al.]. 1998. A landscape plan based on historical fire regimes for a managed forest ecosystem: the Augusta Creek study. Gen. Tech. Rep. PNW-GTR-422. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 82 p.
- Cissel, J.H.; Swanson, F.J.; Weisberg, P.J. 1999. Landscape management using historical fire regimes: Blue River, Oregon. *Ecological Applications*. 9(4): 1217-1231.
- Danehy, R.J.; Kirpes, B.J. 2000. Relative humidity gradients across riparian areas in eastern Oregon and Washington forests. *Northwest Science*. 74(3): 224-233.
- Dong J.; Chen, J.; Brososke, K.D.; Naiman, R.J. 1998. Modelling air temperature gradients across managed small streams in western Washington. *Journal of Environmental Management*. 53: 309-321.
- Forest Ecosystem Management Assessment Team [FEMAT]. 1993. Forest ecosystem management: an ecological, economic, and social assessment. Portland, OR: U.S. Department of Agriculture; U.S. Department of the Interior. [Irregular pagination].
- Forman, R.T.T. 1995. Land mosaics: the ecology of landscapes and regions. Cambridge, United Kingdom: Cambridge University Press. 632 p.
- Forman, R.T.T.; Godron, M. 1986. Landscape ecology. New York: John Wiley and Sons. 619 p.
- Gregory, S.V.; Swanson, F.J.; McKee, W.A.; Cummins, K.W. 1991. An ecosystem perspective of riparian zones. *Bioscience*. 41(8): 540-551.
- Hagar, J.C. 1999. Influence of riparian buffer width on bird assemblages in western Oregon. *Journal of Wildlife Management*. 63(2): 484-496.
- Halpern, C.B.; Raphael, M.G., eds. 1999. Retention harvests in northwestern forest ecosystems: the demonstration of ecosystem management options (DEMO) study. *Northwest Science*. 73, Special issue: 125 p.
- Hayes, J.P.; Chan, S.S.; Emmingham, W.H. [et al.]. 1997. Wildlife response to thinning young forests in the Pacific Northwest. *Journal of Forestry*. 95(8): 28-33.
- Hibbs, D.E.; Giordano, P.A. 1996. Vegetation characteristics of alder-dominated riparian buffer strips in the Oregon Coast Range. *Northwest Science*. 70(3): 213-222.
- Hohler, D.; Sedell, J.; Olson, D. 2001. Aquatic conservation strategy. In: Haynes, R.W.; Perez, G.E., eds. Northwest Forest Plan research synthesis. Gen. Tech. Rep. PNW-GTR-498. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 130 p.
- Machtans, C.S.; Villard, M.; Hannon, S.J. 1996. Use of riparian buffer strips as movement corridors by forest birds. *Conservation Biology*. 10(5): 1366-1379.
- Minore, D.; Weatherly, H.G. 1994. Riparian trees, shrubs, and regeneration in the coastal mountains of Oregon. *New Forests*. 8: 249-263.
- Naiman, R.J.; Bilby, R.E.; Bisson, P.A. 2000. Riparian ecology and management in the Pacific coastal rain forest. *Bioscience*. 50(11): 996-1011.
- Naiman, R.J.; Decamps, H. 1997. The ecology of interfaces: riparian zones. *Annual Review of Ecology and Systematics*. 28: 621-658.

- O'Connell, M.A.; Hallett, J.G.; West, S.D. [et al.]. 2000. Effectiveness of riparian management zones in providing habitat for wildlife. Final report. Washington Department of Natural Resources. TFW-LWAG1-00-01. [Variable pagination].
- Oliver, W.W. 2000. Ecological research at the Blacks Mountain Experimental Forest in northeastern California. Gen. Tech. Rep. PSW-GTR-179. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 66 p.
- Pabst, R.J.; Spies, T.A. 1998. Distribution of herbs and shrubs in relation to land form and canopy cover in riparian forests of coastal Oregon. *Canadian Journal of Botany*. 76: 298-315.
- Pabst, R.J.; Spies, T.A. 1999. Structure and composition of unmanaged riparian forests in the coastal mountains of Oregon, U.S.A. *Canadian Journal of Forest Research*. 29: 1557-1573.
- Swanson, F.J.; Gregory, S.V.; Sedell, J.R.; Campbell, A.G. 1982. Land-water interactions: the riparian zone, Chapter 9. In Edmonds, Robert L., ed. *Analysis of coniferous forest ecosystems in the western United States*. United States / International Biological Programme Synthesis Series 14. Stroudsburg, PA: Hutchinson Ross Publishing Co.: 267-291.
- Tappeiner, J.C.; Huffman, D.; Marshall, D.; Spies, T.A.; Bailey, J.D. 1997. Density, ages, and growth rates in old-growth and young-growth forests in coastal Oregon. *Canadian Journal of Forest Research*. 27:638-648.
- U.S. Department of Agriculture and U.S. Department of Interior. 1994. Record of decision for amendments for U.S. Department of Agriculture, Forest Service and U.S. Department of Interior, Bureau of Land Management within the range of the northern spotted owl. U.S. Department of Agriculture, Forest Service, U.S. Department of Interior, Bureau of Land Management. [Variable Pagination].

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

Deanna H. Olson<sup>1</sup>, Samuel S. Chan<sup>2</sup>, and Charles R. Thompson<sup>3</sup>

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### **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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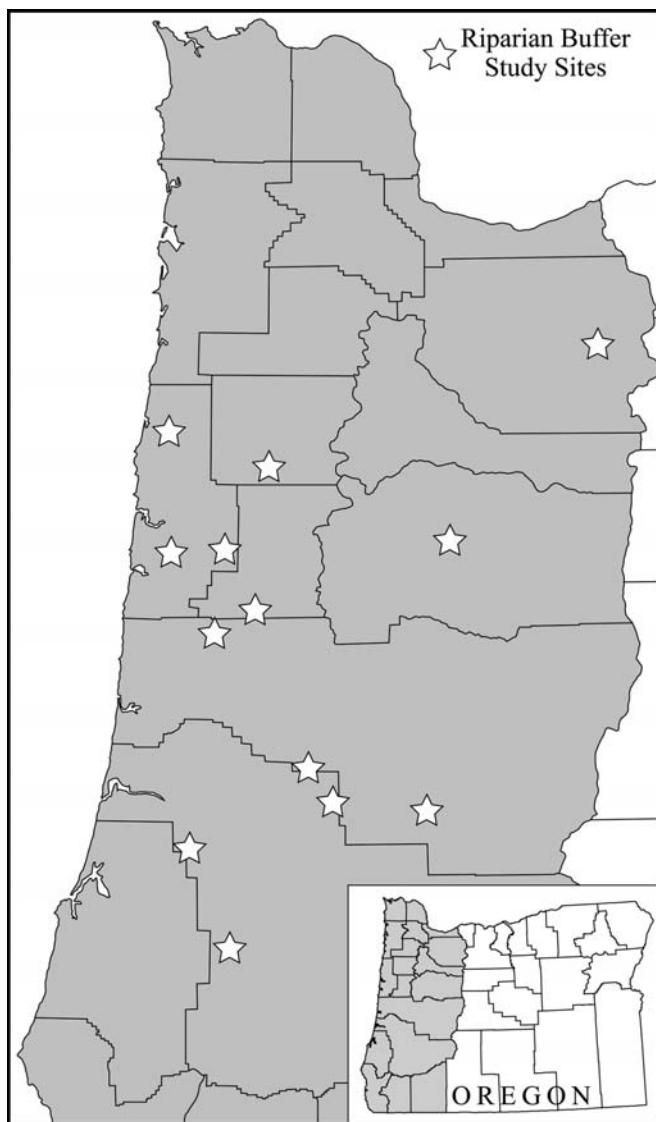


Figure 1—Distribution of 13 sites implementing the riparian buffer and density management studies in western Oregon managed federal forests.

## 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 LSOOG 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

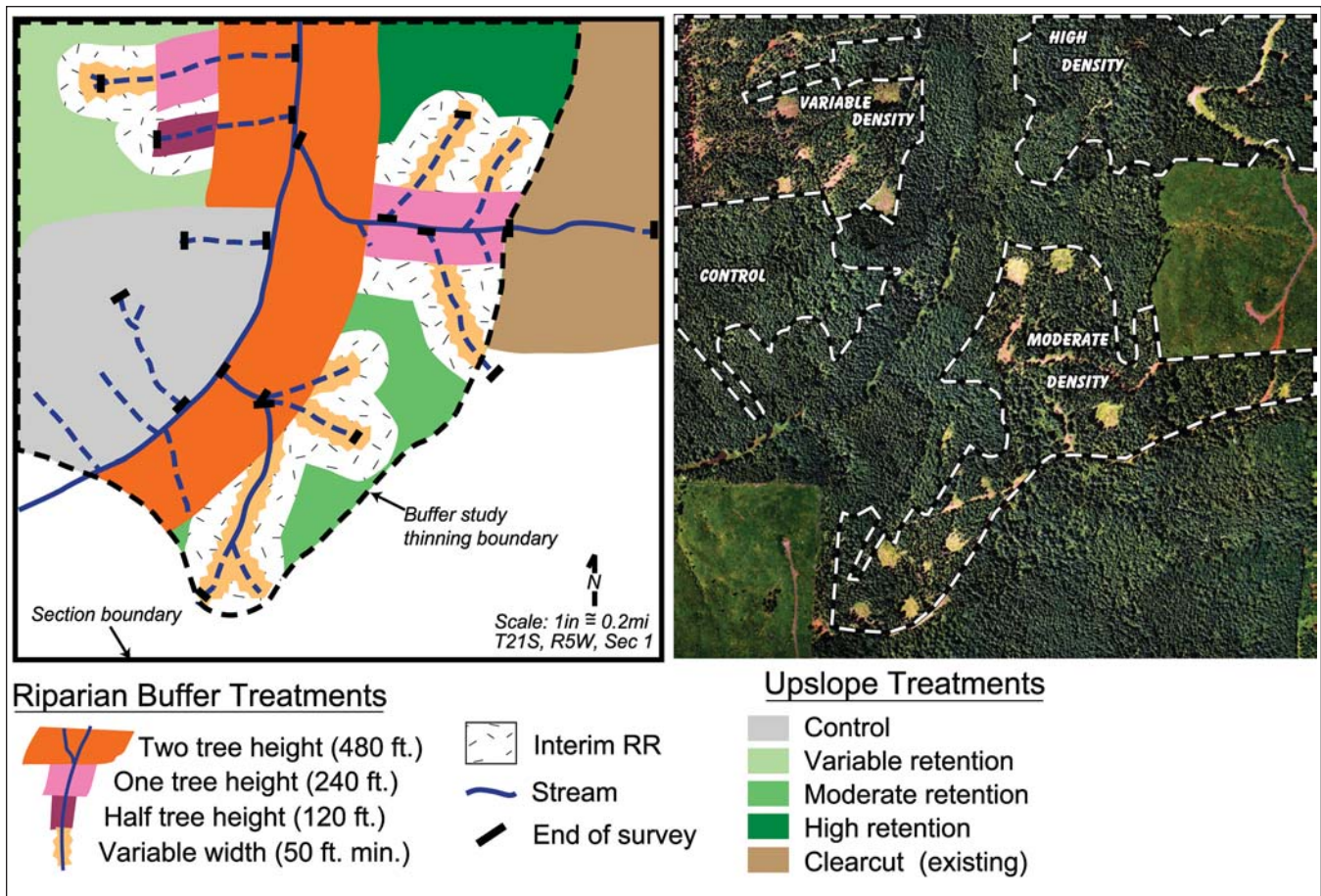


Figure 2—Schematic diagram and aerial photograph of one Bureau of Land Management density management study site (“Bottom Line”) showing four upslope treatments: unthinned control; high retention (density) thinning (120 trees per acre [TPA]); moderate retention thinning (80 TPA); and variable retention 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).

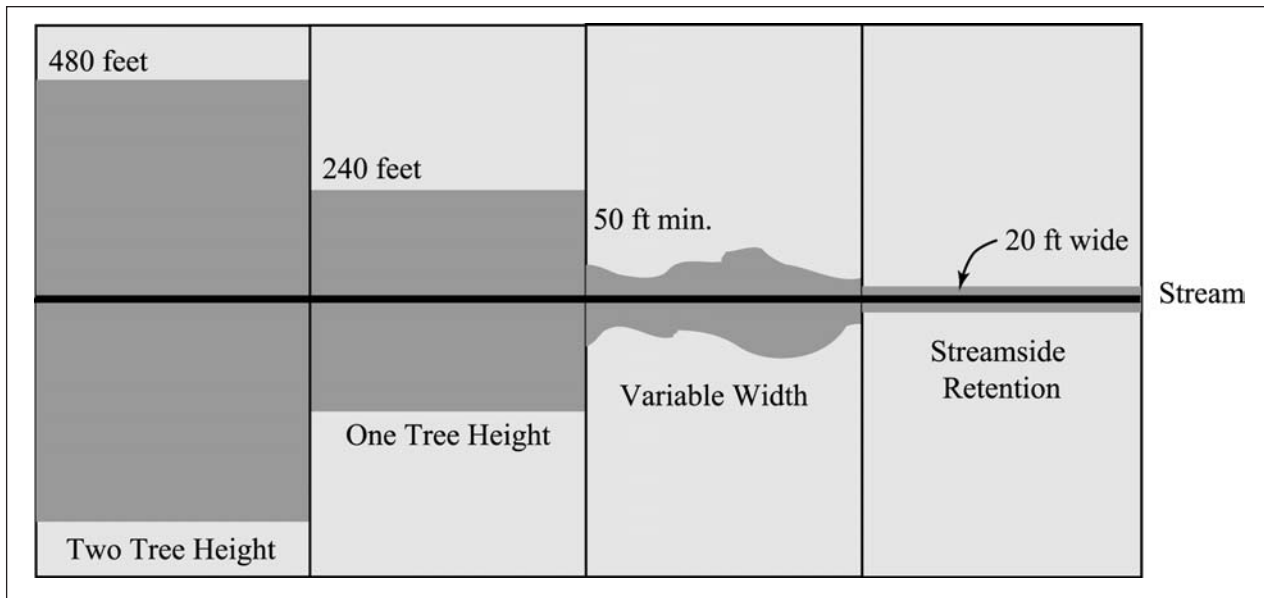


Figure 3—The four unthinned streamside zones under investigation in our joint riparian buffer and density management studies.

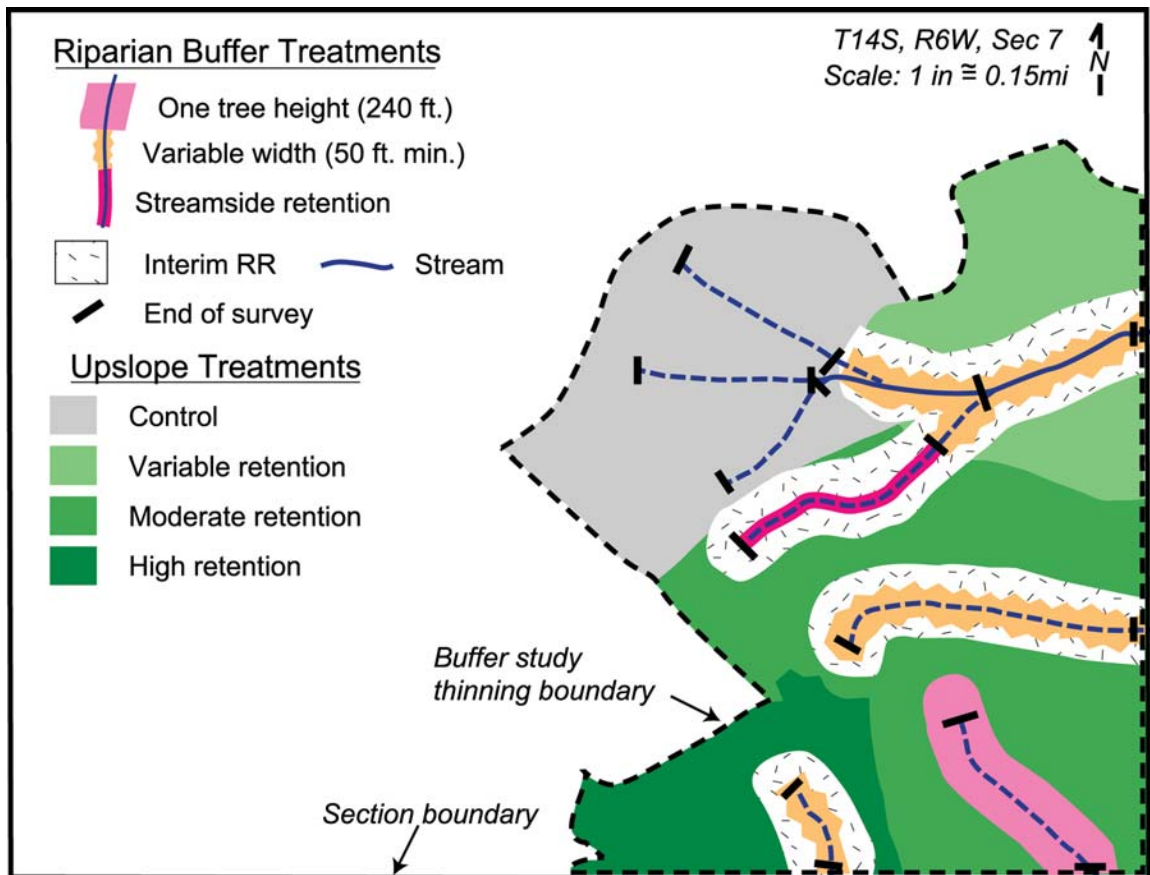


Figure 4—The riparian buffer study is being implemented within the moderate retention thinning treatment (80 trees per acre) at sites that had sufficient stream lengths and upslope forest areas to allow a minimum of two buffer treatments. At this particular site (“Green Peak”), three headwater streams 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           | <ul style="list-style-type: none"> <li>• Most of the change in microclimate from the stream to the upland forest occurs within the first 45 ft from the stream.</li> <li>• Soil and water temperatures within the riparian buffer are similar between thinned and unthinned stands.</li> <li>• 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.</li> <li>• Riparian areas had the most heterogeneous site conditions.</li> <li>• Stands now contain limited large down wood in early stages of decay.</li> </ul> |
| Aquatic vertebrates and habitats - D. Olson    | <ul style="list-style-type: none"> <li>• Headwater vertebrate assemblages differ both longitudinally with stream flow gradients and latitudinally from streams (distinct bank and upslope assemblages).</li> <li>• 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.</li> <li>• Faunal responses to treatments are undergoing analysis.</li> <li>• Upslope fauna appears reliant on legacy down wood.</li> </ul>                              |
| Macroinvertebrates - A. Moldenke and R. Progar | <ul style="list-style-type: none"> <li>• Headwater invertebrate assemblages differ both longitudinally with stream flow gradients and latitudinally from streams.</li> <li>• Near stream riparian zone arthropod assemblage contained all upslope biota.</li> <li>• Small bodied Chironomidae and Mycetophilidae dominated emergence from temporary streams.</li> <li>• Larger Ephemeroptera, Plecoptera, and trichoptera dominated emergence in perennial streams.</li> </ul>                                                                                                                                                                |
| Lichens and bryophytes - P. Muir and B. McCune | <ul style="list-style-type: none"> <li>• Diversity and abundance hotspots are associated with gaps, hardwood trees, old remnant trees, and wolf trees.</li> <li>• Relictual species are associated with legacy features, and feature retention can retain such biodiversity</li> </ul>                                                                                                                                                                                                                                                                                                                                                        |

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)

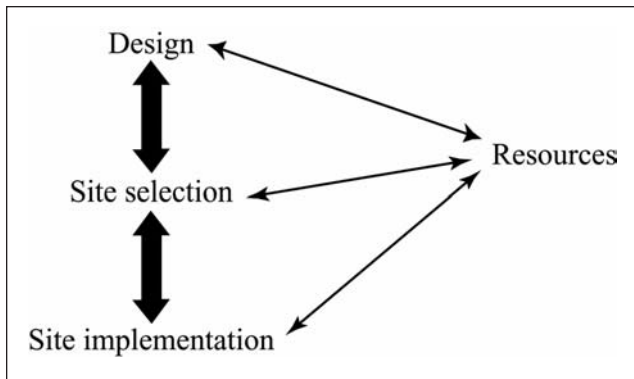


Figure 5—Iterative resource evaluations occurred during project planning and implementation.

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**

| <b>Taxonomic Group<br/>(no. species or taxa)</b> | <b>Species (common or scientific names)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|--------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 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<br>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)                                     | <i>Hypogymnia oceanica</i> , <i>Lobaria oregana</i> , <i>L. pulmonaria</i> , <i>L. scrobiculatea</i> , <i>Nephroma bellum</i> , <i>N. helveticum</i> , <i>N. laevigatum</i> , <i>N. resupinatum</i> , <i>Pannaria leucostichtoides</i> , <i>P. saubinetii</i> , <i>Parmotrema chinense</i> , <i>Peltigera collina</i> , <i>P. pacifica</i> , <i>Plastimatia lacunosa</i> , <i>Pseudocyphellaria anomala</i> , <i>P. anthraxis</i> , <i>P. crocata</i> , <i>Ramalina thrausta</i> , <i>Sticta fuliginosa</i> , <i>S. limbata</i> . |
| Mosses (2)                                       | <i>Buxbaumia piperi</i> , <i>Antitrichia curtipendula</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Fungi (17)                                       | <i>Gymnopilus punctifolius</i> , <i>Aphaecollybia</i> sp., <i>Ramaria aurantiiscescens</i> , <i>Otidea leporina</i> , <i>Sarcosoma mexicana</i> , <i>Cantharellus formaosus</i> , <i>C. subalbidus</i> , <i>C. ciberius</i> , <i>Clavariadelphus liqula</i> , <i>Phaeocollybia</i> sp., <i>Ramaria cyaneigranosa</i> , <i>Gomphus clavatus</i> , <i>G. floccosus</i> , <i>Hydnum repandum</i> , <i>Phaeocollybia attenuata</i> , <i>Cantharellus tubaeformis</i> , <i>Helvella compressa</i>                                      |
| Vascular plants (9)                              | <i>Orobancha pinorum</i> , <i>Monotropa uniflora</i> , <i>Hypopitys monotropa</i> , <i>Pityopus californica</i> , <i>Pleuricospora fimbriolata</i> , <i>Hemitomes congestum</i> , <i>Sparassis crispa</i> , <i>Botrychium virginianum</i> , <i>B. multifidum</i>                                                                                                                                                                                                                                                                  |
| 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  $\frac{1}{4}$  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,<br>Papillose tail dropper,<br>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.                                                                                                                        |
| <i>Orobanche pinorum</i><br>(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.                                |
| <i>Buxbaumia piperi</i> , <i>Antitrichia curtispindula</i> (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.); <i>Sparassis</i>                                    | Helped locate leave islands, application of density management treatments rather <i>crispa</i> 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).<br>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)<sup>1</sup>**

| 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)  |

<sup>1</sup> Data come from environmental assessments

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

## LITERATURE CITED

- Cissel, J.H.; Swanson, F.J.; Grant, G.E.; Olson, D.H. [et al.]. 1998. A landscape plan based on historical fire regimes for a managed forest ecosystem: the Augusta Creek study. Gen. Tech. Rep. PNW-GTR-422. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 82 p.
- Neitlich, P.N.; McCune, B. 1997. Hotspots of epiphytic lichen diversity in two young managed forests. *Conservation Biology*. 11: 172-182.
- Olson, D.H.; Chan, S.S.; Weaver, G.; Cunningham, P. [et al.]. 2000. Characterizing stream, riparian, upslope habitats and species in Oregon managed headwater forests. In: Wiggington, J.; Beschta, R. eds. *Riparian ecology and management in multi-land use watersheds*. International conference of the American Water Resources Association, 30 August, Portland, OR. AWRA Publication TPS-00-2, Middleburg, VA: 83-88.
- Sedell, J.R.; Reeves, G.H.; Burnett, K.M. 1994. Development and evaluation of aquatic conservation strategies. *Journal of Forestry*. 92: 28-31.
- Tappeiner, J.C.; Huffman, D.; Marshall, D.; Spies, T.A.; Bailey, J.D. 1997. Density, ages, and growth rates in old-growth and young-growth forests in coastal Oregon. *Canadian Journal of Forest Research*. 27: 638-648.
- U.S. Department of Agriculture and U.S. Department of Interior. 1993. Forest ecosystem management: an ecological, economic, and social assessment. Report of the Forest Ecosystem Management Assessment Team [FEMAT]. U.S. GPO 1993-793-071. On file with: Regional Ecosystem Office, 333 SW 1<sup>st</sup> Ave, Portland, Oregon, 97208, U.S.A.
- U.S. Department of Agriculture and U.S. Department of Interior. 1994. Record of decision for amendments for Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl (Northwest Forest Plan). U.S. Department of Agriculture, Forest Service and U.S. Department of Interior, Bureau of Land Management, Portland, Oregon, U.S.A. On file with: Regional Ecosystem Office, 333 SW 1<sup>st</sup> Ave, Portland, Oregon, 97208, U.S.A.

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## RESEARCH ON STREAMSIDE ISSUES THROUGH THE WOOD COMPATIBILITY INITIATIVE

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### 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<sup>3</sup>) 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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<sup>3</sup> Berman, C. [N.d.] Assessment of landscape characterization methods. Manuscript in preparation. On file with: Cara Berman, Center for Water and Watershed Studies, Box 352100, University of Washington, Seattle WA 98195-2100

**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 <sup>a</sup> | 0-6 m     | >29            | 5-29           | <5             |
|                    | >6-30 m   | >35            | 5-35           | <5             |

<sup>a</sup>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 <sup>a</sup> | 0-30 m    | >15            | 2-15           | <2             |

<sup>a</sup>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 <sup>a</sup> | 0-30 m    | >2             | 0.5-2          | <0.5           |

<sup>a</sup>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<sup>4</sup>; Monohan<sup>5</sup>) 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<sup>6</sup>).

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<sup>7</sup>). 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

<sup>4</sup> Reidy, C. [N.d.] Extent of hyporheic zones in Puget Sound Lowland streams. M.S. thesis in preparation. On file with: Center for Water and Watershed Studies, Box 352100, University of Washington, Seattle, WA 98195-2100.

<sup>5</sup> Monohan, C. [N.d.] Responses of various riparian buffers to nitrogen loading: nitrogen retention mechanisms, Ph.D. thesis in preparation. On file with: Center for Water and Watershed Studies, Box 352100, University of Washington, Seattle, WA 98195-2100.

<sup>6</sup> Shellberg, J. [N.d.] Hydrologic and geomorphic conditions in selected bull trout spawning streams in western Washington. M.S. thesis in preparation. On file with: Center for Water and Watershed Studies, Box 352100, University of Washington, Seattle, WA 98195-2100.

<sup>7</sup> Clinton, S. [N.d.]. Isotopic and invertebrate signatures in hyporheic zones in the Puget Sound lowlands. Manuscript in preparation. On file with: Center for Water Watershed Studies, Box 352100, University of Washington, Seattle, WA 98195-2100.

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<sup>4</sup>; Monohan<sup>5</sup>; Clinton<sup>7</sup>), and habitat-forming processes (Shellberg<sup>6</sup>) 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<sup>TM</sup> <sup>8</sup>) 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.

<sup>8</sup> 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<sup>9</sup>) 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 ecological 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.

## LITERATURE CITED

Bash, J.S. 1999. Survey of stream restoration and fisheries enhancement monitoring in Washington state. Seattle, WA: University of Washington, 130 p. M.S. thesis

<sup>9</sup> Brauner, J. [N.d.] Decision-making under uncertainty: prioritizing freshwater habitat restoration for salmon recovery. Ph.D. thesis in preparation. On file with: Center for Water and Watershed Studies, University of Washington, Box 352100, Seattle, WA 98195-2100

- Brunke, M.; Gonser, T. 1997. The ecological significance of exchange processes between rivers and groundwater. *Freshwater Biology*. 37: 1-33.
- Clinton, S. 2001. Microbial metabolism, enzyme activity, and production in the hyporheic zone of a floodplain river. Seattle, WA: University of Washington, 86 p. Ph.D. thesis.
- Coe, H. 2001. Distribution patterns of hyporheic fauna in a floodplain riparian terrace. Seattle, WA: University of Washington, 75 p. M.S. thesis.
- Fox, M.J. 2001. A new look at the quantities and volumes of instream wood in forested basins within Washington State. Seattle, WA: University of Washington, 239 p. M.S. thesis.
- Fox, M.J. 2002. Large woody debris: how much is enough? <http://depts.washington.edu/cssuw/Publications/FactSheets/lwd.pdf>
- Fox, M.J.; Bolton, S.; Conquest, L. In press (2002). Reference conditions for instream wood in western Washington. In: Montgomery, D.R.; Bolton, S.; Booth, D.B.; Wall, L., eds. *Restoration of Puget Sound Rivers*. Seattle, Washington, University of Washington Press: 361-393.
- Ise, J.L. 2001. Motivations of rural landowners to participate in conservation-oriented land management programs. Seattle, WA: University of Washington, 121 p. M.S. thesis.
- Johnston, J.G. 2002. Comparison of historic and current stream shade in eastern Washington. Seattle, WA: University of Washington, 130 p. M.S. thesis.
- Kiffney, P.; Riley, S.; Bilby, B.; Inman, C. 2001. Aquatic and terrestrial response to return of anadromous salmonids above Landsburg Dam diversion, Cedar River, Washington. National Marine Fisheries Service working report.
- Mikkelsen, K.; Vesho, I. 2000. Riparian soils: A literature review. Center for Streamside Studies Report. <http://depts.washington.edu/cssuw/Publications/soillitreview.html>
- O'Neal, J.S. 2000. Biological evaluation of stream enhancement: a comparison of large woody debris and an engineered alternative. Seattle, WA: University of Washington, 103 p. M.S. thesis.
- O'Neal, J.S.; Watts, A.; Bolton, S.; Sibley, T. 2000a. A comparison of the hydraulic and biological effects of large woody debris and an engineered alternative. In *CD-ROM Proc. ASCE 1999 Int'l Water Resources Engineering Conf.* Aug 8-11, 1999. Seattle WA.
- O'Neal, J.S.; Savery, A.; Sibley, T.; Bolton, S. 2000b. Center for Streamside Studies Fact Sheet. <http://depts.washington.edu/cssuw/Publications/FactSheets/elwdc.pdf>
- Ryan, C.M.; Ise, J.; Wolf, K.L. 2001. Nonpoint source pollution programs: Assessing methods and behavioral effectiveness. Center for Streamside Studies Fact Sheet. <http://depts.washington.edu/cssuw/Publications/FactSheets/NPS%20Flyer-Aug.pdf>
- Savery, A.W. 2000. A comparison of the hydraulic effect of large woody debris and an engineered alternative. Seattle, WA: University of Washington, 72 p. M.S. thesis.
- Scholz, J.G. 2001. The variability in stream temperatures in the Wenatchee National Forest and their relationship to physical, geological, and land management factors. Seattle, WA: University of Washington, 129 p. M.S. thesis.
- Ward, J.V. 1989. The four-dimensional nature of lotic ecosystems. *Journal of the North American Benthological Society*. 8(1): 2-8.
- Wishnie, M., McClintick, A.; Hansen, J.; Bob, F. 1999a. Riparian conversion monitoring data collection protocols. Center for Streamside Studies fact sheet. <http://depts.washington.edu/cssuw/Publications/FactSheets/protocolsc.pdf>
- Wishnie, M., McClintick, A.; Hansen, J.; Bob, F. 1999b. Lummi Natural Resources Riparian Zone Restoration Project (RZRP): Proposed Data Collection Protocols Field Sheets Damage Codes. Center for Streamside Studies report. Available at <http://depts.washington.edu/cssuw/Research/Lummi/lummi.html>

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## PHYSICAL AND CHEMICAL PROCESSES IN HEADWATER CHANNELS WITH RED ALDER

Adelaide C. Johnson<sup>1</sup> and Richard T. Edwards<sup>2</sup>

### 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  $> 15^\circ$ , 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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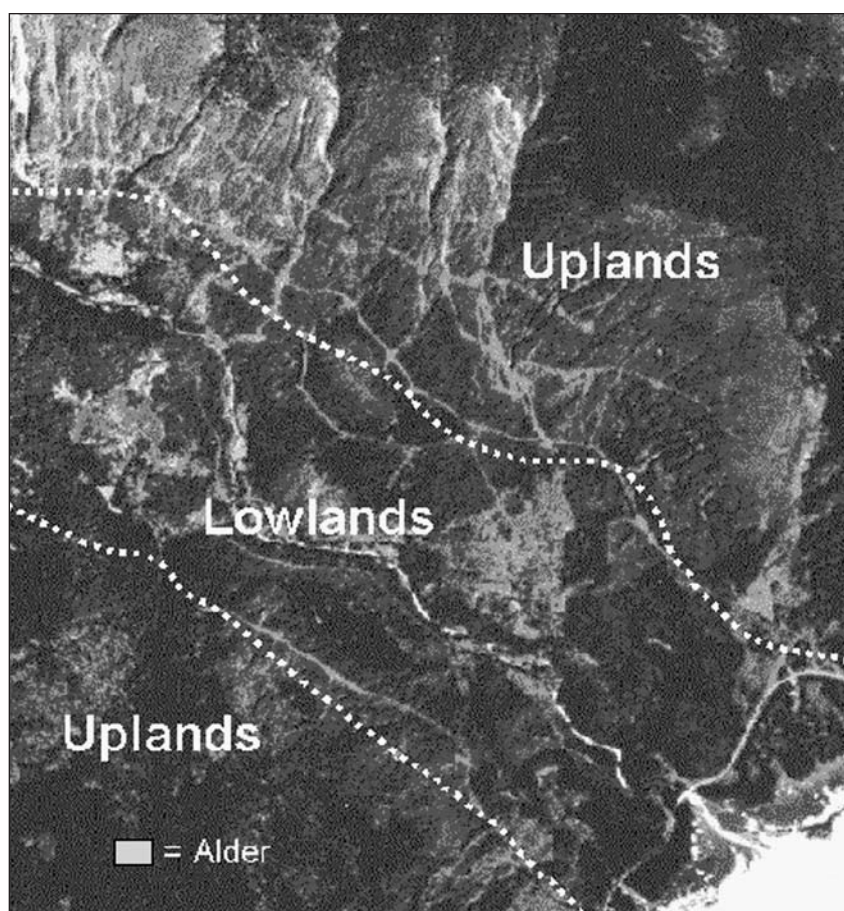


Figure 1—Supervised classification of a false-color infrared image for a portion of the Maybeso watershed. Note: extensive linear patches of alder in the young-growth forests associated with landslides, cable logging, tractor logging, and road building.

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 ( $> 30^\circ$ ) in conjunction with major rainstorms from the 1960s through the 1990s, primarily within areas clearcut in the late 1950s and 1960s (Helmert 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<br>alder | Micrograms nitrate<br>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  $> 15^\circ$  slopes and (2) lowland regions with  $< 15^\circ$  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<sup>3</sup> (1997) to select from an initial unsupervised classification with 25 classes) and landslide inventories

(Helmert 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

<sup>3</sup> 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.

## What grows following landslide disturbance?

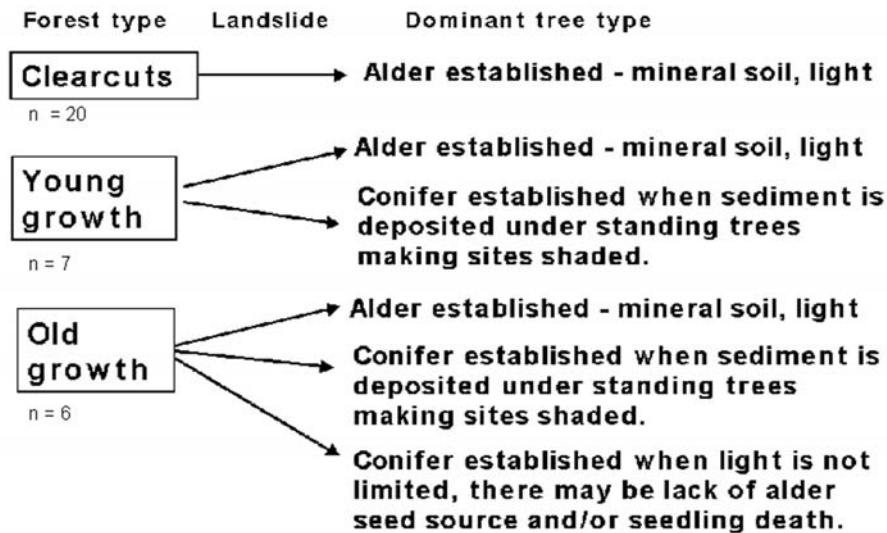


Figure 2—Pattern of alder establishment following landslide occurrence within old growth, young growth, and clearcuts.

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

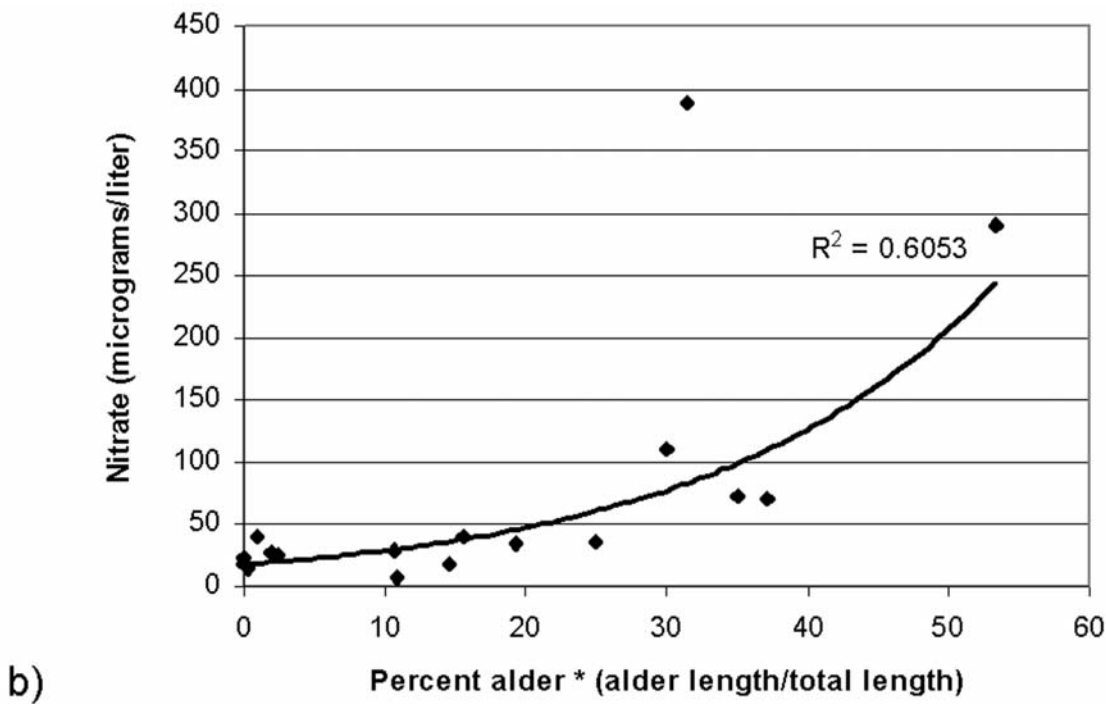
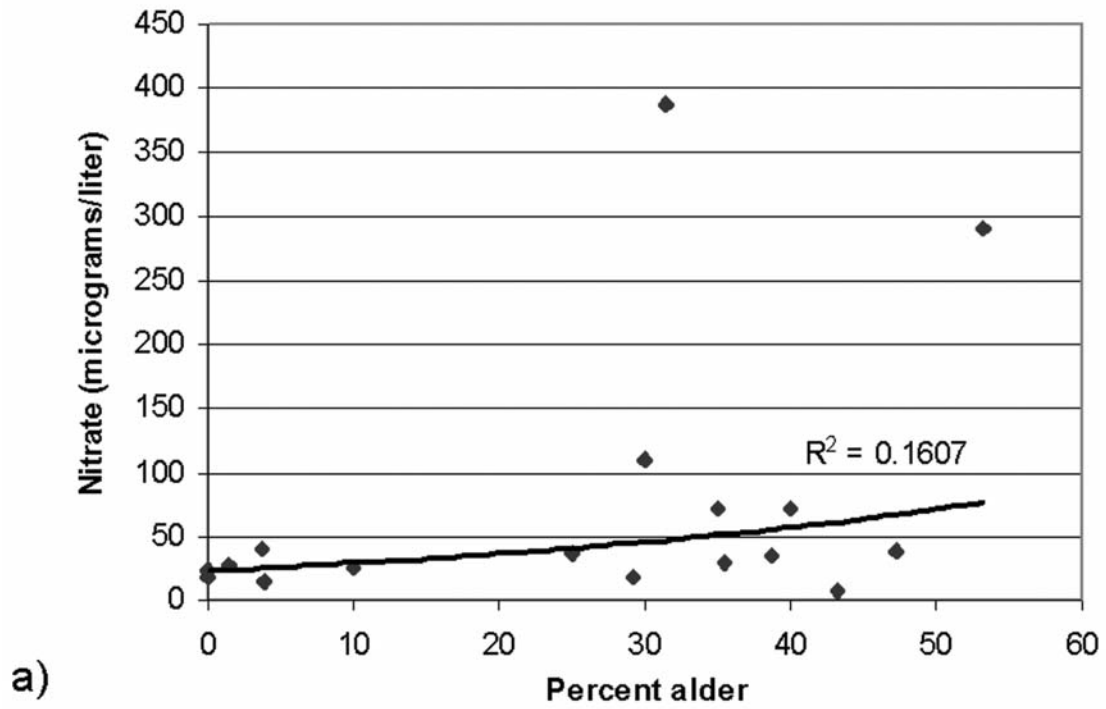


Figure 3—Relationships between nitrate concentration and a) percent alder and b) percent alder multiplied by a factor that accounts for the total length of riparian alder along selected sites.

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  $> 20^\circ$ ) 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  $28^\circ$  ( $16$  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  $> 16^\circ$ ), 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  $25^\circ$ . 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 stream-side 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, land-form 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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## LITERATURE CITED

- Anderson, N.H.; Sedell, J.R.; Roberts, L.M.; Triska, F.J. 1978. The role of aquatic invertebrates in processing of wood debris in coniferous forest streams. *American Midland Naturalist*. 100: 64-82.
- Andrus, C.W.; Long, B.A.; Froelich, H.A. 1988. Woody debris and its contribution to pool formation in a coastal stream 50 years after logging. *Canadian Journal of Fisheries and Aquatic Sciences*. 45: 2080-2086.
- Bilby, R.E.; Ward, J.W. 1991. Characteristics and function of large woody debris in streams draining old-growth, clearcut, and second-growth forests in southwestern Washington. *Canadian Journal of Fisheries and Aquatic Sciences*. 48: 2499-2508.
- Deal, R.L.; Orlikowska, E.H. 2002. Development of mixed alder-conifer stands in southeastern Alaska. In: Johnson, A.C.; Haynes, R.W.; Monserud, R.A.; eds. *Congruent Management of Multiple Resources: Proceedings from the Wood Compatibility Workshop*. Gen. Tech. Rep. PNW-GTR-563. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 127-132.
- Deal, R.L.; Wipfli, M.S.; Johnson, A.C. [et al.]. 2002. Does red alder enhance wildlife, aquatic and fisheries resources in young-growth western hemlock-sitka spruce forests of southeast Alaska? *Proceedings of the National Silviculture Workshop*. Gen. Tech. Rep. PNW-GTR-546. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 93-102.
- ERDAS, Inc., 1997. *Erdas Field Guide*, Version 4. Atlanta, GA.
- Fevold, K. 1998. Sub-surface controls on the distribution of benthic algae in floodplain back channel habitats of the Queets River. Seattle, WA: University of Washington, M.S. thesis.

- Gomi, T.; Sidle, R.C.; Swanston, D.N. [In press]  
Hydrogeomorphic linkages of sediment transport in headwater streams, Maybeso Experimental Forest, southeast Alaska. *Hydrological Processes*.
- Gregory, S.V.; Lamberti, G.A.; Erman, D.C. [et al.]. 1987. Influence of forest practices on aquatic production. In: E.O. Salo and T.W. Cundy, eds. *Streamside management: forestry and fishery interactions. Proceedings of a conference. Institute of Forest Resources Contributions Number 576*. Seattle, WA: University of Washington: 233-255.
- Grette, G.B. 1985. The role of large organic debris in juvenile salmonid rearing habitat in small streams. Seattle, WA: University of Washington. 105 p. M.S. thesis.
- Helmets, A.E., 1961-1985. Unpublished landslide inventory. On file with USDA. Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Juneau, AK.
- Hennon, P. E.; Wipfli, M.S.; Deal, R.L. [et al.] 2002. Mixed alder-conifer forests: managing upland ecosystems in southeast Alaska for wood Products, wildlife, and fish. In: Johnson, A.C.; Haynes, R.W.; Monserud, R.A.; eds. *Congruent Management of Multiple Resources: Proceedings from the Wood Compatibility Workshop*. Gen. Tech. Rep. PNW-GTR-563. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 51-58.
- Hicks, B.J. 1989. The influence of geology and timber harvest on channel morphology and salmonid populations in Oregon Coast Range streams. Corvallis, OR: Oregon State University. 199 p. Ph.D. dissertation.
- Johnson, A.C.; Swanston, D.N.; McGee, K.E. 2000. Landslide initiation, runoff, and deposition within clearcuts and old-growth forests of Alaska. *Journal of American Water Resources Association*. 36(1): 129-142.
- Keim, R.F.; Skaugset, A.E.; Bateman, D.S. 2000. Dynamics of coarse woody debris placed in three Oregon streams. *Forestry Science*. 46: 13-22.
- Luken, J.O.; Fonda, R.W. 1983. Nitrogen accumulation in a chronosequence of red alder communities along the Hoh River, Olympic National Park, Washington. *Canadian Journal of Forest Resources* 13: 1228-1237.
- McDade, M.H.; Swanson, F.J.; McKee, W.A. [et al.]. 1990. Source distances for coarse woody debris entering small streams in western Oregon and Washington. *Canadian Journal of Forest Research*. 20: 326-330.
- Megahan, W.F. 1982. Channel sediment storage behind obstructions in forested drainage basins draining the granitic bedrock of the Idaho batholith. In: Swanson, F.J.; Janda, R.J.; Dunne, T.; Swanston, D.N., eds. *Sediment budgets and routing in forested drainage basins*. Gen. Tech. Rep. PNW-GTR-141. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 114-121.
- Nowacki, G.; Krosse, P.; Fisher, G. [et al.]. 2001. Ecological Subsections of Southeast Alaska and Neighboring Areas of Canada. Tech. Pub. R10 – TR – 75. U.S. Department of Agriculture, Forest Service, Alaska Region.
- Piccolo, J.J.; Wipfli, M.S. 2002. Does red alder (*Alnus rubra*) along headwater streams increase the export of invertebrates and detritus from headwaters to fish-bearing habitats in southeastern Alaska? *Canadian Journal of Fisheries and Aquatic Sciences*. 59(3): 503-513.
- Ralph, S.C.; Poole, G.C.; Conquest, L.L.; Naiman, R.J. 1994. Stream channel morphology and woody debris in logged and unlogged basins of western Washington. *Canadian Journal of Fisheries and Aquatic Sciences*. 51: 37-51.
- Swanston, D.N.; Marion, D.A. 1991. Landslide response to timber harvest in southeast Alaska, In: *Proceedings of the Fifth Interagency Sedimentation Conference*. Federal Energy Regulatory Commission, Las Vegas, Nevada.
- Wipfli, M.S.; Deal, R.L.; Hennon, P. E. [et al.]. 2002. Managing young upland forests in southeast Alaska for wood products, wildlife, aquatic resources, and fishes: study plan. Gen. Tech. Rep. PNW-GTR-558. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
- Wipfli, M.S.; Gregovich, D.P. 2002. Export of invertebrates and detritus from fishless headwater streams in southeastern Alaska: implications for downstream salmonid production. *Freshwater Biology*. 47(5): 957-969.



*SECTION C*  
**SCALE ISSUES**

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

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

<sup>1</sup> 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 indicators 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 many 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<br>Trees 25-50 cm dbh<br>Trees > 75 cm dbh<br>Diameter diversity index<br>Quadratic mean diam stand                          | Nesting/roosting: 0.6 ha<br>Foraging: 28 ha; 200 ha; 1,800 ha; |
| Pileated Woodpecker  | Nesting: Snags 50-75 cm d.<br>Snags >75 cm d.<br>Foraging: Trees >50 cm d.<br>Vol CWD                                                           | Nesting: 0.6 ha<br>Foraging: 452 ha                            |
| Western Blue Bird    | Snags > 50 cm d. and 5 m t.<br>Snags 25-50 cm d. & 5 m t.<br>Canopy cover (%)                                                                   | Territory: 0.6 ha                                              |
| Old Growth           | Trees > 100 cm d.<br>Diameter diversity index<br>Snags > 50 cm d. & 15 m t.<br>Large logs m <sup>3</sup> /ha<br>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

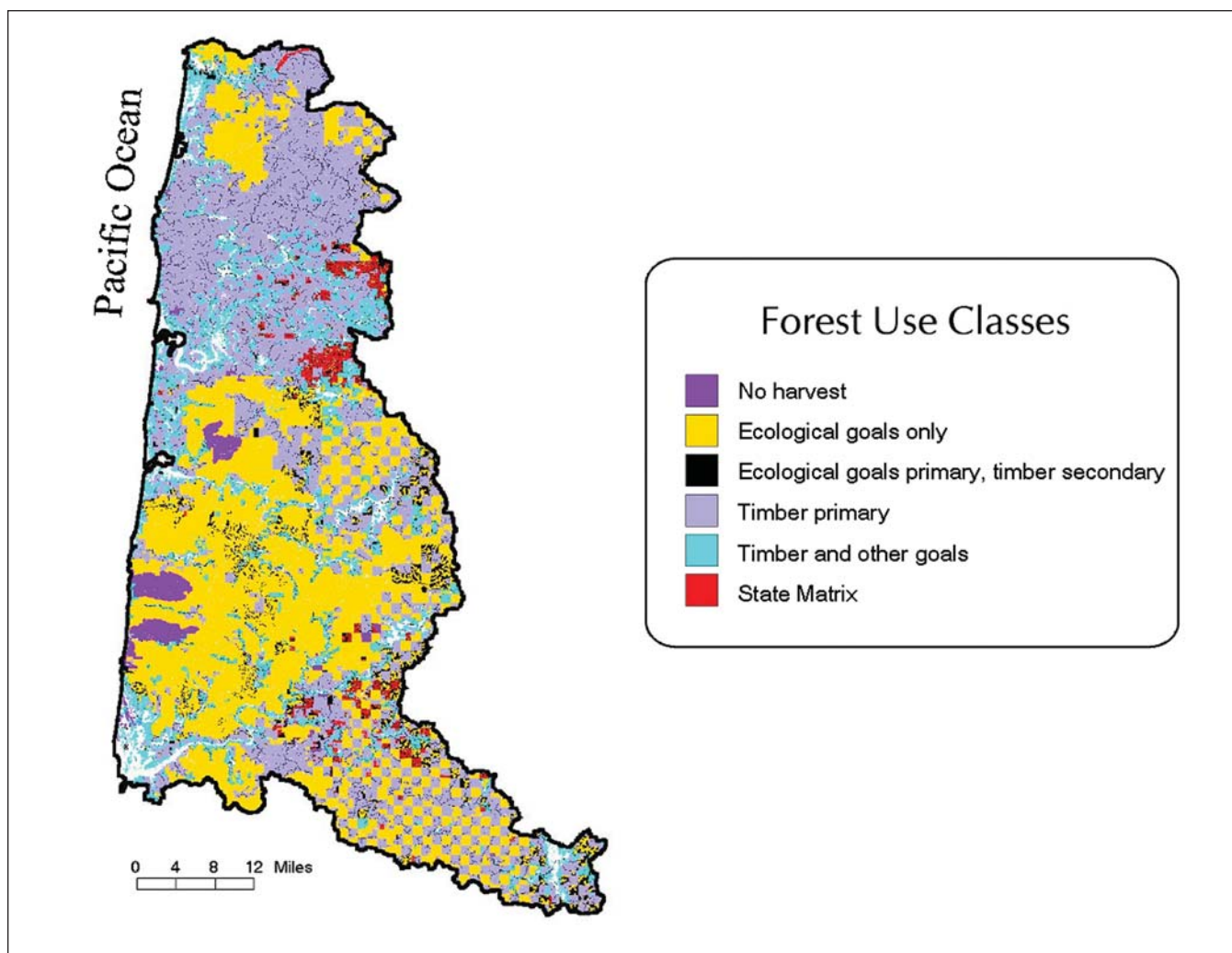


Figure 1—Pattern of forest use classes in central Coast Range of Oregon. No harvest = congressionally designated wilderness; ecological goals only = federal late successional reserves; ecological primary, timber secondary = riparian buffers and federal matrix land; timber primary = private industrial 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 m <sup>2</sup> /ha in stands less than 40 years of age                        |
| Long rotation       | Private         | 80 year rotation                                                                                    |

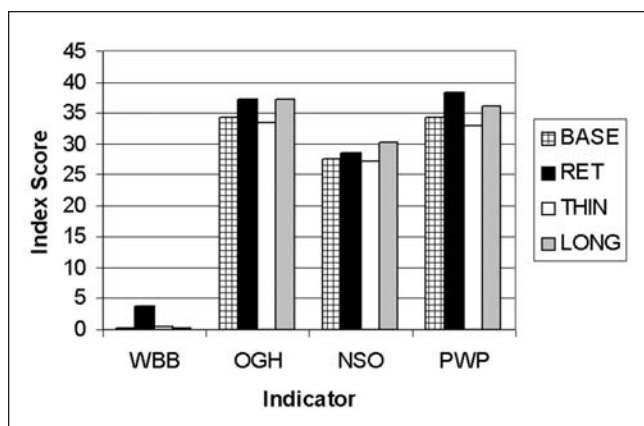


Figure 2—Mean index scores at 100 years for four different ecological indicators and four different scenarios in the central Coast Range. Index scores, which originally ranged from 0 to 1, have been multiplied by 100 to eliminate decimals. Ecological indicators: WBB = western bluebird; OGH = old-growth 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 Adams 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

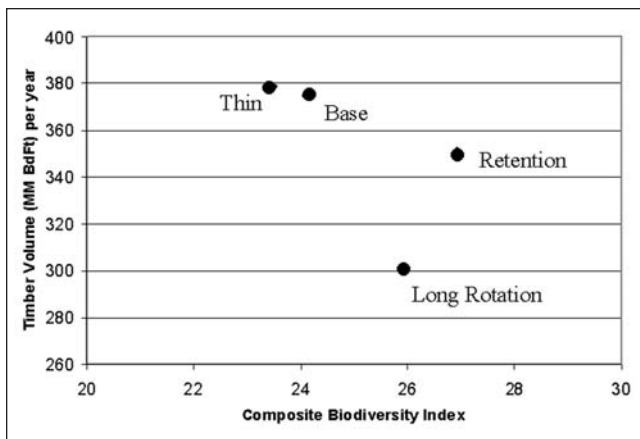


Figure 3—Relationship of timber volume production to the composite biodiversity index at year 100 for four different scenarios (see Figure 2 and Table 2 for explanations).

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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## LITERATURE CITED

- Adams, D.M.; Schillinger, R.A.; Latta, G.; Van Nalts, A. 2001. Timber harvest projections for private lands in western Oregon. Corvallis, OR: Oregon State University. Report prepared for the Oregon Department of Forestry, Salem, OR. 70 p.
- Bettinger, P.; Lennette, M. 2002. Landscape Management and Policy Simulator (LAMPS). Version 1.1. User's Manual. Oregon State University, College of Forestry. 98 p.
- Botkin, D.; Cummins, K.; Dunne, T. [et al.]. 1995. Status and future of salmon of western Oregon and northern California: Findings and Options, Report #8. The Center for the Study of the Environment, Santa Barbara, California. 300 p.
- Burnett, K.M. 2001. Relationships among juvenile anadromous salmonids, their freshwater habitat, and landscape characteristics over multiple years and spatial scales in Elk River, Oregon. Corvallis, OR: Oregon State University. 244 p. Ph.D. dissertation.
- Cajander, A.K. 1926. The theory of forest types. *Acta Forestalia Fennica* 29. 108 p.
- Carey, A.B. 1995. Sciurids in Pacific Northwest managed and old-growth forests. *Ecological Applications*. 5: 648-661.
- Carey, A.B.; Harrington, C.A. 2001. Small mammals in young forests: implications for management for sustainability. *Forest Ecology and Management*. 154: 289-309.
- Carey, A.B.; Lippke, B.R.; Sessions, J. 1999. Intentional systems management: managing forests for biodiversity. *Journal of Sustainable Forestry*. 9: 83-125.
- Committee of Scientists. 1999. Sustaining the people's lands: recommendations for stewardship of the national forests and grasslands into the next century. Washington, DC: U.S. Department of Agriculture. <http://www.fs.fed.us/forum/nepa/rule/cosreport.shtml>. (5/31/2002)
- Csuti, B.; Kimerling, A.J.; O'Neil, T.A. [et al.]. 1997. Atlas of Oregon wildlife: distribution, habitat, and natural history. Corvallis, OR: Oregon State University Press. 492 p.
- Davis, L.; Johnson, K.N.; Bettinger, P.; Howard, T. 2001. *Forest Management* (4<sup>th</sup> edition). New York, NY: McGraw Hill. 804 p.
- De Leo, G.A.; Levin, S.A. 1997. The multifaceted aspects of ecosystem integrity. *Conservation Ecology* 1(1): 3. <http://www.consecol.org/vol1/iss1/art3>. (5/31/2002)
- Forest Ecosystem Management Assessment Team [FEMAT]. 1993. Forest ecosystem management: an ecological, economic, and social assessment. Portland, OR: U.S. Department of Agriculture; U.S. Department of the Interior [and others]. [Irregular pagination].
- Karr, J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries*. 6(6): 21-27.
- Karr, J.R. 1991. Biological integrity: a long-neglected aspect of water resource management. *Ecological Applications*. 1: 66-84.
- Lambeck, R.J. 1997. Focal species define landscape requirements for nature conservation. *Conservation Biology*. 11: 849-956.

- McComb, W.C.; McGrath, M.; Spies, T.A.; Vesely, D. 2002. Models for mapping potential habitat at landscape scales: an example using Northern Spotted Owls. *Forest Science* 48 (2): 203-216.
- Montreal Process Criterion and Indicators. ([http://www.mpci.org/meetings/ci/ci\\_e.html](http://www.mpci.org/meetings/ci/ci_e.html))
- Noss, R.F.; O'Connell, M.A.; Murphy, D.D. 1997. *The science of conservation planning: habitat conservation under the Endangered Species Act*. Washington, DC: Island Press. 246 p.
- Quigley, T.M.; Haynes, R.M.; Hann, W.J. 2001. Estimating ecological integrity in the interior Columbia River basin. *Forest Ecology and Management*. 153: 161-178.
- Reeves, G.H.; Benda, L.E.; Burnett, K.M. [et al.]. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. In: Nielsen, J.L., ed. *Evolution and the aquatic ecosystem: defining unique units in population conservation*. American Fisheries Society Symposium 17. Bethesda, MD: American Fisheries Society: 334-349.
- Reeves, G.H.; Bisson, P.A.; Dambacher, J. 1998. Fish communities. In: Naiman, R.J.; Bilby, R.E., eds. *River ecology and management: lessons from the Pacific coastal ecoregion*. New York, NY: Springer-Verlag: 200-234.
- Reeves, G.R.; Everest, F.H.; Sedell, J.R. 1993. Diversity of juvenile anadromous salmonid assemblages in coastal Oregon basins with different levels of timber harvest. *Transactions of the American Fisheries Society*. 122(3): 309-317.
- Reeves, G.R.; Burnett, K.M.; Gregory, S.V. [In press]. *Fish and aquatic ecosystems of the Oregon Coast Range*. COPE Book. Oregon State University Press.
- Schamberger, M.L.; O'Neil, L.J. 1986. Concepts and constraints of habitat model testing. In: Verner, J.; Morrison, M.L.; Ralph, C.J., eds. *Wildlife 2000: modeling habitat relationships of terrestrial vertebrates*. Madison, WI: University of Wisconsin Press: 5-10.
- Spies, T.A. 1998. Forest structure: a key to the ecosystem. In: Trofymow, J.A.; Mackinnon, A., eds. *Proceedings of a workshop on structure, process and diversity in successional forests of coastal British Columbia*. Northwest Science. 72 (special issue 2): 34-39.
- Spies, T.A.; Franklin, J.F. 1991. The structure of natural young, mature, and old-growth Douglas-fir forests. In: Ruggiero, L.F.; Aubry, K.B.; Carey, A.B.; Huff, M.H., tech. coords. *Wildlife and vegetation of unmanaged Douglas-fir forests*. Gen. Tech. Rep. PNW-GTR-285. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 91-110.
- Spies, T.A.; Reeves, G.H.; Burnett, K.M. [et al.]. 2002a. Assessing the ecological consequences of forest policies in a multi-ownership province in Oregon. In: Liu, J.; Taylor, W.W., eds. *Integrating landscape ecology into natural resource management*. Cambridge University Press.
- Spies, T.A.; Johnson, K.N.; Bettinger, P. [et al.]. 2002b. Challenges to integrating wood production, biodiversity, and other socioeconomic values at broad scales: an example from Coastal Oregon. In: Johnson, A.C.; Haynes, R.W.; Monserud, R.A., eds. *Congruent Management of Multiple Resources: A proceedings from the Wood Compatibility Workshop*; WA. Gen. Tech. Rep. PNW-GTR-563. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 13-25.
- Thomas, J.W. 1979. *Wildlife habitats in managed forests of the Blue Mountains of Oregon and Washington*. U. S. Forest Service Agricultural Handbook Number 5532. Washington DC. 512 p.
- Westra, L.; Miller, P.; Karr, J.R. [et al.]. 2000. Ecological integrity and the aims of the global integrity project. In: Pimentel, D.; Westra, L.; Noss, R.F., eds. *Ecological integrity: integrating environment, conservation, and health*. Washington, DC: Island Press: 19-44.
- Wimberly, M.A.; Spies, T.A.; Long, C.J.; Whitlock, C. 2000. Simulating historical variability in the amount of old forests in the Oregon Coast Range. *Conservation Biology*. 14(1): 167-180.

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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<sup>2</sup> 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 multi-resource 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.

## **ACKNOWLEDGMENTS**

The Wood Compatibility Initiative (WCI) gave opportunity to add an important dimension to work underway, to synthesize on-going work on several separate tracks, and to consider interactions from a tradeoffs perspective. We thank Keith Reynolds and Tom Spies for helpful comments. Publications and theses by Busing and Garman (2002); Berkley (2000); and Pennington (2002) were funded largely by WCI; and work reported by Weisberg and Swanson (in press) received significant support from the WCI, as did some field sampling for the Young Stand Thinning and Diversity study.

## **LITERATURE CITED**

- Berkley, E.L. 2000. Temporal and spatial variability of fire occurrence in western Oregon, A.D. 1200 to present. Eugene, OR: University of Oregon. 110 p. M.S. thesis.
- Busing, R.T.; Garman, S.L. 2002. Promoting old-growth characteristics and long-term wood production in Douglas-fir forests. *Forest Ecology and Management*. 160(2002): 161-175.

- Cissel, J.H.; Swanson, F.J.; Grant, G.E. [et al.]. 1998. A landscape plan based on historical fire regimes for a managed forest ecosystem: the Augusta Creek study. Gen. Tech. Rep. PNW-GTR-422. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 82 p.
- Cissel, J.H.; Swanson, F.J.; Weisberg, P.J. 1999. Landscape management using historical fire regimes: Blue River, Oregon. *Ecological Applications*. 9(4): 1217-1231.
- Daily, G.C. 1997. Nature's services: societal dependence on natural ecosystems. Washington, DC: Island Press. 392 p.
- Franklin, J.F.; Forman, R.T.T. 1987. Creating landscape patterns by forest cutting: ecological consequences and principles. *Landscape Ecology*. 1(1): 5-18.
- Garman, S.L.; Cissel, J.H.; Mayo, J.H. [In press]. Accelerating development of late-successional conditions in young managed Douglas-fir stands: a simulation study. Gen. Tech. Rep. PNW-GTR-557. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
- Garman, S.L.; Swanson, F.J.; Spies, T.A. 1999. Past, present, and future landscape patterns in the Douglas-fir region of the Pacific Northwest. In: J.A. Rochelle, L.A. Lehmann, J. Wisniewski (eds.). *Forest fragmentation: wildlife and management implications*. Brill. Boston. 61-86.
- Gunderson, L.J.; Holling, C.S.; Light, S.S. 1995. *Barriers and bridges to the renewal of ecosystems and institutions*. New York: Columbia University Press. 593 p.
- Holling, C.S. 2001. Understanding the complexity of economic, ecological, and social systems. *Ecosystems*. 4: 390-405.
- Hunter, M.L., Jr.; Jacobson, G.L., Jr.; Webb, T., III. 1988. Paleocology and the coarse-filter approach to maintaining biological diversity. *Conservation Biology*. 2: 375-385.
- Johnson, K.N.; Swanson, F.; Herring, M.; Greene, S. 1999. *Bioregional assessments: science at the crossroads of management and policy*. Washington, DC: Island Press. 395 p.
- Landres, P.B.; Morgan, P.; Swanson, F.J. 1999. Overview of the use of natural variability concepts in managing ecological systems. *Ecological Applications*. 9(4): 1179-1188.
- Morgan, P.; Aplet, G.H.; Haufler, J.B. [et al.]. 1994. Historical range of variability: a useful tool for evaluating ecosystem change. *Journal of Sustainable Forestry* 2: 87-111.
- Pennington, D.D. 2002. *Structural and functional comparison of human-induced and natural forest landscapes in the western Cascades of Oregon*. Oregon State University. PhD dissertation. 263 p.
- Spies, T.A.; Franklin, J.F. 1991. The structure of natural young, mature, and old-growth Douglas-fir forests in Oregon and Washington. In: Ruggiero, L.F.; Aubry, K.E.; Carey, A.B.; Huff, M.J., tech. eds. *Wildlife and vegetation of unmanaged Douglas-fir forests*. Gen. Tech. Rep. PNW-GTR-285. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 91-109.
- Spies, T.A.; Johnson, K.N.; Bettinger, P. [et al. 2002]. Challenges to integrating wood production, biodiversity, and other socioeconomic values at broad scales: an example from Coastal Oregon. In: Johnson, A.C.; Haynes, R.W.; Monserud, R.A.; eds. *Congruent Management of Multiple Resources: A proceedings from the Wood Compatibility Workshop*; Gen. Tech. Rep. PNW-GTR-563. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 13-25.
- Swanson, F.J.; Jones, J.A.; Wallin, D.O.; Cissel, J.H. 1994. Natural variability—implications for ecosystem management. In: Jensen, M.E.; Bourgeron, P.S., tech. eds. *Eastside Forest Ecosystem Health Assessment—Volume II: Ecosystem management: principles and applications*. Gen. Tech. Rep. PNW-GTR-318. Portland, OR: U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station: 89-106.
- Weisberg, P.J.; Swanson, F.J. [In press]. Regional synchronicity in fire regimes of western Oregon and Washington, USA. *Forest Ecology and Management*.

## DEVELOPMENT OF MIXED RED ALDER-CONIFER STANDS IN SOUTHEAST ALASKA

Robert L. Deal<sup>1</sup> and Ewa H. Orlikowska<sup>2</sup>

### 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 clear-cutting 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<sup>2</sup> 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

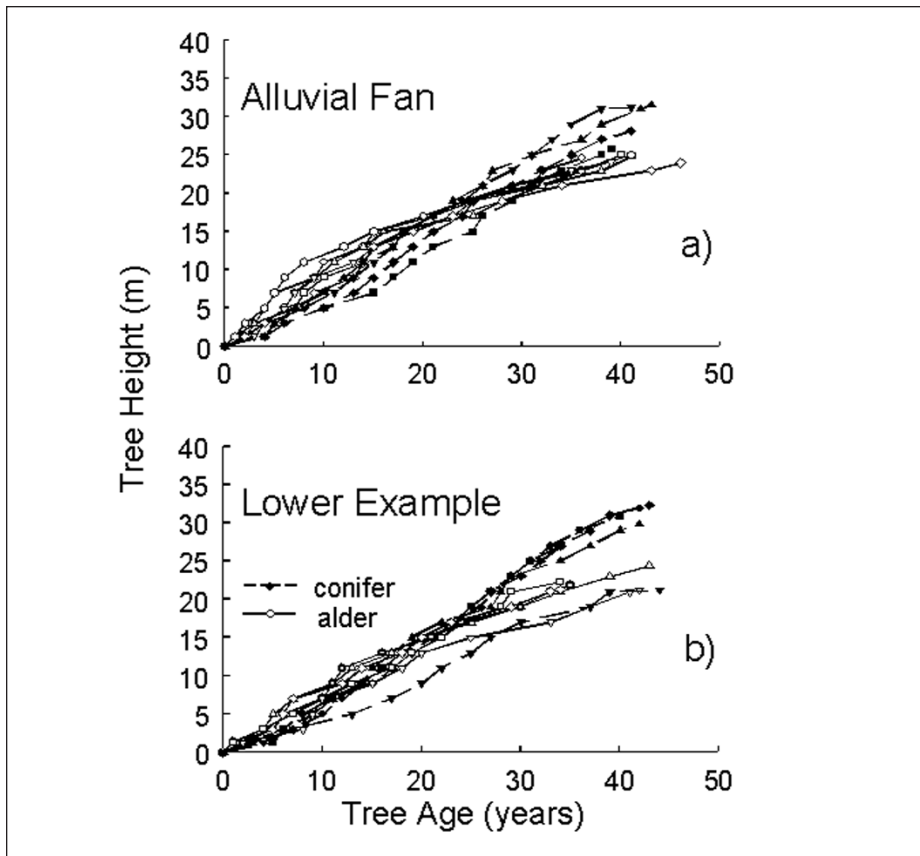


Figure 1—Tree height growth reconstructions for dominant red alders and conifers (Sitka spruce and western hemlock) at two of our research sites. The Alluvial Fan site (a) is a predominantly alder overstory stand, and the Lower Example site (b) is a conifer-dominated stand.

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**

| Data Set     | Species Diversity Measures |       |      |      |      |
|--------------|----------------------------|-------|------|------|------|
|              | 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 ( $E$ ) =  $H' / \ln(\text{Richness})$ , from (Pielou 1975); Diversity ( $H'$ ) =  $-\sum (p_i * \ln(p_i))$  where  $p_i$  = importance probability in element  $i$ , from (Shannon and Weaver 1949);  $D' = 1 - \sum (p_i)$  from (Shannon and Weaver 1949). The herb data set included herbaceous plants and ferns. The shrub data set included woody shrubs and tree seedlings.

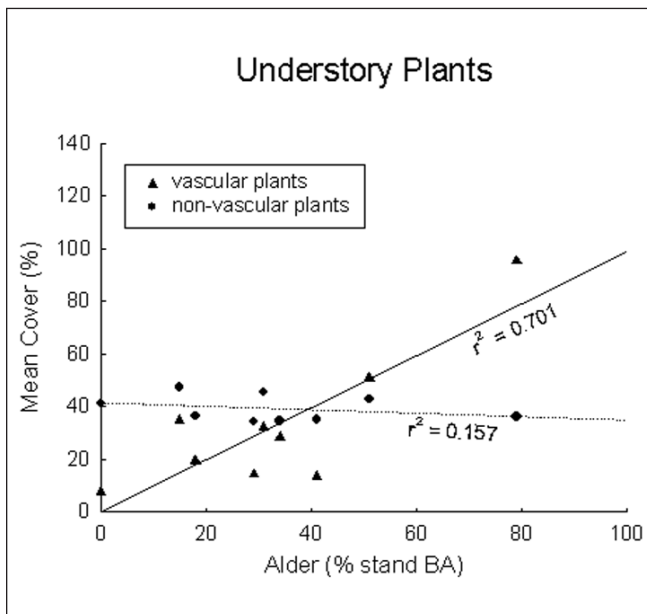


Figure 2—The mean canopy cover of vascular and non-vascular plants as a function of the proportion of alder basal area for all nine of our research sites combined.

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  $\text{m}^2 \text{ha}^{-1}$ ) than our sites (37-63  $\text{m}^2 \text{ha}^{-1}$ ) 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 Alluvial 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.

## ACKNOWLEDGEMENTS

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## LITERATURE CITED

- Alaback, P.B. 1982a. Dynamics of understory biomass in Sitka spruce-western hemlock forests of southeast Alaska. *Ecology*. 63(6): 1932-1948.
- Alaback, P.B. 1982b. Forest community structural change during secondary succession in southeast Alaska. In: Means, J.E., ed. *Proceedings of the Symposium: Forest Succession and Stand Development Research in the Northwest*. Oregon State University, Forestry Research Laboratory, Corvallis, OR: 70-79.
- Alaback, P.B. 1984. A comparison of old-growth forest structure in the western hemlock-Sitka spruce forests of southeast Alaska. In: Meehan, W.R.; Merrell, T.R.; Hanley, T.A., eds. *Fish and Wildlife Relationships in Old-Growth Forests*. Proceedings of a symposium. Juneau, AK: Alaska District, American Institute of Fishery Research Biologists; Northwest section, the Wildlife Society; Alaska Council on Science and Technology: 219-226.
- Deal, R.L. 1997. Understory plant diversity in riparian alder-conifer stands after logging in southeast Alaska. Res. Note. PNW-RN-523. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. 8 p.

- Deal, R.L.; Farr, W.A. 1994. Composition and development of conifer regeneration in thinned and unthinned natural stands of western hemlock and Sitka spruce in southeast Alaska. *Canadian Journal of Forest Research*. 24(5): 976-984.
- Dellasala, D.A.; Hagar, J.C.; Engel, K.A. [et al.]. 1996. Effects of silvicultural modifications of temperate rain-forest on breeding and wintering bird communities, Prince of Wales Island, Southeast Alaska. *Condor*. 98: 706-721.
- Hanley, T.A. 1993. Balancing economic development, biological conservation, and human culture: the Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) as an ecological indicator. *Biological Conservation*. 66: 61-67.
- Hanley, T.A. 1996. Small mammals of even-aged, red alder-conifer forests in southeastern Alaska. *Canadian Field Naturalist*. 110(4): 626-629.
- Hanley, T.A.; Barnard, J.C. 1998. Red alder, *Alnus rubra*, as a potential mitigating factor for wildlife habitat following clearcut logging in southeastern Alaska. *Canadian Field Naturalist*. 112(4): 647-652.
- Hanley, T.A.; Hoel, T. 1996. Species composition of old-growth and riparian Sitka spruce-western hemlock forests in southeastern Alaska. *Canadian Journal of Forest Research*. 26: 1703-1708.
- Harrington, C.A.; Zasada, J.C.; Allen, E.A. 1994. Biology of Red Alder (*Alnus rubra* Bong.). In: Hibbs, D.S., DeBell, D.S., Tarrant, R.F. eds. *The biology and management of Red Alder*. Corvallis, OR. Oregon State University Press: 3-22.
- Harris, A.S.; Farr, W.A. 1974. The Forest Ecosystem of southeast Alaska. 7. Forest ecology and timber management. Gen. Tech. Rep. PNW-GTR-25. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 109 p.
- Johnson, A.C.; Edwards, R. 2002. Physical and chemical processes in headwater channels. In: Johnson, A.C.; Haynes, R.W.; Monserud, R.A.; eds. *Congruent Management Multiple Resources: Proceedings of the Wood Compatibility Initiative*. Gen. Tech. Rep. PNW-GTR-563. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 101-108.
- Newton, M.; Cole, E. C. 1994. Stand development and successional implications: pure and mixed stands. In: Hibbs, D.S., DeBell, D.S., Tarrant, R.F. eds. *The biology and management of Red Alder*. Corvallis, OR. Oregon State University Press: 106-115.
- Pielou, E.C. 1975. *Ecological diversity*. John Wiley & Sons, New York. 165 p.
- Ruth, R.H.; Harris, A.S. 1979. Management of western hemlock-Sitka spruce forests for timber production. Gen. Tech. Rep. PNW-GTR-88. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 197 p.
- Schoen, J.W.; Kirchhoff, M.D.; Hughes, J.H. 1988. Wildlife and old-growth forests in southeastern Alaska. *Natural Areas Journal*. 8: 138-145.
- Schoen, J.W.; Wallmo, O.C.; Kirchhoff, M.D. 1981. Wildlife-forest relationships: is a reevaluation necessary? *Transactions of the North American Wildlife and Natural Resources Conference*. 46: 531-544.
- Shannon, C.E.; Weaver, W. 1949. *The mathematical theory of communication*. University of Illinois Press, Urbana, IL. 117 p.
- Tappeiner, J.C. II; Alaback, P.B. 1989. Early establishment and vegetative growth of understory species in the western hemlock-Sitka spruce forests of Southeast Alaska. *Canadian Journal of Botany*. 67: 318-326.
- Thedinga, J.F.; Murphy, M.L., Heifetz, J. [et al.]. 1989. Effects of logging on size and age composition of juvenile coho salmon (*Oncorhynchus kisutch*) and density of pre-smolts in southeast Alaska streams. *Canadian Journal of Fisheries and Aquatic Sciences*. 46: 1383-1391.
- Wallmo, O.C.; Schoen, J.W. 1980. Response of deer to secondary forest succession in southeast Alaska. *Ecology*. 26(3): 448-462.
- Worthington, N.P., Ruth, R.H., Matson, E.E. 1962. Red alder: its management and utilization. Vol. 881. Washington, D.C.: U.S. Department of Agriculture Forest Service. 44 p.

continue



*SECTION D*  
**SILVICULTURE  
STUDIES**

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## **DO LARGE TREES ALWAYS HAVE HIGHER WOOD PRODUCT VALUE?**

R. James Barbour<sup>1</sup>, David D. Marshall<sup>2</sup>, Dean L. Parry<sup>3</sup>, and Glenn Christensen<sup>4</sup>

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### **ABSTRACT**

When the Northwest Forest Plan for the Recovery of the Northern Spotted Owl (NWFP) and associated species was established in 1994, it shifted federal land management emphasis toward noncommodity outputs. Since then, forest practices on state land in Oregon and Washington were also modified to emphasize resources other than timber. At the same time, commercial forest owners have moved to shorter rotations and most of the region's sawmills have been retooled to process smaller (< 24 inch, 61 cm) logs. Management plans for public land allow a variety of management activities, some of which may remove trees that are 50 to 120 years old and 20 or more inches (51 cm) in diameter at breast height (dbh). It is likely that these trees are larger and older than those removed from private land but because of their relatively young age, they might not necessarily yield higher value wood products. Some of the logs cut from these trees might also be too large to process in the region's sawmills making them less attractive to potential buyers. We used empirical wood product recovery data to conduct an analysis to contrast the economic value of 20 to 30 inch (51 to 76 cm) dbh trees in the 50 to 80 year and 100 to 150 year age classes. The purpose of this analysis was to illustrate the importance of age in controlling economic value in trees of the same size. The older trees had dollar values of as much as 55% higher per board foot than the younger trees. This analysis suggests that some of proposed treatments on public land will result in trees that could be difficult to market to the region's wood processors and, therefore, might not provide the economic returns anticipated under the Northwest Forest Plan or by state forestry plans in Oregon and Washington.

**KEY WORDS:** Wood quality, silviculture, wood products, lumber, western Oregon and Washington.

### **INTRODUCTION**

Forest management practices on public and private land in western Oregon and Washington are diverging. This could potentially create a dichotomy in the wood characteristics of the resource which might influence the economic value and marketability of timber harvested by various owners. Federal land is now mainly managed to emphasize non-commodity outputs with recognition that removal of some commodities is important to local communities (USDA and USDI 1994). State lands in both Washington (Belcher 2001) and Oregon (Paul and Kendy 1999) still carry a mandate to produce revenues for public programs, such as education, but management practices now place more emphasis on a range of outputs in addition to financial returns. Private industrial landowners want to maintain as much freedom to manage their lands as possible but they also recognize the importance of public opinion in shaping

forest practices laws. As a result, they constantly search for management options that justify their investment while also protecting the non-economic outputs that the public identifies as important for good land stewardship on private land.

These differences in broad management objectives could result in removal of timber with noticeably different characteristics from each land ownership category. Private industrial landowners will generally produce smaller, younger timber with rotation ages usually between 40 and 60 years (Briggs and Trobaugh 2001). Trees from these lands will typically have maximum breast-height diameters of 20 inches (51 cm) or less. Much of the timber produced from federal and state land over the next two decades will come from thinnings applied in young plantations. This timber will readily blend with the timber from private lands. At some point in the future, federal and state land managers could begin to implement treatments in some stands that

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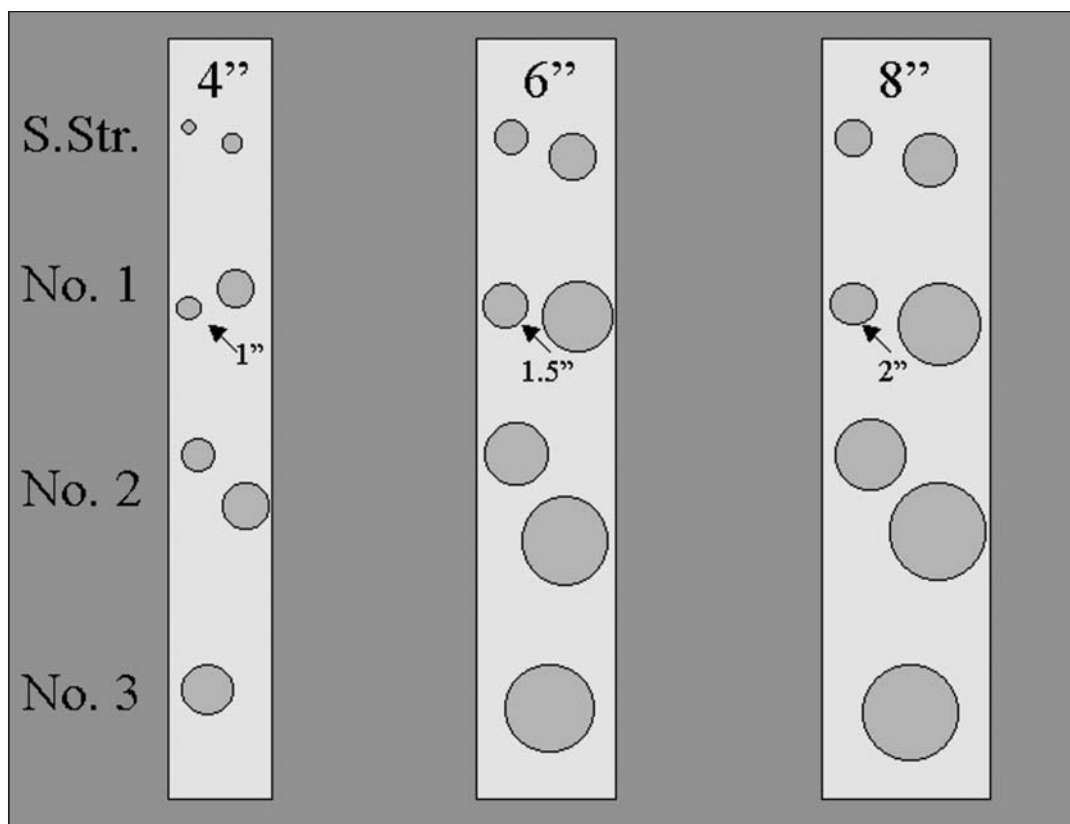


Figure 1—Influence of lumber width on acceptable knot size measurements based on the American Lumber Standards (Western Wood Products Association 1998).

remove older larger trees. These treatments will probably be designed to enhance or maintain habitat for late successional species. Various management scenarios accomplish this through combinations of group selections, uniform thinnings, variable density thinnings, and extended rotations (Curtis et al. 1998; Emmingham 1996; Carey et al. 1996). Although many forest managers feel that given the current political climate, cutting treatments will never be applied in these older stands, we feel it is prudent to examine scenarios where cutting does occur to test some of the basic assumptions of the Northwest Forest Plan (USDA and USDI 1994) or state management plans and to inform future policy debates. Our full analysis will consider the actions of all landowner classes and the likely outcomes in terms of wood characteristics, wood product potential, and volume. The analysis presented here covers only Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) trees in the 20 to 30 inch (51 to 76 cm) diameter class. Combining this analysis with information on anticipated

volumes from different landowner classes will allow evaluation of how the structure of the wood products industry might change through time.

When developing management alternatives for the NWFP, a key assumption was that the larger older timber removed would have a higher economic value than the young trees grown on state and private land and that eventually the sale of these larger trees would enable non-timber related management activities. Presumably these large trees might come from sources such as: group selections in 80 to 120 year old stands in matrix land<sup>5</sup>, final thinnings in 50 to 80 year-old stands in late successional reserves<sup>6</sup>, regeneration harvests on state and private lands, hazard tree removal, clearing for development on all ownerships, etc.

The stand ages where these types of treatments are anticipated coincide with an important transition in Douglas-fir wood characteristics. Trees from unmanaged Douglas-

<sup>5</sup> The "matrix" as defined under the Northwest Forest Plan is the land between the other land allocations and it is where most timber management is expected.

<sup>6</sup> Late Successional Reserves (LSRs) are areas designated under the NWFP to support species associated with late successional forests.

fir stands younger than about 80 years old are generally suitable for manufacture of structural wood products but do not usually yield significant volumes of high value appearance products. This is because Douglas-fir trees from unmanaged stands do not typically shed the branches on their lower stems until at least age 80 (Kachin 1940). When stand density is managed from a young age, slower crown recession can further delay the loss of lower stem branches. Three recent studies suggest that young stand management could postpone the transition in wood product potential until stands are more than 100 years old depending on intensity of treatments and whether branches are pruned (Briggs and Fight 1992; Christensen 1997; Barbour and Parry 2001).

It is also likely that some of the logs manufactured from trees over 60 years old that were grown on high site class land will be too large to process in most of the region's sawmills (Christensen 1997; Barbour and Parry 2001). An effective maximum large end diameter of 24 inches (61 cm) is becoming common, although there are still a few mills that can handle 30 inch logs and at least two that can process logs up to 50 inches. Given the types of raw material available from private land, it seems unlikely that these mills will retain the capability to process larger logs for long.

In addition to retooling sawmills to efficiently process smaller logs, the forest products industry is rapidly turning to engineered wood products, like glue laminated beams and wood I-beams, to replace wider widths of solid lumber (i.e., >8 inches; 20 cm). For example, in recent years, wood I-beams captured much of the market once held by solid sawn floor joists (Fleishman et al. 2000). Substitution of engineered wood products into structural lumber markets, where wide lumber is currently used, erodes a class of moderately high valued products for large trees with good structural characteristics but not suited for appearance products. Such trees tend to have larger and more numerous knots. These are often tolerated in wide lumber but not narrow lumber. Figure 1 illustrates the interaction of knot size and lumber width in determining structural lumber grades. This relation helps to explain why markets for wide lumber widths are necessary to produce structural lumber grades from large logs with large branches.

Log size, together with the number and size of knots, is therefore important for determining the mix of products manufactured from a given resource. The way public and private landowners choose to manage stand density will influence both stem size and the number and size of knots

(Briggs and Fight 1992). In this analysis, we compare differences in lumber grades that are potentially expected from large trees with different ages and management histories. Specifically, we use data from empirical wood product recovery studies to illustrate the product options that are possible from large trees grown under different management scenarios. Subsequent analyses should examine the volumes of logs in different size and quality classes to provide information about the potential structure of the region's future industry.

## METHODS

We summarized results from two empirical wood product recovery studies for Douglas-fir that were conducted by the USDA, Forest Service, Pacific Northwest Research Station. The data selected from these studies included trees varying in age but approximately the same size. The first data set came from a variety of natural stands located from west of Salem and south to Medford, in Oregon's coast range. They were harvested and processed in 1981 (Willits and Fahey 1988). Trees in these stands ranged from about 100 years old to more than 350 years old. The trees in the 20 to 30 inch (51 to 76 cm) diameter range selected for this analysis varied in age from about 100 to about 150 years old. This data set is referred to as T100 to signify that most of the trees were 100 years old or older. The second data set used 20 to 30 inch trees that came from a variety of stands located throughout western Oregon and Washington with ages ranging from about 35 to about 80 years old. Their selection followed an exhaustive search for stands that represented characteristics expected from managed stands. They were harvested and processed in 1987 (Fahey et al. 1991). This data set is referred to as T50 to indicate that the average age of the trees was about 50 years old. While the selected trees represent what is expected from young managed stands, they are somewhat conservative in their representation of more intensively managed plantations that include wider initial spacings and early control of competing vegetation.

Data from the two wood product recovery studies included a log-by-log accounting of the volume and grade of each piece of lumber recovered from every tree. Lumber recovery data were summarized by five-inch breast height diameter classes and reported as percent of lumber volume in each grade group. The sawmills used in each of the wood product recovery studies cut a different set of lumber sizes and grades making it impossible to compare results directly. It is, however, reasonable to combine the lumber grades into logical grade groups and compare the percent yield of

**Table 1—Average stump ring counts by tree breast height diameter for trees included in this analysis**

| Tree breast height diameter class | Average stump ring count |     |
|-----------------------------------|--------------------------|-----|
|                                   | T100                     | T50 |
| 20 in (50 cm)                     | 95                       | 51  |
| 25 in (64 cm)                     | 119                      | 52  |
| 30 in (76 cm)                     | 154                      | 56  |

appearance, structural, and low quality lumber. Appearance quality lumber was defined as lumber that is used for appearance purposes. This included grades such as Selects and Finish (pieces with no or few knots), upper grades of Factory lumber (No. 3 and Better Shop), and Moulding. Structural quality lumber was defined as lumber that is used for structural or other general construction purposes and included grades such as Select Structural, No. 2 and Better dimension lumber, and No. 4 and Better Commons. Low quality lumber was defined as lumber that does not meet the criteria for the other two groups. It included categories such as shop out<sup>7</sup> and grades such as No. 5 Common, Utility, and Economy. For detailed descriptions of these grades see the Western Wood Products Association (1998) grading rules.

A third set of data was taken from a wood product recovery study designed to illustrate the effect of sawing lumber of various widths from logs with different diameters. These data come from a collaborative study between the USDA, Forest Service, Pacific Northwest Research Station and the New Zealand Forest Research institute that examined 50 year-old plantation-grown Douglas-fir from New Zealand (Kimberley et al. 1995; McConchie et al. 1995).

## RESULTS AND DISCUSSION

### Influence of Age

The age of the older T100 trees increased substantially over the target diameter range (Table 1). Although there is no documented stand level information for the T100 trees, based on their age and when the study was conducted it is likely that they came from mature and old-growth stands that developed without management. The relation between tree age and diameter for the trees in the study from which the T100 trees were selected (Figure 2) is similar to that

found in old-growth stands in the Oregon coast range by Tappeiner et al. (1997). Tappeiner et al. (1997) showed that old-growth stands can have a wide range of tree ages, diameters and growth rates, but in most cases the growth rates of the main canopy trees were greater than the under-story trees. The trees selected for this analysis presumably came from the younger cohorts and therefore probably had slower growth rates than the main canopy trees.

In contrast, the average age of the younger T50 trees remained fairly constant across the range of diameters (Table 1). The similarity in diameters across the age range represented in the data set is likely the result of differences in site productivity or initial stand density and from pre-commercial or commercial thinning treatments. All of these trees were, however, fairly rapidly grown as compared to the T100 trees.

### Influence of Knots

The wood quality characteristics of interest in Douglas-fir trees less than 200 years old are usually related to the initial growth rate (juvenile wood proportion), stem form, and presence or absence of branches and the condition of branch stubs. All of the trees selected for both studies were straight and generally free from obvious external defects (Willits and Fahey 1988; Fahey et al. 1991). This means that the size and number of knots is the main quality concern in these types of trees. The change in quality over time associated with branches can be thought of as a step function where knot free straight-grained (clear) wood is the best quality and wood containing dead loose (black) knots or holes is considered the worst quality (i.e., clear wood > live knots > tight dead knots > loose black knots or knot holes). This step function is firmly ingrained in the logic used in developing lumber grading rules (for rules see Western Wood Products Association 1998). At young ages (less than 200 or 300 years), time improves quality in Douglas-fir. In slowly growing trees, there is plenty of time for dead branches to fall before stem diameter growth overgrows dead branches. This reduces the amount of wood with knotholes or black knots. Rapidly growing young trees will, however, tend to overgrow more length of branches before they are shed. This simplified explanation does not account for the interactions among branch stub length and condition (i.e., smooth or rough), branch diameter, stem diameter, and growth rate documented for pruned Douglas-fir (Petruncio et al. 1997) and other species (Gosnell 1987). Nonetheless, the wide age range in the T100 trees is expected to have a positive influence on quality, as measured by

<sup>7</sup> Lumber manufactured to thickness appropriate for Factory lumber but not meeting the requirements for the No. 3 Shop grade.

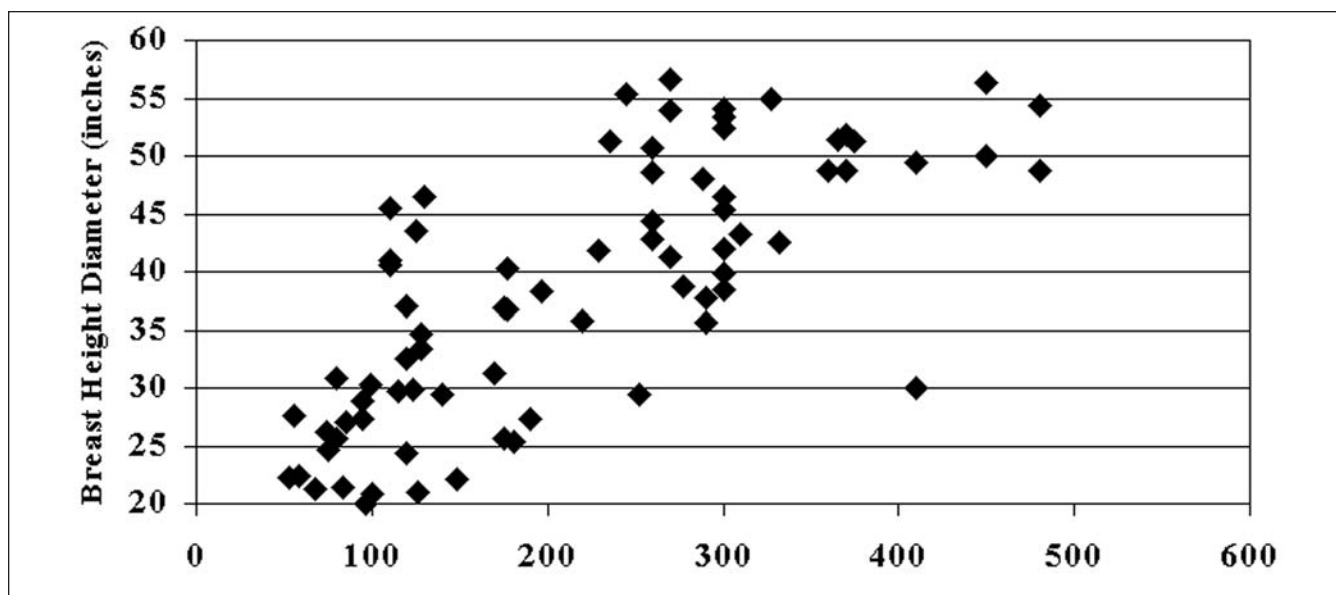


Figure 2—Breast height diameter in inches versus stump ring count for all trees with ages from the T100 data set (Willits and Fahey 1987). These trees display a diameter to age relation similar to that described for old-growth stands in Oregon's Coast Range by Tappeiner et al. (1997).

Table 2—Average percent lumber grade yield by broad grade groups and study

| Tree diameter<br>class (inches) | Study T100 |            |                | Study T50  |            |                |
|---------------------------------|------------|------------|----------------|------------|------------|----------------|
|                                 | Appearance | Structural | Low<br>quality | Appearance | Structural | Low<br>quality |
| 20                              | 10.4       | 75.1       | 13.7           | 0.4        | 68.6       | 30.7           |
| 25                              | 9.6        | 79.0       | 11.4           | 0.1        | 59.3       | 40.3           |
| 30                              | 14.2       | 71.1       | 14.2           | 0.0        | 40.1       | 59.7           |

knots and their condition, while the young ages and narrow age range of the T50 trees would tend to amplify the negative influence of branches.

We did not include juvenile wood in the analysis because no information on initial growth rate was available for the T100 trees. However, the T100 trees might have less juvenile wood as a proportion of their volume than the T50 trees. They came from the youngest age cohort in the sample (Figure 2) and probably occupied less dominant canopy positions. This suggests that they grew more slowly making their juvenile cores smaller than the rapidly grown T50 trees.

#### Lumber Grade Yields

Age is apparently an important factor in determining the visual lumber grade yield for trees of the same size (Table 2).

The older T100 trees yielded far more appearance grade lumber, more structural lumber, and much less low quality lumber than the younger T50 trees. There is a weak ( $r^2$  0.35) but highly significant ( $p < 0.0001$ ) linear relation between proportion of appearance grade lumber and age for the T100 trees. This suggests that quality improves over time perhaps because of the occlusion of knots. On the other hand, the amount of low quality lumber increased with increasing diameter in the younger T50 trees (Table 2). This suggests that the branch size increased with diameter in these trees.

It is likely that the way the T50 trees were sawn overstates the amount of low quality lumber but it is unlikely that it greatly reduced the amount of appearance grade lumber. This is because six-inch lumber was the widest width lumber sawn from any log, regardless of its diameter

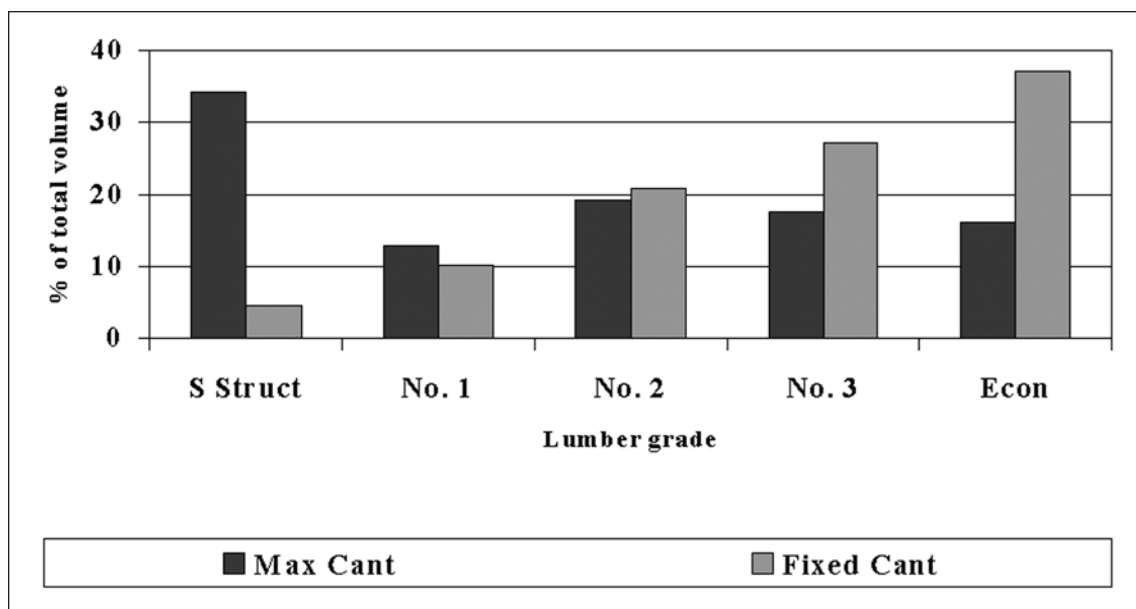


Figure 3—Effect sawing pattern on lumber grade from plantation-grown Douglas-fir logs greater than 20 inches in diameter when they are sawn to a fixed 4 and 6 inch cant widths or to the maximum cant that would fit into the log up to 12 inches (data from McConchie et al. 1995, Kimberley et al. 1995).

(Fahey et al. 1991). This sawing strategy over emphasizes the importance of knots in structural lumber grades but tends to produce more pieces with few or no knots because of the narrow widths. It also gives a better estimate of the suitability of the material for engineered wood products because six inches is the widest width commonly used in many of these products.

The importance of lumber width is illustrated in Figure 3. This figure represents results where one set of logs was sawn to a fixed lumber width of four or six inches regardless of log diameter. Another set of logs was sawn to remove the widest lumber possible, up to 12 inches, from each log (Kimberley et al. 1995; McConchie et al. 1995). The results clearly demonstrate the negative affect of sawing narrow lumber from large logs, especially those with large branches. They suggest that such logs are not well suited for use in engineered wood products that require high quality four and six-inch dimension lumber.

The results illustrate the point that large young trees grown in ways that maintain fast growth rates might not yield much in the way of high value wood products. These results, however, are not definitive because there were numerous differences in the design and implementation of the empirical studies, the groups of trees were not paired, and the target products from each mill was different. The results do suggest that alternatives to the NWFP that result in harvest of older trees grown under relatively conserva-

tive regimes (Carey et al. 1996; Cissel et al. 1999) could result in timber with a wider range of product potential and, therefore, greater economic value, than those grown under the current Northwest Forest Plan.

### Financial Implications

The financial implications of large knots and other factors associated with fast growth in young stands are illustrated in Figures 4 and 5. Figure 4 contains average lumber grade yields, while gross product values for lumber from the T50 and T100 trees plus a third scenario (50MAX) are presented in Figure 5. The 50MAX scenario uses the appearance grade results from the T50 scenario but reduces the low quality lumber to 10%. The 50MAX scenario represents a rule of thumb commonly applied in the sawmilling industry that an average mill should produce at least 90% Standard and Better or Number 2 and Better lumber. This scenario reflects the minimum grade yields expected from a mill that was free to maximize grade yield by changing lumber width, edging, and trimming. The T50 result could be thought of as a worst-case scenario where the market for wide lumber has disappeared because of continuation of the shift to engineered wood products.

The T100 trees receive a 54% premium when compared to the less optimistic T50 scenario and a 16% premium in comparison the more optimistic 50MAX scenario (Table 2). These results highlight the importance of appearance grade lumber in influencing gross product value per thousand

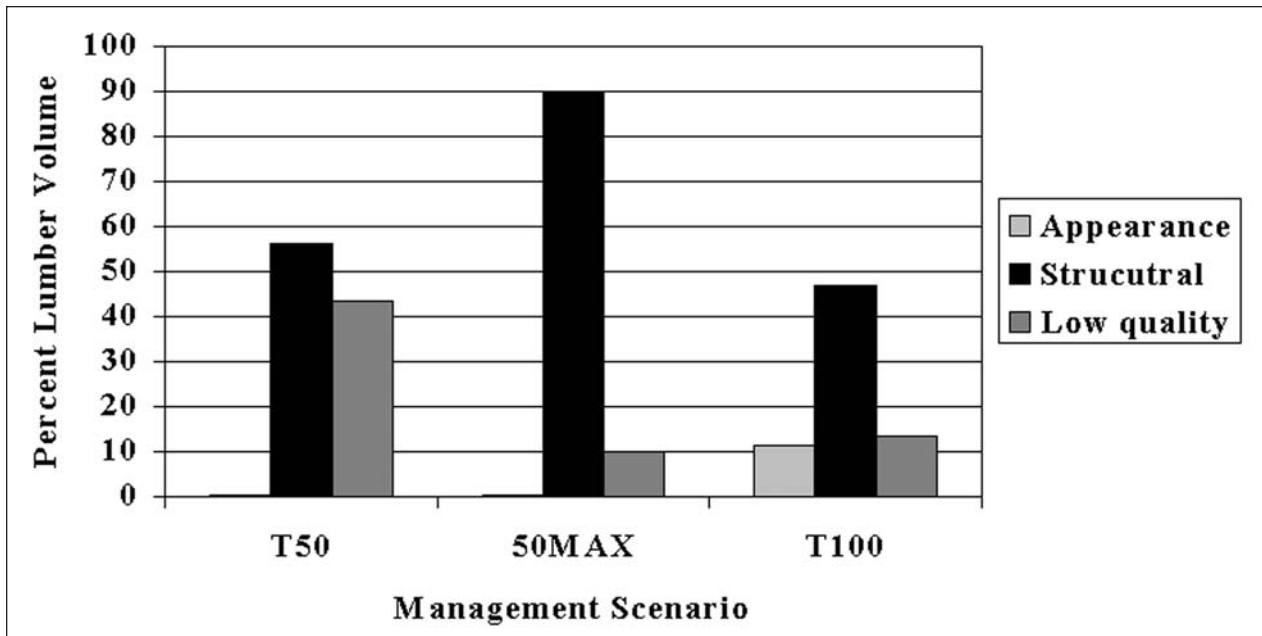


Figure 4—Percent lumber volume for each of three management scenarios used to demonstrate the financial implications of high and low quality lumber (see Figure 3). The T50 represents actual data for large 50 year-old trees sawn into 4 and 6 inch dimension lumber, 50MAX represents the likely yield if the mill had sawn to wider widths and maximized grade with edging and trimming.

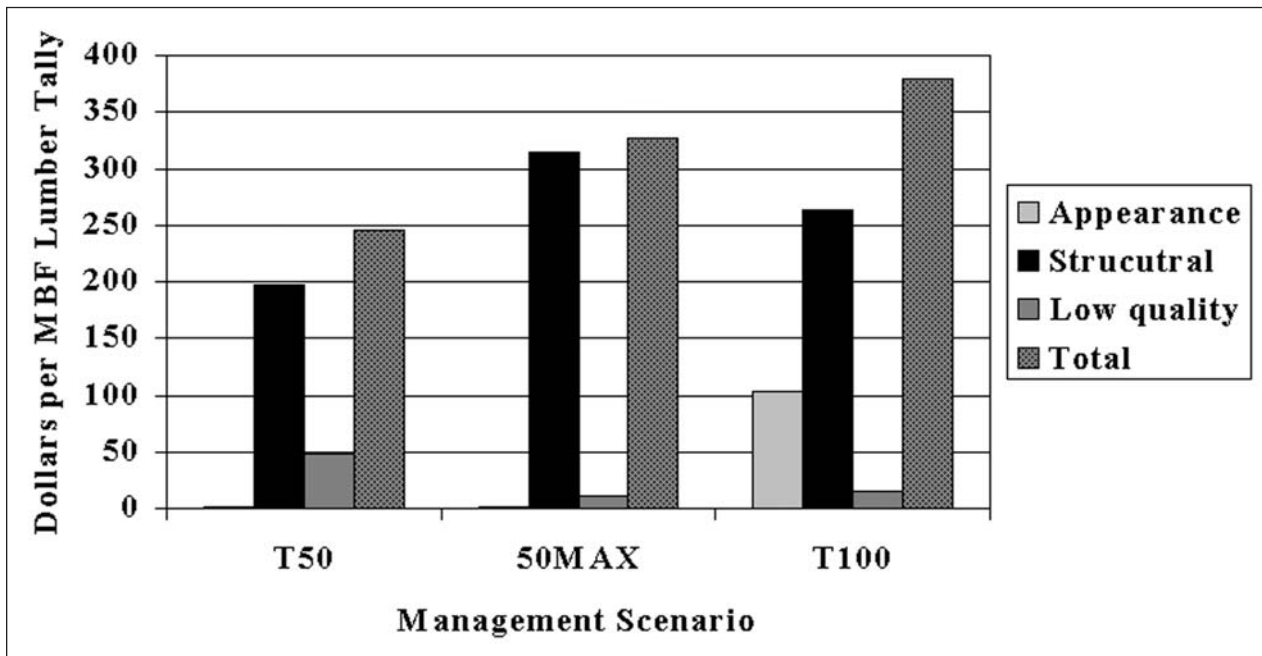


Figure 5—Gross product value for lumber recovered under three management scenarios. The T50 and T100 scenarios represent the gross product value for the corresponding data sets described in the text. The 50MAX scenario represents the T50 scenario where low quality lumber volume was reduced to 10% to represent a mill with discretion on lumber width, trimming, and edging decisions.

board feet (MBF) of lumber. This example does not consider any costs or revenues from chips, sawdust, or bark. It does, however, help to show how tree characteristics, particularly branchiness, might influence economic value by demonstrating broad product classes to which trees grown under different conditions are suited.

The results seen here support conclusions from analyses conducted by Briggs and Fight (1992); Barbour et al. (1997); and Barbour and Parry (2001). Empirical results for log grades from long term thinning trials in 80 to 100 year old stands considered by Barbour and Parry (2001) also suggest that it is possible to maintain good growth rates, produce large trees, and maintain relatively high quality if thinnings are implemented after crowns have receded above the first 40 ft log. Barbour and Parry (2001) examined trees from two trials, one received a series of light to moderate basal area removals the other involved more aggressive thinning that began at an earlier age (Curtis 1995). The yield of high quality logs from the less aggressively thinned trial was better than from the more aggressively thinned trial. Trees from both of those trials, however, had much smaller branches and slower growth rates than those projected by Barbour et al. (1997) for the very early heavy thinning trials (initial entries at ages 15 and 30 to 30 and 60 trees per acre) that were implemented by the Coastal Oregon Productivity Enhancement (COPE) program (Emmingham 1996). These earlier, heavier, thinnings were designed to rapidly develop old stand structures in young uniformly spaced plantations on National Forests in Oregon's Coast Range (Emmingham 1996).

When all of the available information is considered, it seems likely that the characteristics of trees harvested from 80 to 100 year old stands on federal and state land will be suitable for structural products but will probably only yield small volumes of appearance grade products. As a result, these trees will probably have a similar per unit volume gross product value to the 40 to 60 year old trees that are harvested from industrial land. In addition, if current trends in mill design continue, future price discounts for large logs are likely. This will further reduce the economic value of large trees with characteristics that make them suitable for structural products but not for appearance products.

On the other hand, if attention is paid to product potential and a high proportion of the volume from large trees was in logs, such as those from the later lighter thinning trials described by Barbour and Parry (2001), their processing might not be a problem. Sufficient supply of larger,

higher value logs might spur wood processors to find innovative manufacturing options to recover the high value material from the older more slowly grown trees. Alternatives to the existing Standards and Guidelines in the Record of Decision for the NWFP (USDA and USDI 1994) such as those suggested by Cissel et al. (1999) or Carey et al. (1996) might yield large trees with these more desirable characteristics and also meet the other objectives of the NWFP.

## CONCLUSIONS

Early stand tending (before age 40) is important in determining if larger (>24 inches; 61 cm dbh) Douglas-fir trees harvested at ages 50 and up will have characteristics that make them suitable for higher value appearance grades of lumber and veneer or whether they will only be suited for structural wood products. This analysis suggests that trees from stands where long crowns were maintained either by wide initial spacing or early thinning will not be suited for production of appearance products. The trend toward more efficient sawmills that process logs with maximum large end diameters of less than 24 inches, the decline of the veneer industry, and the trend toward engineered wood products all suggest that such trees will not be in demand by the wood products industry. The validity of this conclusion and its importance to landowners who grow large trees depends on the volume of these trees that is available on an annual basis and their distributions across the landscape. This analysis did not provide estimates of the expected volumes of large logs in the region and this information will be necessary before wood processors can determine if investing in manufacturing facilities that can handle them is justified.

## LITERATURE CITED

- Barbour, R.J.; Parry, D.L. 2001. Log and lumber grades as indicators of wood quality in 20- to 100-year-old Douglas-fir trees from thinned and unthinned stands. Gen. Tech. Rep. PNW-GTR-510. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.
- Barbour, R.J.; Johnston, S.; Hayes, J.P.; Tucker, G.F. 1997. Simulated stand characteristics and wood product yields from Douglas-fir plantations managed for ecosystem objectives. *Forest Ecology and Management*. 91: 205-219.

- Belcher, J.M. 2001. Turning the ship around. *Conservation Biology in Practice* 2(4): 17-23.
- Briggs, D.G.; Fight, R.D. 1992. Assessing the effects of silvicultural practices on product quality and value of coast Douglas-fir trees. *Forest Products Journal*. 42: 40-46.
- Briggs, D.G.; Trobaugh, J. 2001. Management practices on Pacific Northwest west-side industrial forest lands, 1991-2000: with projections to 2005. Stand Management Cooperative, College of Forest Resources, University of Washington, Seattle, WA. SMC Working Paper No. 2.
- Carey, A.B.; Elliot, C.; Lippke, B.R.; Sessions, J. [et al.] 1996. Washington Forest Landscape Management Project: a pragmatic, ecological approach to small-landscape management. Washington State Department of Natural Resources, Olympia, WA. Washington Forest Landscape Management Project Report No. 2. 99 p.
- Christensen, G.A. 1997. Development of Douglas-fir log quality, product yield, and stand value after repeated thinnings in western Oregon. Corvallis, OR: Oregon State University. 176 p. M.S. thesis.
- Cissel, J.H.; Swanson, F.J.; Weisberg, P.J. 1999. Landscape management using historical fire regimes: Blue River, Oregon. *Ecological Applications*. 9(4): 1217-1231.
- Curtis, R.O. 1995. Extended rotations and culmination age of coast Douglas-fir: old studies speak to current issues. Res. Pap. PNW-RP-485. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 49 p.
- Curtis, R.O.; DeBell, D.S.; Harrington, C.A. [et al.]. 1998. Silviculture for multiple objectives in the Douglas-fir region. Gen. Tech. Rep. PNW-GTR-435. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 123 p.
- Emmingham, W.H. 1996. Commercial thinning and underplanting to enhance structural diversity of young Douglas-fir stands in the Oregon Coast Range: an establishment report and update on preliminary results. COPE Report (Coastal Oregon Productivity Enhancement Program) 9 2/3. Corvallis, OR: Oregon State University: 2-4.
- Fahey, T.D.; Cahill, J.M.; Snellgrove, T.A.; Heath, L.S. 1991. Lumber and veneer recovery from intensively managed young-growth Douglas-fir. Res. Pap. PNW-RP-437. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 25 p.
- Fleishman, S.J.; Eastin, I.L.; Shook, S.R. 2000. Material substitution trends in residential construction, 1995 vs. 1998. University of Washington, Seattle, WA. Center for International Trade in Forestry (CINTRAFOR), Working Paper WP73. 76 p.
- Gosnell, T. 1987. Equations for predicting defect core size for pruned radiata pine butt logs. New Zealand Ministry for Forest Research, Rotorua, New Zealand. Forest Research Institute Bulletin. No. 131.
- Kachin, T. 1940. Natural pruning in second-growth Douglas-fir. Res. Note 31. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station.
- Kimberley, M.O.; McConchie, D.L.; McKinley, R.B.; Barbour, R.J. 1995. Relating site and silviculture to yield and value of Douglas-fir: Douglas-fir sawing study- unpruned logs. Part 1-grade recovery and conversion. Rotorua, New Zealand. New Zealand Forest Research Institute Report No. Pacific Northwest 93-025-2.
- McConchie, D.L.; Barbour, R.J.; McKinley, R.B. [et al.]. 1995. Relating site and silviculture to yield and value of Douglas-fir: Douglas-fir sawing study- unpruned logs. Part 1: Grade recovery and conversion. Rotorua, New Zealand. New Zealand Forest Research Institute FRI Report No. Pacific Northwest 93-025-1.
- Paul, J.T.; Kendy, E. 1999. Integrating science into the Oregon forest practices policy-making process: a case study. Science into policy: water in the public realm. In: Proceedings, Speciality Conference, Bozeman, Montana, USA, June 30 - July 2, 1999, 55-60. American Water Resources Association (AWRA); Middleburg, PA.
- Petruncio, M.; Briggs, D.; Barbour, R.J. 1997. Predicting pruned branch stub occlusion in young, coastal Douglas-fir. *Canadian Journal of Forest Research*. 27: 1074-1082.

- Tappeiner, J.C.; Huffman, D.; Marshall, D. [et al.]. 1997. Density, ages, and growth rates in old-growth and young-growth forests in coastal Oregon. *Canadian Journal of Forest Research*. 27(5): 638-648.
- U.S. Department of Agriculture; U.S. Department of the Interior. 1994. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl. [Place of publication unknown]. 74 p. [plus Attachment A: standards and guidelines].
- Western Wood Products Association. 1998. Western lumber grading rules 98. Portland, OR. Western Wood Products Association. 248 p.
- Willits, S.; Fahey, T.D. 1988. Lumber recovery of Douglas-fir from the Coast and Cascade ranges of Oregon and Washington. Portland, OR. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Research Paper. PNW-RP-400. 32 p.

## STEM CHARACTERISTICS AND WOOD PROPERTIES: ESSENTIAL CONSIDERATIONS IN SUSTAINABLE MULTIPURPOSE FORESTRY REGIMES

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### ABSTRACT

The management of forest resources in the Pacific Northwest has changed greatly since the first harvests of large-diameter old-growth trees to the more recent harvests of younger, small diameter trees grown in plantations managed for rapid growth and wood production. This change continues with an increased emphasis on managing for both wood production and a range of other objectives, including aesthetics, wildlife habitat and other nontimber values. Much of our accumulated silvicultural knowledge can help in developing regimes to meet these new goals, however, these alternative regimes may produce trees and wood with very different characteristics than in the past. This could have large impacts on value. To date, only minor attention is placed on the impacts of silvicultural practices on wood quality, especially for species other than Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco). We provide four examples using research on western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), red alder (*Alnus rubra* Bong.), black cottonwood (*Populus trichocarpa* Torr. & Gray) (and hybrid poplar) and western redcedar (*Thuja plicata* Donn.) to demonstrate how silvicultural practices can alter stem characteristics and wood properties.

**KEY WORDS:** Wood quality, Douglas-fir, (*Pseudotsuga menziesii*), western hemlock, (*Tsuga heterophylla*), red alder, (*Alnus rubra*), black cottonwood, (*Populus trichocarpa*), western redcedar, (*Thuja plicata*).

### INTRODUCTION

The vast forests that early settlers found in the Pacific Northwest provided the basis for a large forest products industry. For the first century of its existence, raw materials to supply this wood processing industry came primarily from the harvest of these existing older forests. Over the past several decades, however, the forest industry in the region has been in transition. Beginning in the 1950s, a shift began from reliance on Douglas-fir from naturally grown, primarily old-growth stands, to younger natural forests, and then to managed Douglas-fir plantations. These changes are accompanied and influenced by research and development of plantation establishment practices, spacing guidelines, fertilization and improved genetic stock. More recently, numerous events in the region have prompted further changes to occur. These changes include an increased importance of more species and a greater emphasis on forest

derived values other than wood production via multi-purpose forest management regimes.

Although most of the technology of forest management was developed with the goal of enhanced wood production (Curtis and Carey 1996), the various silvicultural practices can be readily modified to meet a broad range of multiple objectives (Curtis et al. 1998). The values that society seeks from such multi-purpose forestry may include commodity or non-commodity uses that come directly or indirectly from trees in the form of wood products, wildlife habitat, water, other plants, scenery and recreation.

Management planning and decisionmaking must consider the value of forest outputs (whether commodity or non-commodity); such consideration requires realistic assessment of quality and not just quantity of the outputs. Although wood outputs are probably the most easily valued,

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**Table 1—Some potentially important stem characteristics and wood properties for assessing wood quality**

| Stem Characteristics                | Wood Properties                                    |
|-------------------------------------|----------------------------------------------------|
| Diameter                            | Ring characteristics (e.g. width)                  |
| Straightness                        | Density—specific gravity (average and variability) |
| Grain                               | Fiber dimensions (length and angle)                |
| Age                                 | Reaction wood                                      |
| Branch/knot (size and distribution) | Growth stresses (e.g. reaction/compression wood)   |
|                                     | Juvenile wood / mature wood distribution           |
|                                     | Chemical content                                   |
| Bark                                | Moisture content                                   |
| Decay                               | Heartwood / sapwood proportion                     |

past evaluations of management regimes and benefits were quantified in terms of improved volume yields or decreased time to achieve a desired tree size. Yet the change from harvesting of old-growth stands with trees of large size or younger managed stands to harvests in stands based on regimes designed to meet multiple objectives, not only produces other valued benefits, but trees grown under these new regimes can have different stem characteristics and wood properties which may result in different values. It is critical to accurately assess the value of wood produced because the economic returns from harvesting wood often finance, directly or indirectly, the costs of forest ownership and management for other forest derived values. Still, little attention is paid to wood quality considerations when developing silvicultural regimes, particularly for species other than Douglas-fir.

# EVALUATING WOOD QUALITY AND POTENTIAL SILVICULTURAL IMPACTS

Wood quality—as a term or concept—is not easy to define nor simple to measure or apply. There are many possible products and quality measures that will vary with product or end use. Therefore, no single measure is necessarily appropriate for all uses. General definitions of wood quality are similar to the one given by Briggs and Smith (1986), “Wood quality is a measure of the aptness of wood for a specific use.” Central to this definition is the notion of wood’s suitability for an end product. This suitability is dependent on various stem characteristics and wood properties that affect the yield of end products, cost of processing raw material from forest to end products and the serviceability value of end products (product quality). Some potentially important stem and wood property characteristics are given in Table 1.

Of the species that are found in the northwest, most of the information about wood quality and potential impacts from silvicultural practices is for Douglas-fir. There are several studies which used this information to predict future trends in value. Ernst and Fahey’s (1986) analysis suggested that the major impact of the change from old-growth to young-growth logs would be a decrease in log size and a decrease in appearance grade lumber. They suggested pruning to increase the production of clear wood for appearance grades and thinning to increase average size and average recovery. They also pointed out that thinning might also produce larger limbs and a greater proportion of juvenile wood resulting in a decrease in quality. Juvenile wood is the column of wood that forms around the pith of a tree; it has inferior mechanical properties and dimensional stability (Senft et al. 1985). The transition from juvenile to mature wood is not well understood and probably refers to a zone, but this transition is thought to occur about 20 years from the pith in Douglas-fir (Megraw 1986). Maguire et al. (1991) developed models to predict maximum branch size and juvenile wood core for Douglas-fir. Projecting stands with different thinning strategies (both residual density and structure) they found that stand density management could impact branch size, whorl frequency and the amount of juvenile wood produced. Briggs and Fight (1992) used these methods and the TREEVAL model to predict the quality and value of products produced from two stands with widely differing initial spacing (370 and 1,876 trees per hectare). They found that if they ignored tree characteristics other than tree size, the larger trees produced by the wider initial spacing had greater value (1.06 times greater

at age 70). However these wider spaced trees also produced larger limbs, had a greater proportion of juvenile wood and lower density wood. Considering the associated tree characteristics and wood properties of the trees produced by silvicultural regimes, the resulting value at age 70 of the denser stand was 1.31 times greater than the widely spaced stand. Barbour et al. (1997) also used these methods to analyze the potential impact on wood quality from ecosystem management on federal lands. They found that management strategies could be designed to accelerate the development of important ecosystem structures while producing wood comparable to that grown in commercial plantations. However, they also concluded that early heavy thinnings would produce greater proportions of lower grade lumber. Use of lighter and later thinning treatments could reduce this impact. To date, little research has been done for Douglas-fir on how fertilization and genetics impact crown lift, juvenile wood formation, branch size and clear wood production.

While we have developed some understanding regarding Douglas-fir, our current knowledge will not be adequate in the future as we emphasize different management systems, new and modified silvicultural practices, and additional species—some of which were formerly considered “weed” species with no or limited value. Through the Pacific Northwest (PNW) Research Station’s Wood Compatibility Initiative, research is conducted on various species that were previously neglected in order to provide information for the evaluation of silvicultural practices and the potential impacts these practices could have on wood quality. This work takes advantage of past research and permanent plots established in various species by the Westside Silvicultural Options Team in Olympia, Washington. In addition to the authors, other researchers that have contributed are Constance Harrington and Leslie Chandler Brodie of the PNW Research Station, Olympia Forestry Sciences Laboratory; and Barbara Gartner and Ryan Singleton of the Forest Products Department at Oregon State University.

## EXAMPLES OF SILVICULTURE AND WOOD QUALITY INTERACTIONS

To demonstrate the importance of considering potential impacts on wood quality from silvicultural practices, we provide four examples of current research. While these results are preliminary, they demonstrate the practical importance of considering wood quality when evaluating silvicultural option. The first two examples demonstrate the importance of stem characteristics and their relationship to wood quality using western hemlock and red alder. This is followed with

two other examples that demonstrate how wood properties impact wood quality for black cottonwood (and hybrid poplar) and western redcedar.

*Western hemlock* has increased in importance in the region because of: (1) expanding emphasis on ecosystem management and alternative management regimes that favor more shade-tolerant species, (2) growing concern over Swiss needle cast and its negative impacts on the growth of Douglas-fir on many coastal sites where western hemlock grows well, and (3) western hemlock’s machinability and color that make it an excellent candidate for value-added uses. However, fluting (longitudinal depressions in the bole from inconsistent radial growth) is common stem characteristic of western hemlock growing in Alaska (Julin et al. 1993) and it can cause difficulties in debarking, sawing and peeling logs. In addition, out of roundness or off-centered pith may cause problems with grade recovery in lumber manufacture and under- or over-estimation in many mensurational procedures.

Western hemlock from young managed stands in northwestern Oregon that represented a range of growth rates were investigated for stem eccentricity and fluting. For these stands, the magnitude of eccentricity and fluting was highly variable but primarily impacted the lower bole and decreased in importance up the tree. Stem eccentricity had little or no correlation to tree-level and stand-level characteristics, however, fluting was positively correlated with tree size, growth rate, and age but negatively correlated with stand density. Flutes up to 5-10 cm deep at breast height were observed in trees that were over 50 cm in diameter. Results to date suggest that forestry practices that lead to wider spacings, more rapid growth, and longer rotations are likely to result in more extensive fluting; there will be little or no influence on out-of-roundness or off-centered pith, however (Singleton et al. in press).

*Red alder* is the most abundant hardwood species in the region and it is playing an increasingly important role in management of soil productivity (nitrogen addition), riparian zones, and ecosystem diversity. Its’ wood is useful for many products, but highest values are associated with clear wood for furniture and paneling. Because of its rapid early growth, it can reach merchantable sizes on short rotations, especially at wide spacings. However, at wide spacings, branches can persist and reduce value. Pruning may offer a silvicultural option for producing more clear wood of much greater value, but methods need to be developed and assessed.

The effect of season (month) of pruning of live branches in young red alder plantations was evaluated. In addition, the affect of wounding the branch collars of dead branches was also studied. Preliminary results show that the average time and distance for occlusion and production of clear wood was a little less than 2 years and about 2 centimeters. Differences among dates of pruning with regard to such times or distances were minor, though pruning during the growing season gave slightly better results than pruning in the dormant season. Pruning dead branches flush with the bole, which wounded the branch collar, led to more rapid healing and shorter distance to production of clear wood. The time and distance needed to begin producing clear wood increased with branch stub length, height in the tree, and branch size. No, or minimal, wood decay was associated with pruning. Thus, early pruning of red alder appears to be a feasible management option.

*Black cottonwood and hybrid poplar* plantations have been established on thousands of hectares over the past decade, in part to replace reductions in fiber supplies from curtailed harvests from federal lands. Intensive management regimes and the fast growth of these species and hybrids allow for short rotations for fiber (about 7 years) or lumber (about 15 years). With such short rotations, however, most, or all, of the tree's volume is likely to consist of juvenile wood.

Using cross-sections cut from 9-year old trees of black cottonwood and two hybrid clones, fiber length and wood density were found to increased with age, but neither property was affected by growth rate. This suggests that silvicultural practices and genetic selections can increase growth of cottonwood and poplar plantations with little fear of reducing fiber length or wood density (DeBell et al. submitted).

*Western redcedar* is one of the most shade-tolerant tree species of the Pacific Northwest, it has a high commercial value, and has received little attention in past or current management. In the future, however, the species will play an increasingly important role in alternative management regimes designed to broaden species composition and enhance structural diversity in managed stands. Much of the high market value of naturally-grown, old-growth western redcedar wood is associated with its resistance to decay due to high extractive content, particularly tropolones (DeBell et al. 1999). Such decay resistance also affects its desirability as coarse woody debris in riparian zones.

Future logs, whether contributing as lumber for home and yard projects or as debris in streamside habitats, will come from managed young-growth stands. Little is known about the influence of silvicultural practices on wood characteristics of young-growth western redcedar. We are currently investigating some of the interrelationships among growth rate, wood density and tropolone content in young-growth trees from research trials of initial spacing, thinning, and fertilization. Preliminary analyses revealed a strong negative relationship between growth rate and wood density (probably not a problem, given the major uses of western redcedar). Contrary to expectations, tropolone content appears higher in vigorous trees with more rapid growth. It appears that wood with high tropolone content (and decay resistance) can be produced via silvicultural practices designed to enhance growth and yield in young, managed stands.

## CONCLUSIONS

It is important to know the potential impacts of silvicultural regimes on wood quality. Will management strategies that emphasize growth produce clear, strong wood? Will regimes that create desirable stand structures for wildlife by encouraging the development of large trees and intolerant species in the understory of multi-layered stands produce trees that cause problems in the way we process logs and lumber in the future? Can potential problems be corrected through modified or new silvicultural strategies, changes in processing, grading rules or marketing methods? Will differences in the types of wood removed have impacts on regional processors, economies and markets? We have knowledge about how Douglas-fir stem characteristics and wood properties will change in response to the way we plan to manage forests in the region. However, we probably think we know more than we really do for Douglas-fir and we know even less for other species in the region. What we do know shows the importance of quantifying wood quality to determine value. This is not just important for today, but a fundamental knowledge of stem characteristics and wood properties and how these relate to silvicultural practices are important for the future where we will develop new silvicultural regimes and using the wood produced in new and different ways (e.g. new manufacturing equipment and engineered products). What is clear is that we cannot rely exclusively on a database of information and models based on naturally grown Douglas-fir. To begin to answer the above questions, further information is required and quantitative tools developed for a broader range of stand and management conditions and species in the Pacific Northwest.

## LITERATURE CITED

- Barbour, R.J.; Johnston, S.; Hayes, J.P.; Tucker, G.F.  
1997. Simulated stand characteristics and wood product yields from Douglas-fir plantations managed for ecosystem objectives. *Forest Ecology and Management*. 91: 205-219.
- Briggs, D.G.; Fight, R.D. 1992. Assessing the effects of silvicultural practices on product quality and value of coast Douglas-fir trees. *Forest Products Journal*. 42: 40-46.
- Briggs, D.G.; Smith, R. 1986. Effects of silvicultural practices on wood properties of conifers: a review. In: Oliver, C.D.; Hanley, D.P.; Johnson, J.A., eds. *Douglas-fir: stand management for the future*. Contrib. 55. Seattle: University of Washington, College of Forest Resources, Institute of Forest Resources: 108-117.
- Curtis, R.O.; Carey, A.B. 1996. Timber supply in the Pacific Northwest: managing for economic and ecological values in Douglas-fir forests. *Journal of Forestry*. 94(9): 35-37.
- Curtis, R.O.; DeBell, D.S.; Harrington, C.A. [et al.]. 1998. Silviculture for multiple objectives in the Douglas-fir region. Gen. Tech. Rep. PNW-GTR-435. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 123 p.
- DeBell, D.S.; Singleton, R.; Harrington, C.A.; Gartner, B.L. Submitted. Wood density and fiber length in young *Populus* stems: relation to clone, age, growth rate and pruning. *Wood and Fiber Science*.
- DeBell, J.D.; Morrell, J.J.; Gartner, B.L. 1999. Within-stem variation in tropolone content and decay resistance of second-growth western redcedar. *Forest Science*. 45(2): 101-107.
- Ernst, S.; Fahey, T.D. 1986. Changes in product recovery of Douglas-fir from old growth to young growth. In: Oliver, C.D.; Hanley, D.P.; Johnson, J.A., eds. *Douglas-fir: stand management for the future*. Contrib. 55. Seattle: University of Washington, College of Forest Resources, Institute of Forest Resources: 103-107.
- Julin, K.R.; Shaw III, C.G.; Farr, W.A.; Hinckley, T.M. 1993. The fluted western hemlock of southeast Alaska. II. Stand observations and synthesis. *For. Ecol. Manage.* 60(1-2): 133-141.
- Megraw, R.A. 1986. Douglas-fir wood properties. In: Oliver, C.D.; Hanley, D.P.; Johnson, J.A., eds. *Douglas-fir: stand management for the future*. Contrib. 55. Seattle: University of Washington, College of Forest Resources, Institute of Forest Resources: 81-96.
- Maguire, D.A.; Kershaw Jr., J.A.; Hann, D.W.; 1991. Predicting the effects of silvicultural regime on branch size and crown wood core in Douglas-fir. *Forest Science*. 37: 1409-1428.
- Senft, J.F.; Bendtsen, B.A.; Galligan, W.L. 1985. Weak Wood. Fast-grown trees make problem lumber. *Journal of Forestry*. 83(8): 476-484.
- Singleton, R.; DeBell, D.S.; Marshall, D.D.; Gartner, B.L. In press. Eccentricity and fluting in young-growth western hemlock. *Western Journal of Applied Forestry*.

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## HOW ADAPTABLE ARE FOREST GROWTH MODELS FOR SIMULATING ALTERNATIVE SILVICULTURES IN THE NORTHWEST?

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### ABSTRACT

We apply criteria that assess the adaptability of forest growth simulation models for modeling alternative silvicultural systems under experimentation in the Northwest. The ability to simulate stand growth under increasingly heterogeneous structures and mixed-species compositions is an important aspect of evaluating the compatibility of management alternatives. The most important criteria summarize the infrastructure of the model: portability, extendibility, source code availability, and adequate documentation. We apply these criteria to seven stand growth simulation models from the region. Although none of the candidate models is fully adaptable, the Forest Vegetation Simulator (FVS) came closest. The value of spatial information for predicting stand growth is in need of reevaluation in light of these new silvicultural alternatives.

KEY WORDS: Model comparison, adaptability, forest growth models, Pacific Northwest.

### INTRODUCTION

After a half century of relying on the economic efficiencies of clearcutting and intensive plantation management (Curtis et al. 1998), the Douglas-fir region of western Oregon and Washington is undergoing a paradigm shift in public perceptions of forest values (Committee of Scientists 1999). The focus has shifted toward old-growth mixed-species 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 forest lands on a biologically and economically sustainable basis (Curtis et al. 1998; Committee of Scientists 1999). Silviculturists are examining new management methods, including alternatives to clearcutting such as variable thinning, green tree retention, and variable retention (Arnott and Beese 1997, Coates et al. 1997; Monserud 2002). Often, the goal is to increase rather than

decrease structural heterogeneity within a stand and a watershed. In a strong break from the uniform plantation management of the past, these silvicultural alternatives often include mixed-species compositions and an attempt to obtain uneven-aged structures (e.g., retaining legacy trees). The ability to simulate stand growth under increasingly heterogeneous structures and mixed-species compositions is an important aspect of evaluating the compatibility of management alternatives.

Because the available stand simulation models for the Northwest were mostly developed using even-aged or plantation growth data, it is not clear how adaptable these models are for the complex stand structures and compositions under consideration by silviculturists. We therefore attempt to identify a collection of forest growth models that can simulate, or can be easily adapted to simulate, the effects of a wide range of new management alternatives. Candidate models are those that have already been applied in the Douglas-fir/western hemlock (*Psuedotsuga menziesii* - *Tsuga heterophylla*) zone (Franklin and Dyrness 1973). We also include immediate environs such as closely associated

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interior British Columbia (BC) forests, the mixed conifer forests of northern California, and the coastal forests of British Columbia and southeastern Alaska. Candidate models should simulate the full range of stand structures, species compositions, and age distributions, including both mixed-species uneven-aged stands, as well as even-aged pure stands typically created in the Douglas-fir region in the previous half-century. Our goal is first, to develop criteria that are useful in comparing the adaptability of growth models for such new situations and management, and second, to apply them to a list of candidate models.

We restrict consideration to stand growth models using the individual tree as the fundamental modeling unit. In such a model, the simulation begins with a tree list, then updates the size characteristics of each of these trees using tree-level equations, and results in an updated tree list and summary statistics. The alternative is a stand-level model where the unit is an aggregate of trees and other possible biota. This pool or aggregate is updated by the rate of change equations. Individual tree information is obtained only by disaggregating the stand or pool characteristics. Examples of useful stand models that we do not consider include DFSIM (Curtis et al 1981) and FORECAST (Kimmins et al. 1999). Second, we consider only models that are implemented in mixed-species systems, precluding single-species simulators such as TASS/TIPSY (Mitchell 1975; Mitchell et al. 2000) and 3-PG (Landsberg and Waring 1997).

## **CRITERIA FOR EVALUATING MODEL ADAPTABILITY**

Robinson and Monserud (in press) developed several criteria that assess the adaptability of forest growth simulation models for extension into new populations and applications. The most important criteria summarize the infrastructure of the model: portability, extendibility, source code availability, and adequate documentation. If these four criteria are met, then all other omissions can be compensated for, if the motivation and resources are sufficient. If lacking, they are the most difficult to compensate for. The next layer of criteria is concerned with model inputs. These criteria are very useful for simulating forest management and reasonably universal in implementation and application. They include site calibration, supporting a variety of sample designs, and imputing unmeasured tree dimensions for a subsample of the trees (e.g., missing heights and crown ratios). The third layer of criteria speaks to the

conditions under which simulation is likely required. This is again relatively broad, and generally useful, such as the ability to simulate the effects of silviculture, regeneration, and disturbance. The final and least critical criteria cover the output information required for decision-making. They are the ability to report biomass, wood volume, wood quality, and economic state variables. These outputs would be the easiest to compensate for if lacking.

## **CANDIDATE GROWTH MODELS**

Seven candidate growth models were examined.<sup>3</sup> Ritchie (1999) is a very good source for further information about many of these models, including available literature citations.

### **CACTOS**

The CACTOS (California Conifer Timber Output Simulator) model was developed by a research cooperative and parameterized with private data from northern California timber companies (Ritchie 1999). It is an individual tree nonspatial forest growth simulator that simulates growth and dynamics of multiple species on a 5-year growth step (Wensel and Robards 1989). The model was designed for heavily managed industrial forests. Model exclusions accurately reflect the needs of the designers; for example, there is no ingrowth component.

### **FPS**

The Forest Projection System (FPS) is an integrative forest planning and management tool surrounded by a suite of forest management tools (Arney and Milner 2000). This is owned, maintained, and supported by Forest Biometrics, a forest consulting company in Montana. The heart of FPS is a unique response-surface methodology for simulation; it requires Microsoft Access® for database capabilities. Instead of using parameters or models, the simulator uses a library that summarizes stand development response surfaces, which are used as lookup tables. Therefore, there are no equations built into FPS, only interpolation routines for the response surfaces.

### **FVS**

Originally known as Prognosis (Stage 1973; Wykoff et al. 1982), the Forest Vegetation Simulator (FVS) is an individual-tree nonspatial forest growth model built around a

<sup>3</sup> 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.

set of empirically derived equations of diameter growth, height growth, crown ratio, regeneration and mortality. The geographic reach of FVS and its variants is national (21 variants), two of which cover the Douglas-fir region (Pacific Northwest Coast (PN) and West Cascades (WC)). Therefore, the utility of FVS depends, to some extent, on the variant. For example, SEAPROG (SE Alaska) simulates natural regeneration, and PN and WC do not. FVS is now one of the most widely used forest growth models. It simulates a wide array of different forest processes other than simple volume accretion, including several types of natural disturbance (Teck et al. 1997).

## **ORGANON**

The ORGANON (OREgon Growth ANALysis and projectiON) simulator is a nonspatial, statistically based model of individual tree growth and mortality. There are three variants: for young mixed-conifer stands in southwest Oregon (SWO), for young Douglas-fir stands in northwest Oregon (NWO), and for young Douglas-fir and western hemlock stands in southwestern British Columbia, western Washington, and northwest Oregon (SMC) (Hann et al. 1997). The model was originally developed in southwest Oregon to simulate the growth of both even-aged and uneven-aged mixed-species stands (Ritchie 1999). The data used for parameterization of two of the variants were taken principally (NWO) or exclusively (SMC) from even-aged stands.

## **SORTIE**

The SORTIE simulation approach was originally written and parameterized for the deciduous forests of the northeastern United States (Pacala et al. 1993, 1996). We focus on SORTIE/BC, which is extensively modified for the mixed conifer forests (nine tree species) of northwestern British Columbia. SORTIE is an individual tree vector spatial model that owes much to the gap model tradition of JABOWA/FORST (Botkin et al. 1972; Shugart 1984); it differs from this tradition in that plot size is not a growth parameter. The BC version of the model simulates four processes: competition for light (Canham et al. 1999), tree growth as a function of light availability (Wright et al. 1998) and tree history (Wright et al. 2000), mortality (Kobe and Coates 1997), and seedling recruitment as a function of parent abundance and seedbed substrate (LePage et al. 2000).

## **SPS**

The Stand Projection System (SPS) is a proprietary forest growth model complemented by a suite of forest management tools, called the Stand Inventory System (SIS)

(Mason, Bruce and Girard, Inc. 1988). The system requires that Microsoft Access® be installed, and relies upon and benefits from its database handling capacities. SPS is unusual in that it projects the growth of top height first, with diameter growth following as a function of relative tree size.

## **ZELIG.PNW**

Working in the gap-phase tradition of JABOWA/FORST (Botkin et al. 1972), Busing and Garman (2002) parameterized ZELIG (Urban 1993) for the Pacific Northwestern states (ZELIG.PNW). A gap-phase model is intended to simulate succession following the death of a large tree, which creates a gap (0.4 ha) in the forest (Botkin et al. 1972; Shugart 1984). The specific locations of trees are not known within the gap; spatial location of all the gaps is known. Like all such gap models, it was designed to test ecological theory rather than serve as a forest management tool. However, ZELIG.PNW is used to examine large-scale silvicultural policy (Hansen et al. 1995) and is also being used by CLAMS (Spies et al. in press), which is a province-level forest management study for the entire Oregon Coast Range.

## **RESULTS AND DISCUSSION**

Using the criteria developed by Robinson and Monserud (in press), none of the models is fully adaptable or entirely appropriate for the alternative silvicultures being proposed for the Northwest. Of the seven candidate models, FVS was the most adaptable. It checks favorably on almost all criteria: open source, a broad geographic coverage, and a well-documented fitting process. It also has powerful extensions such as the Event Monitor (Crookston 1990) and the Parallel Processor (Crookston and Stage 1991). The original Northern Idaho variant (NI) has undergone extensive critical examination and field-testing for over a quarter of a century. The other geographic variants of FVS were tested for shorter times and remain less scrutinized. This NI variant was designed to simulate the mixed-species compositions and heterogeneous, uneven-aged structures that are increasingly prescribed by silviculturists in the Northwest. However, others among the models have facilities that FVS would benefit from, such as the wood quality module of ORGANON. It would also be improved if the effects of fertilization and pruning could be simulated, and if a natural regeneration module were available for all FVS variants.

One of the strongest testimonials of adaptability is the independent development of variants for other populations, for this is directly related to the definition of adaptability.

FVS is a strong case in point. First, approximately 20 regional variants were built for the US by the development group in Fort Collins, CO. Second, the British Columbia Ministry of Forests has adopted the North Idaho variant of FVS for application in the Interior Douglas-fir Zone of southeastern BC (Temesgen and LeMay 1999; BC Ministry of Forests 2000). Third, Monserud et al. (1997) developed the PROGNAUS simulator for Austria.

Another approach to assessing adaptability is to focus on model genealogy. Which models have been applied to the widest range of different populations? The two models that have dominated their respective genres most over the past thirty years are Prognosis/FVS (Stage 1973; Teck et al. 1997) in forestry and JABOWA/FORET (Botkin et al. 1972; Shugart 1984) in ecology. Their influence arguably derives from their adaptability: both are based on simple principles that are exhaustively documented, and both have source code freely available. It is also possible that the wide propagation of FVS is partially due to the available resources and wide influence of the USDA Forest Service, which is the largest landholder and user. However, model adaptation is a concrete test of model adaptability, and there is no doubt that the FVS model is adapted to more regions than any of the other models.

These seven simulation models fall into two general categories: forest ecology models (SORTIE, ZELIG.PNW) and forest management models (all the rest). Although SORTIE and ZELIG-PNW were not designed as forest management tools, there is increasing interest in applying them and hybrid models like 3-PG (Landsberg and Waring 1997) to forest management problems (Spies et al. in press). We see commonalities in the shortcomings of these models relative to the expectations and needs of forest managers. The forest management models accommodate a broader array of inputs and outputs important to forest planning and forest operations: they are site-specific, and allow a variety of sample designs, range of silviculture, wood products, and economics. Developing the forest ecology models in this well-established direction would create a very useful blend between the strengths of each of these major modeling approaches.

### **Spatial Information**

Spatial heterogeneity within stands is one of the goals in several alternative silvicultural experiments currently underway in the Northwest. The Alternatives to Clearcutting

(ATC) study in S.E. Alaska is examining different spatial patterns of retained trees at a given density: uniform dispersal, clumps within a uniform matrix, and gaps within a uniform matrix (McClellan et al. 2000). Both the Olympic Habitat Development Study (OHDS; Harrington and Carey 1997<sup>4</sup>) and the Forest Ecosystem Study (FES; Carey et al. 1999) are examining several spatial patterns: variable-density thinning with 10% of area in uncut patches, 15% of area in openings (small patch cuts), and 25-30% BA removal in remaining stand. These alternatives eschew homogeneous stand structures, and intentionally seek to create a non-uniform spatial distribution within the stand (Monserud 2002). Because the vast majority of stand simulation models used for forest management are non-spatial models, the tenuous assumption of a homogeneous spatial distribution calls for a close examination of these management models.

In the 1960's and 1970's, several spatial simulation models were developed (see Biging and Dobbertin 1995), but few survived the practical test of requiring mapped tree locations before forest management prescriptions were generated (e.g., Mitchell 1975 is still in use). Most ended as academic exercises, but some new approaches are quite promising (e.g., SORTIE/BC). An important result was obtained by Biging and Dobbertin (1995), who found no advantage to using spatial information to predict growth, provided that crown information was incorporated into the prediction. Clearly, a careful reevaluation of the importance of spatial information for stand prediction is needed, especially in relation to alternative silvicultures that aim for heterogeneous stand structures. The several large-scale experiments testing alternative silvicultures (e.g., Harrington and Carey 1997<sup>4</sup>; Carey et al. 1999; McClellan et al. 2000) will eventually provide crucial observations for testing the value of spatial information for predicting stand growth under alternative silviculture, although the experiments are currently too new for a clear test.

### **ACKNOWLEDGMENTS**

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<sup>4</sup> Harrington, C.A.; Carey, A.B. 1997. The Olympic Habitat Development Study: conceptual study plan. Unpublished manuscript on file at the Olympia Forestry Sciences Laboratory, Pacific Northwest Research Station, 3625 SW 93rd Avenue, Olympia, WA 98512-9193. 38 p.

## LITERATURE CITED

- Arney, J.D.; Milner, K.S. 2000. Biometrics of forest inventory, forest growth, and forest planning. Technical Report # 10, Forest Biometrics Library. 279 p.
- Arnott, J.T.; Beese, W.J. 1997. Alternatives to clearcutting in BC coastal montane forests. *For. Chron.* 73: 670-678.
- BC Ministry of Forests. 2000. Prognosis<sup>BC</sup> version 2.0: user's guide and tutorials. BC Ministry of Forests, Victoria, BC. 21 p. URL: <http://www.for.gov.bc.ca/research/gymodels/progbc>. July 2000.
- Biging, G.S.; Dobberty, M. 1995. Evaluation of competition indices in individual tree growth models. *Forest Sci.* 41: 360-377.
- Botkin, D.B.; Janak, J.F.; Wallis, J.R. 1972. Rationale, limitations, and assumptions of a Northeastern forest growth simulator. *IBM Journal of Research and Development* 16(2): 101-116.
- Busing, R.T.; Garman, S.L. 2002. Promoting old-growth characteristics and long-term wood production in Douglas-fir forests. *Forest Ecology and Management* 160 (1-3): 161-175.
- Canham, C.D.; Coates, K.D.; Bartemucci, P.; Quaglia, S. 1999. Measurement and modeling of spatially-explicit variation in light transmission through interior Cedar-Hemlock forests of British Columbia. *Canadian Journal of Forest Research* 29: 1775-1783.
- Carey, A.B.; Thysell, D.R.; Brodie, A.W. 1999. The Forest Ecosystem Study: background, rationale, implementation, baseline conditions, and silvicultural assessment. Gen. Tech. Rep. PNW-GTR-457. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 129 p.
- Clayoquot Scientific Panel. 1995. Scientific panel for sustainable forest practices in Clayoquot Sound, Report 5, Sustainable ecosystem management in Clayoquot Sound: planning and practices, Victoria, B.C., 296 p.
- Coates, K.D.; Banner, A.; Steventon, J.D. et al. The Date Creek silvicultural systems study in the Interior Cedar-Hemlock forests of northwestern British Columbia: overview and treatment summaries. B.C. Ministry of Forests, Victoria, B.C. Land Manage. Handb. 38 p.
- Committee of Scientists. March 15, 1999. Sustaining the people's lands: recommendations for stewardship of the national forests and grasslands into the next century. U.S. Department of Agriculture, Washington, D.C. xlii+187 pp. URL: <http://www.fs.fed.us/news/science/>. May 1999.
- Crookston, N.L. 1990. User's guide to the event monitor: part of Prognosis Model version 6. Gen. Tech. Rep. INT-275. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 21 p.
- Crookston, N.L.; Stage, A.R. 1991. User's guide to the Parallel Processing Extension of the Prognosis model. Gen. Tech. Rep. INT-281. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 88 p.
- Curtis, R.O.; Clendenen, G.W.; DeMars, D.J. 1981. A new stand simulator for coast Douglas-fir: DFSIM user's guide. Gen. Tech. Rep. PNW-GTR-128. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 79 p.
- Curtis, R.O.; DeBell, D.S.; Harrington, C.A. et al. 1998. Silviculture for multiple objectives in the Douglas-fir region. Gen. Tech. Rep. PNW-GTR-435. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 123 p.
- FEMAT (Forest Ecosystem Management Assessment Team). 1993. Forest ecosystem management: an ecological, economic, and social assessment. U.S. Department of the Interior, U.S. Department of Agriculture, U.S. Department of Commerce, and U.S. Environmental Protection Agency, Washington, D.C. 729 p. + appendices.
- Franklin, J.F.; Dyrness, C.T. 1973. Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW-GTR-8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 417 p.
- Hann, D.W.; Hester, A.S.; Olsen, C.L. 1997. ORGANON user's manual: edition 6.0. Department of Forest Resources, Oregon State University, Corvallis, Oregon. 133 p.

- Hansen, A.J.; Garman, S.L.; Weigand, J.F. et al. 1995. Alternative silvicultural regimes in the Pacific Northwest: simulations of ecological and economic effects. *Ecological Applications* 5(3): 535-554.
- Kimmins, J.P.; Mailly, D.; Seely, B. 1999. Modelling forest ecosystem net primary production: the hybrid simulation approach used in FORECAST. *Ecological Modelling* 122: 195-224.
- Kobe, R.K.; Coates, K.D. 1997. Models of sapling mortality as a function of growth to characterize interspecific variation in shade tolerance of eight tree species of northwestern British Columbia. *Can. J. For. Res.* 27: 227-236.
- Landsberg, J.J.; Waring, R.H. 1997. A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning. *Forest Ecology & Management* 95(3): 209-228.
- LePage, P.; Canham, C.D.; Coates, K.D.; Bartemucci, P. 2000. Seed source versus substrate limitation of seedling recruitment in interior cedar-hemlock forests of British Columbia. *Canadian Journal of Forest Research* 30: 415-427.
- McClellan, M.H.; Swanston, D.N.; Hennon, P.E. et al. 2000. Alternatives to clearcutting in the old growth forests of southeast Alaska: study plan and establishment report. Gen. Tech. Rep. PNW-GTR-494. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 40 p.
- Mason, Bruce and Girard, Inc. 1988. SPS User's Guide v. 2.4. Portland, OR. 48 p.
- Mitchell, K.J. 1975. Dynamics and simulated yield of Douglas-fir. *For. Sci. Monogr.* 17. 39 p.
- Mitchell, K.J.; Stone, M.; Grout, S.E. et al. 2000. TIPSYS version 3.0. Ministry of Forests, Research Branch, Victoria B.C. URL: <http://www.for.gov.bc.ca/research/gymodels/tipsy/>. July 2000.
- Monserud, R.A. 2002. Large-scale management experiments in the moist maritime forests of the Pacific Northwest. *Landscape and Urban Planning* 59(2002): 159-180.
- Monserud, R.A.; Sterba, H.; Hasenauer, H. 1997. The single-tree stand growth simulator PROGNAUS. In: Teck, R.; Moeur, M.; Adams, J., comps. *Proceedings: Forest Vegetation Simulator conference; 1997 February 3-7; Fort Collins CO.* Gen. Tech. Rep. INT-GTR-373. Ogden, UT; Intermountain Research Station. 50-56.
- Pacala, S.W.; Canham, C.D.; Silander, J.A. 1993. Forest models defined by field measurements: I. The design of a northeastern forest simulator. *Canadian Journal of Forest Research*. 23(10): 1980-1988.
- Pacala, S.W.; Canham, C.D.; Saponara, J. et al. 1996. Forest models defined by field measurements: II. Estimation, error analysis, and dynamics. *Ecol. Mon.* 66: 1-43.
- Ritchie, M.W. 1999. A compendium of forest growth and yield simulators for the Pacific Coast states. Gen. Tech. Rep. PSW-GTR-174. Albany CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 59 p.
- Robinson, A.P.; Monserud, R.A. In press. Criteria for comparing the adaptability of forest growth models. *Forest Ecology and Management*.
- Shugart, H.H. 1984. A theory of forest dynamics: the ecological implications of forest succession models. Springer-Verlag, New York. 278 p.
- Spies, T.A.; Reeves, G.H.; Burnett, K.M. et al. In press. Assessing the ecological consequences of forest policies in a multi-ownership province in Oregon. In Liu, J.; Taylor, W.W., eds. *Integrating landscape ecology into natural resource management*. Cambridge Univ. Press.
- Stage, A.R. 1973. Prognosis model for stand development. Research Paper INT-137. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.
- Teck, R.; Moeur, M.; Adams, J., eds. 1997. *Proceedings: Forest Vegetation Simulator Conference. General Technical Report INT-GTR-373*, U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 222 p.
- Temesgen, H.; LeMay, V. 1999. Examination of large tree height and diameter increment models modified for Prognosis<sup>BC</sup>. URL: <http://www.for.gov.bc.ca/research/gymodels/progbc/sitemap.htm>. July 2000.

- Urban, D.L. 1993. A user's guide to ZELIG version 2 with notes on upgrades from version 1. Dept. of Forest Sciences, Colorado State University, Fort Collins. 77 p.
- Wensel, L.C.; Robards, T.A. 1989. Revised parameter estimates for CACTOS growth models. Northern California Forest Yield Cooperative Research Note No. 23. URL: <http://www.cnr.Berkeley.edu/~wensel/cactos/revised/revintro.htm>. August 2000.
- Wright, E.F.; Coates, K.D.; Canham, C.D.; Bartemucci, P. 1998. Species variability in growth response to light across a climatic gradient in northwestern British Columbia. *Canadian Journal of Forest Research*. 28: 871-886.
- Wright, E.F.; Canham, C.D.; Coates, K.D. 2000. Effects of suppression and release on sapling growth for eleven tree species of northern, interior British Columbia. *Canadian Journal of Forest Research*. 30: 1571-1580.
- Wykoff, W.R.; Crookston, N.L.; Stage, A.R. 1982. User's guide to the stand prognosis model. Gen. Tech. Rep. GTR-INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 112 p.

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## **FACTORS INFLUENCING GROWTH AND FLOWERING OF UNDERSTORY PLANTS IN CONIFER STANDS IN WESTERN WASHINGTON**

Constance A. Harrington<sup>1</sup>, Karl R. Buermeyer<sup>2</sup>, Leslie Chandler Brodie<sup>3</sup>, and Bryan W. Wender<sup>4</sup>

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### **ABSTRACT**

Managing forest stands to produce wood while also producing other values, such as wildlife habitat, recreation, or special forest products, requires information on forest components not always measured in traditional silviculture studies. For example, some managers may want to predict potential growth rates of herbs, shrubs, and trees in the understory—as these components will determine future forest composition and structure—or may be interested in flowering of plants in forest understories, since berry and seed production are important factors in determining species habitat suitability. We conducted several studies in conifer stands in western Washington to determine the effects of stand and site conditions on (1) response of understory vegetation to changes in overstory density, (2) flowering of selected shrub species, and (3) tree growth in forest understories. Responses of most factors were quite variable and indicate that managers may have to accept a lower level of certainty or invest more in research and monitoring when managing for components of forest stands other than overstory trees. The general results and management implications from the three studies are discussed and a reading list presented.

**KEY WORDS:** Plant ecology, silviculture, flowering, shrubs, understory, tree growth.

### **INTRODUCTION**

For many forest lands in the Pacific Northwest, fiber production was the dominant objective for much of the 20<sup>th</sup> century. During the past 50 years, many stands were clearcut, planted with Douglas-fir, and managed as single-species, even-aged stands; research information produced during that time was geared to provide information pertinent to that type of management. In the late 1980's, however, management objectives for some lands broadened or changed to (1) produce or protect habitat for wildlife species with declining populations, (2) accelerate development of stand structures and plant and animal communities associated with late-successional forests, (3) produce special forest products, (4) meet aesthetic concerns, or (5) produce wood in ways compatible with achieving several other management objectives. The changes in management emphasis meant that more information was needed on stand components other than overstory trees. This report summarizes study results regarding three components relevant to the

new information needs: development of understory vegetation after thinning, flowering of shrubs in forest understories, and height growth of understory trees.

### **DEVELOPMENT OF UNDERSTORY VEGETATION AFTER THINNING**

The amount and type of plants found in forest understories will vary with plant association, site conditions, current overstory conditions, and past history of stand (e.g., burning, thinning, ground disturbance). Thinning, whether uniformly applied or with a variable density prescription, alters overstory density and light quality (if species composition was changed as a result of the thinning) and disturbs the soil and existing plant cover (creating a good seedbed for some species but damaging some existing plants). Because past management has focused primarily on tree growth in the main canopy, we do not have much information on understory response. Some researchers evaluated the effects of thinning on regeneration or understory vegetation but only limited information is available and the results

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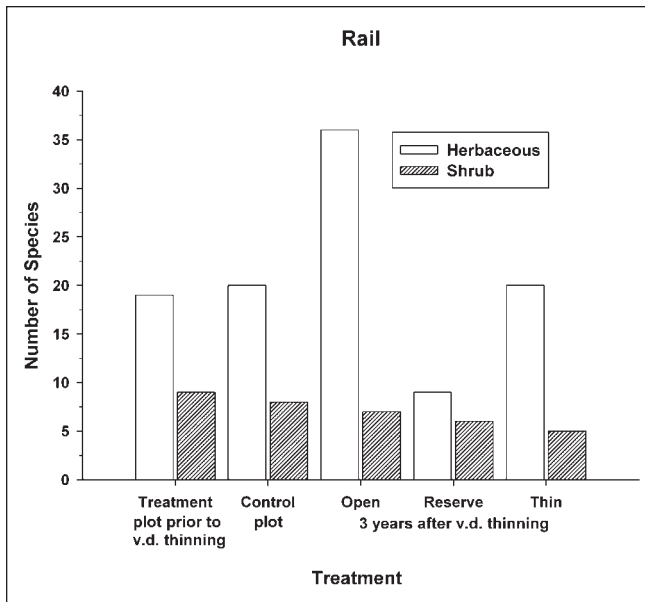


Figure 1—Number of herbaceous and shrub species at the Rail study area of the Olympic Habitat Development Study in an untreated control plot and in a thinned plot, before and 3 years after, implementation of a variable-density thinning. The “open,” “reserve,” and “thin” designations represent the three components of the variable-density thinning treatment.

were mixed (Kruger 1960; Worthington and Heebner 1964). Information available on understory response to thinning will greatly increase in the near future, however, since many recent Northwest studies have included an understory component in their measurements (c.f., Halpern et. al 1999; Halpern and Spies 1995; Thysell and Carey 2000).

We collected information on understory vegetation prior to and 3 years following implementation of a variable density thinning at two blocks in the Olympic Habitat Development Study. Both blocks were near Forks, WA (Clallam County). The variable density prescription included retaining uncut patches and creating gaps or openings as well as thinning within the general stand matrix. The uncut patches were also “no-entry” zones for equipment. One block, Fresca, had a dense stand of western hemlock and Sitka spruce, had not been thinned prior to implementation of variable density thinning, and had very low cover of understory species. The second block, Rail, primarily had Douglas-fir in the overstory; in some portions of the stand there were substantial numbers of understory western hemlock. The Rail stand had been thinned in the early 1980s. Prior to the implementation of the variable density thinning in 1997 at Rail, there was a fair amount of understory cover that was dominated by salal.

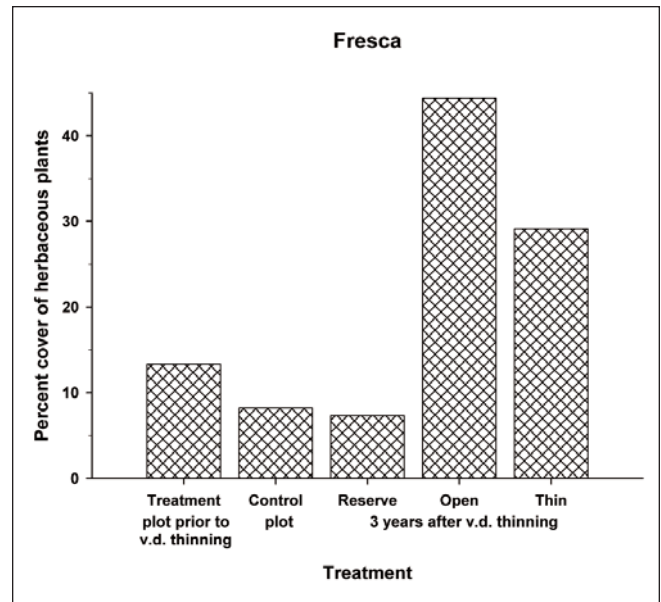


Figure 2—Percent cover of herbaceous plants at the Fresca study area of the Olympic Habitat Development Study in an untreated control plot and in a thinned plot, before and 3 years after, implementation of a variable-density thinning. The “open,” “reserve,” and “thin” designations represent the components of the variable-density thinning treatment.

Three years following variable density thinning, the results from these two blocks were:

1. Number of herbaceous species was least in the unthinned areas (control plots and uncut or reserve portions of thinned plots), greatest in the openings or gaps, and intermediate in the thinned areas (Figure 1).
2. Number of shrub species did not differ among the unthinned areas, the gaps, or the thinned matrix (Figure 1).
3. The greatest numbers of tree seedlings in both blocks were western hemlock. Bigleaf maple seedlings were only found in open areas.
4. Percent cover of herbaceous plants was greatest in the openings (Figure 2).
5. Percent cover of shrubs at the Fresca block prior to variable density thinning was low (< 2%); shrub cover post-thinning remained low but exhibited the expected pattern of % cover in the open > % cover in the thinned areas > % cover in the uncut areas.
6. Percent cover of shrubs at the Rail block prior to treatment was patchy but overall was much higher than at the Fresca block; shrub cover 3 years after treatment at Rail

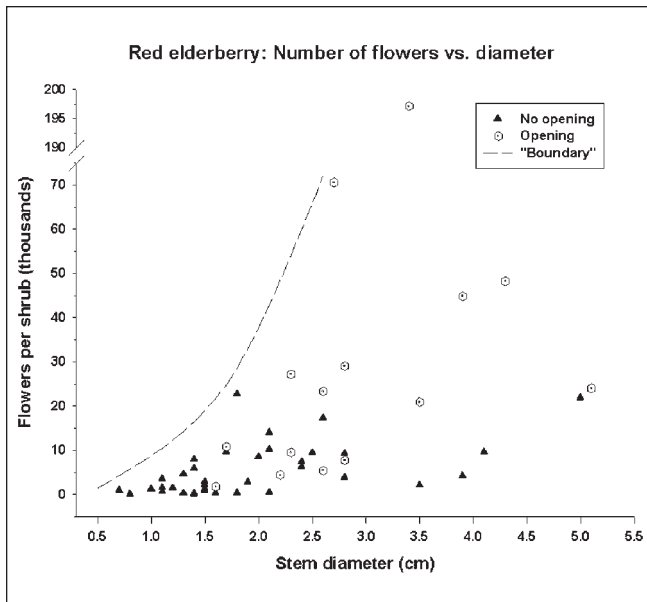


Figure 3—Relationship between number of red elderberry flowers per plant and stem diameter. The dashed line represents the upper boundary of the data. Note the tendency for plants in canopy openings to be larger in diameter than those not in openings and, for the same stem diameter, for plants in openings to have more flowers than those under intact forest canopies.

was more related to pretreatment conditions than to whether it was in an open, thinned, or uncut area.

7. The presence of salal at Rail prior to treatment may have reduced the opportunity for germination and development of other species.

## FLOWERING OF SHRUBS IN FOREST UNDERSTORIES

Some resource managers are interested in increasing flowering and fruit production of some understory shrub species to produce fleshy berries as food for wildlife species or for human consumption. Most managers are more interested in fruit production than flowering; however, flowering is a prerequisite to fruiting. In addition, fruit production is influenced by many factors not under management control such as spring frosts or summer drought. Thus, if we want to understand the importance of stand and site conditions on fruiting, we are most likely to be successful if we study flowering first.

Most species vary from year to year in flower production, so it would take several years of observation to accurately estimate or predict mean flowering per plant. The information in this report is preliminary as it is based on only one year.

We studied the relationships between flowering and attributes of plant size, age, overstory characteristics, light, and site conditions in eight shrubs common in understories of conifer stands in western Washington (Clallam, Grays Harbor, Mason, Pierce, and Thurston Counties). At least 50 observations were made for each species. The shrubs were salal, Oregon grape, vine maple, hazelnut, evergreen huckleberry, red elderberry, red huckleberry, and Indian plum. A sampling frame was used to select salal and Oregon grape “plants” because these species have rhizomes (underground stems) and it is difficult to determine individual plants.

Results from the flowering study indicated:

1. These species are adapted to growing in forest understories and the majority of plants flowered regardless of the light conditions.
  - a. About 65% of plants flowered for Oregon grape, vine maple, and evergreen huckleberry,
  - b. 85-90% of plants flowered for Indian plum and hazelnut, and
  - c. 96-98% of plants flowered for salal, red huckleberry, and red elderberry.
2. Ages of sampled stems ranged from 1 to 64 years (not all plants were aged); four species had sampled stems > 20 years old (vine maple, hazelnut, evergreen huckleberry, and red huckleberry).
3. Species with the greatest maximum sizes had the greatest range in diameter or height.
4. The line that passes through the highest value of the dependent variable at each level of the independent variable defines the upper boundary of the points and may reveal the underlying relationship between the variables when other factors are not limiting. Boundary lines indicated possible relationships between number of flowers and some of the measured variables (Figure 3).
5. Predicting number of flowers from shrub size or age, overstory characteristics, light, and site variables was not very successful ( $R^2$  values were never > 0.50 for models with one or two variables).
6. Characteristics of shrub size, especially stem diameter, were almost always the best predictors of number of flowers (Figure 3). Large shrubs were not only more likely to flower and produce seed, they also contribute to vertical structure in forest stands (Figure 4).



Figure 4—Large shrubs, such as the vine maple shown here, are important components in forest stands. They provide vertical structure as well as producing large numbers of flowers which will result in large amounts of seed.

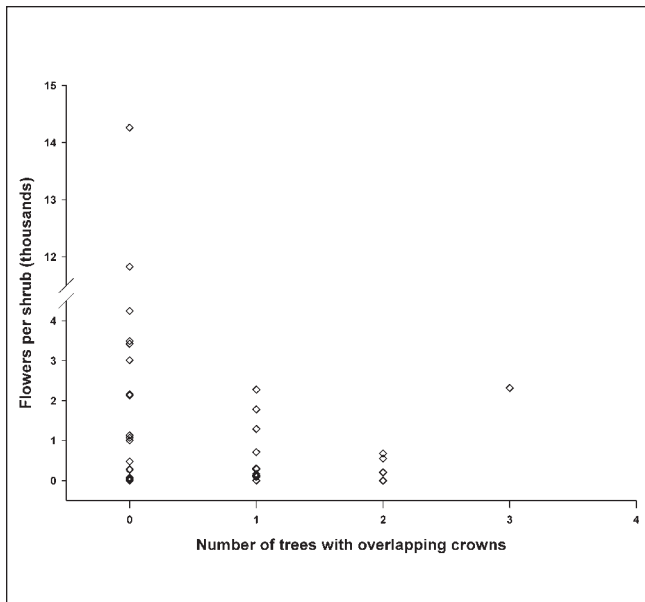


Figure 5—Relationship between number of evergreen huckleberry flowers per plant and number of trees whose canopies overlap the huckleberry plant canopy.

7. Three species—Indian plum, red huckleberry, and evergreen huckleberry— had improved prediction models for number of flowers if percent light, presence of a canopy gap or overstory characteristics were included; overall, these species also had the best fit models (Figure 5).
8. Salal, Oregon grape, and vine maple had the poorest fit prediction models for flowering. These clonal shrubs may share resources among above-ground stems, thus allowing stems in poorer environments to persist and flower. See Management Implications for more information on clonal shrubs.
9. Analyses that predicted which plants flowered did not select the same variables as the models predicting number of flowers (based on plants which *did* flower).
10. Direct measurement of light was only significant for Indian plum; thus, direct measurements (which require specialized equipment) may not be necessary to predict flowering.

## HEIGHT GROWTH OF UNDERSTORY TREES

Most past management in Pacific Northwest forests focused on even-aged stands which had a single main canopy, had one or two main tree species, and were going

to be regenerated by planting. Tree species in the understory or midstory were of little interest; advanced regeneration was often something to get rid of before planting, and midstory trees were usually too small to be of commercial value. In the late 1980's, interest in more complex forest structures began to increase because on some public lands it was deemed desirable to try to accelerate the development of stands with late-successional characteristics, such as multiple canopy layers, large diameter trees, several tree species, and presence of snags and down wood (See Franklin et al. 1986). In addition, some managers became interested in managing for natural regeneration. Thus, there is a need to understand more about trees in understory or midstory positions, especially their growth rates and ability to respond to release.

We sampled 75 forest stands in western Washington (Grays Harbor, Jefferson, King, Lewis, Mason, Pierce, Snohomish, and Thurston Counties) that had conifers present in understory or midstory positions. Understory trees (up to 8 m tall) of Douglas-fir, western hemlock, and western red-cedar were measured for height, last 3-year height growth, crown length, and diameter. The overstory was characterized (height, distance to bottom of crown of dominant and codominant trees, length of crown for dominant and codominant trees, basal area), and the light environment and micro-site conditions were recorded. For each site, the plant association was determined and a soil moisture class assigned (dry, mesic, moist, or wet). The light environment was assessed in several ways: percent of full sunlight, analysis of digital photos of the sky with specialized software to determine percent of open sky, sunflecks, and other measures of light from the photographs, and a count of the number of open sky segments along the sun's path. The last variable, which we named "sunpath," was determined by drawing a line that represents the sun's mid-summer path, dividing the line into 20° segments, and then counting the number of segments that have 50% or more of the path without branches or stems blocking the sun.

Results were:

1. Trees in understory positions were found for all three species (Douglas-fir, western hemlock, and western red-cedar) on several plant associations (except no Douglas-fir was present on the wettest plant associations).
2. For all three species, height growth was best on the "moist" sites.
3. For all three species, height growth prediction equations were better when done individually for the four moisture classes than when all moisture classes were combined.

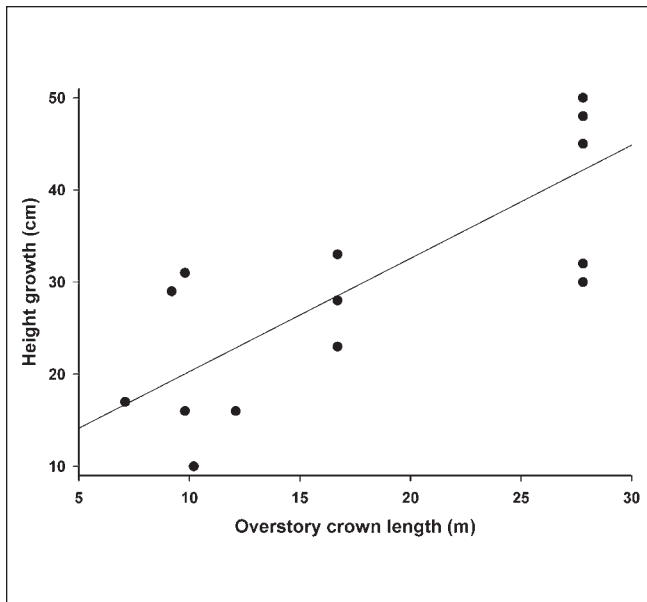


Figure 6—Relationship between 3-year height growth for Douglas-fir seedlings and saplings and mean of overstory trees crown length on plant associations classified as “dry” ( $R^2 = 0.64$ ).

4. For 7 of the 11 species-moisture class combinations, a variable measuring tree size or size ratio was the first or only variable in the models predicting 3-yr height growth.
  - a. Length of the live crown or live crown ratio was the best variable for predicting growth in several of the species-by-moisture-class models.
  - b. Height/diameter ratio and stem volume were also selected but used in fewer models.
5. The model fit varied substantially among the species-moisture class combinations.
  - a. Models were least successful for western hemlock (the best models had  $R^2$  values of 0.35 and 0.37 for western hemlock on wet and mesic sites, respectively).
  - b. Best-fit models were for Douglas-fir on dry sites ( $R^2 = 0.71$ ) and western redcedar on moist sites ( $R^2 = 0.83$ ). See Figure 6.

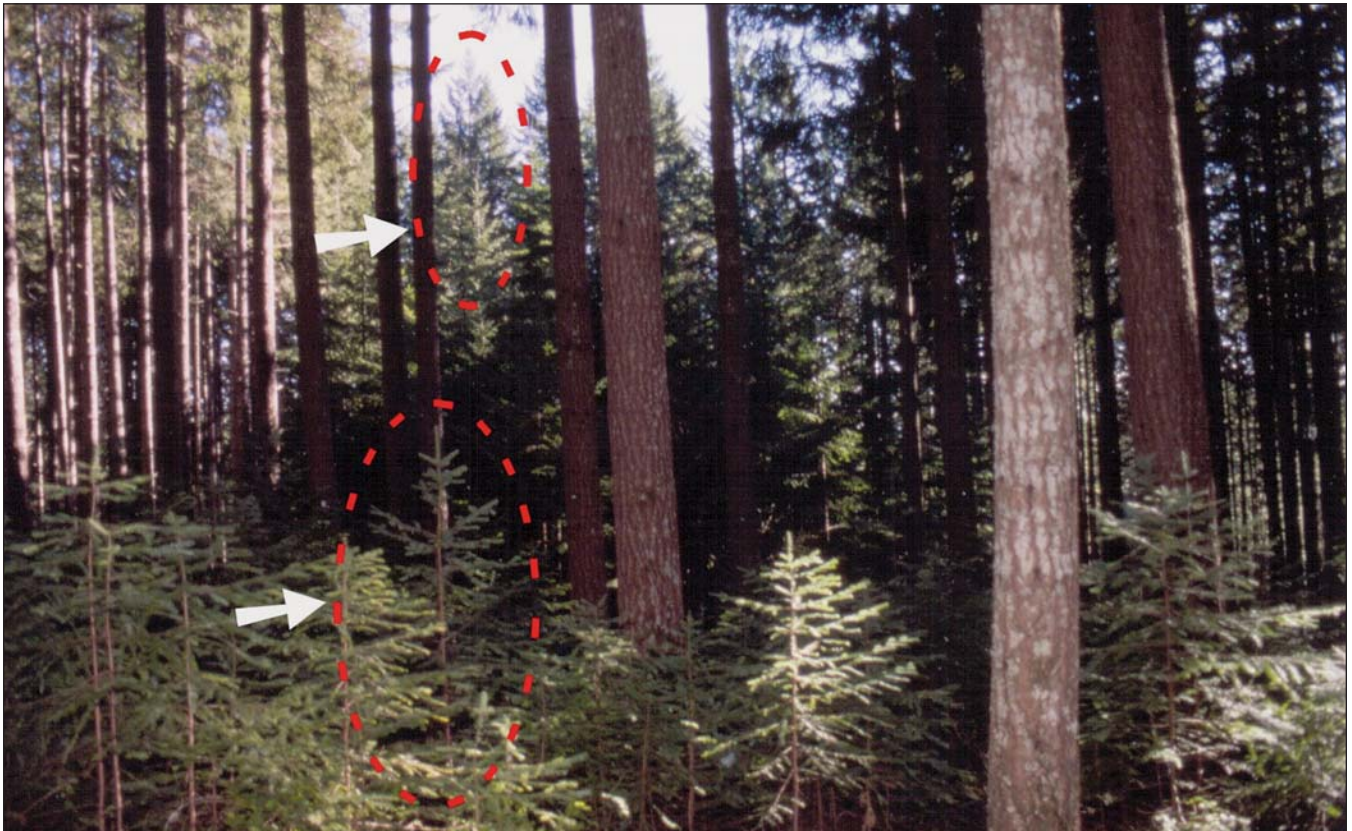


Figure 7—Many tree species will regenerate under a forest canopy but their future growth will depend on both overstory characteristics as well as site conditions. For example, the two groups of Douglas-fir saplings, indicated by the arrows above, are the same age but differ substantially in size.

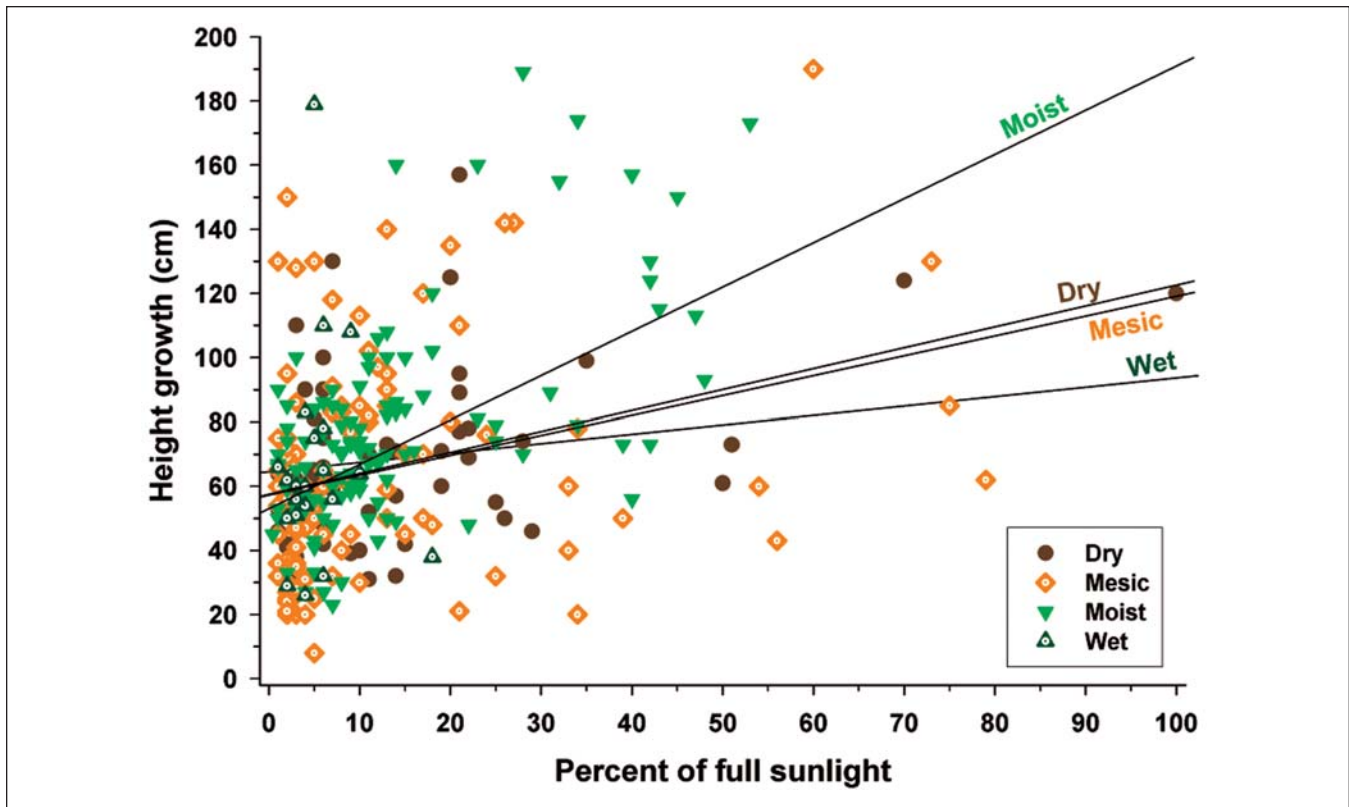


Figure 8—Relationship between 3-year height growth for western hemlock and percent of full sunlight by moisture class. Note that the regression line is steepest for the “moist” moisture class and the relationship is weak for the other three moisture classes.

6. Overstory characteristics were important variables in some height-growth prediction models, but the overstory characteristic selected varied among the species by moisture class combinations.
7. Growth rates of understory trees can differ substantially based on overstory conditions (Figure 7).
8. Overstory characteristics selected for models may provide clues to the factors limiting tree growth. For example, the fact that the best-fit model for western redcedar on dry sites includes basal area may indicate root competition is important as basal area is probably correlated with below-ground competition. On the other hand, selection of mean overstory crown length in the Douglas-fir model may indicate that light is more limiting growth than moisture on these sites; this would be consistent with the lower shade tolerance of Douglas-fir compared to western hemlock or western redcedar.
9. Five of the 11 models selected a light variable but the light variable selected the most, sunpath, was one that does not require specialized measurement equipment or software, or favorable weather and sun conditions.
10. Effects of light were most important on moist sites (Figure 8). This does not mean light was not a factor influencing growth on drier sites, merely that other variables were more strongly correlated with growth on the drier sites.

## MANAGEMENT IMPLICATIONS

Our results are limited to a relatively small number of site and stand conditions, however, we can expand our scope of inference to some degree by looking at results from other researchers. The next section contains a list of suggested readings related to these topics. Based on our results, other field observations we have made, plus information in the literature from other studies, we have developed a list of management implications or ideas for managers to consider:

- Although measurable differences in vegetation composition and cover can occur fairly quickly after thinning, it will take many years to determine the overall response to treatment. Studies on new management techniques do not yet have long-term data so the results should be viewed with caution.

- Short-term understory response is strongly influenced by pre-treatment conditions (environmental conditions, presence of established plants, and seed sources) as well as type of treatment.
- Substantial spatial variation can exist in pretreatment cover and species composition; post-treatment response can be assessed more sensitively if pretreatment information is collected and used in the analysis.
- Salal, Oregon grape, vine maple, and salmonberry are examples of clonal shrubs. Although they reproduce by seed, they also reproduce vegetatively (via rhizomes, underground stems, or layering) to form large clonal colonies. Clonal shrubs (especially salal and salmonberry) can expand in cover very quickly when environmental conditions are favorable.
- Clonal shrubs may share resources so variations in growing conditions may be “averaged” within the clone.
- Thinning often favors expansion of clonal shrubs; thus, when they are present, different prescriptions may be necessary to achieve desired understory conditions.
- Large, older individuals of desired shrub species should be considered as legacies to be protected during thinning or other forest operations.
- Repeated thinning will accelerate the production of large diameter trees but may also introduce non-native species and promote development of dense understories. These conditions could delay or prevent the development of plant communities associated with late-successional stands. On the other hand, individual species characteristic of late-successional stands—such as western hemlock—will benefit from thinning. Managers need to determine which species, communities, or structures to target in prescriptions for individual stands.
- Variable density management, practiced on a stand basis (variation in density within a stand) or a landscape basis (varying density from stand to stand) has the potential to accelerate production of large diameter trees in some areas while maintaining optimal conditions for specific vegetation in other areas.
- Release of individual trees rather than a general thinning may prevent undesirable understory conditions from developing on some site types or plant associations.

- “No cut” patches within stands or uncut stands should also be “no entry” areas to prevent ground disturbance to reduce spread of exotic plants and expansion of less desired native species. No-cut patches may also be valuable to protect older shrubs.
- Adoption of one or a few “best guess” management prescriptions over a large portion of the managed forest landscape could result in producing many stands with undesirable vegetation characteristics. Responses to prescriptions should be monitored to verify that they are effectively meeting management objectives.

For those interested in predicting understory characteristics, we offer some additional observations:

- Models predicting growth or percent cover for plants in understory or midstory positions are often more complex and less accurate than models for overstory tree growth because plants below the main canopy are growing in a more complex competitive environment. Predicting functional attributes, such as flowering, is even more difficult.
- Models will vary by species and most will be improved by inclusion of variables that assess site conditions (such as moisture class) or variables that assess overstory competition. Variables selected in prediction models may provide clues to indicate which growth factors are limiting.
- A simple inexpensive technique of measuring light availability (“sunpath”) gave superior results in models predicting height growth to techniques that require expensive specialized equipment and software.

## SUGGESTIONS FOR FURTHER READING

### **New Management Ideas or Techniques**

Carey et al. 1999  
Curtis et al. 1998  
DeBell and Curtis 1993  
Franklin 1989

### **Understory Plant Communities**

Halpern and Spies 1995  
Halpern et al. 1999  
North et al. 1996  
Thysell and Carey 2000

### **Forest Shrubs and Flowering**

Huffman and Tappeiner 1997  
Huffman et al. 1994  
O'Dea and Zasada 1995  
Tappeiner et al. 1991

### **Understory Tree Growth**

Brandeis, et al. 2001  
Carter and Klinka 1992  
Del Rio and Berg 1979  
Wang, et al. 1994

### **Exotic Plant Species**

Heckman 1999  
Soule 1990  
Duncan 2001

### **Other Topics**

Franklin et al. 1986  
Liefers et al. 1999

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## **LITERATURE CITED**

- Brandeis, T.J.; Newton, M.; Cole, E.C. 2001. Underplanted conifer seedling survival and growth in thinned Douglas-fir stands. *Canadian Journal of Forest Research*. 31: 302-312.
- Carey, A.B.; Thysell, D.R.; Brodie, A.W. 1999. The Forest Ecosystem Study: background, rationale, implementation, baseline conditions, and silvicultural assessment. Gen. Tech. Rep. PNW-GTR-457. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 129 p.
- Carter, R.E.; Klinka, K. 1992. Variation in shade tolerance of Douglas-fir, western hemlock, and western red cedar in coastal British Columbia. *Forest Ecology and Management*. 55: 87-105.
- Curtis, R.O.; DeBell, D.S.; Harrington, C.A. [et al.]. 1998. Silviculture for multiple objectives in the Douglas-fir region. Gen. Tech. Rep. PNW-GTR-435. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 123 p.
- DeBell, D.S.; Curtis R.O. 1993. Silviculture and new forestry in the Pacific Northwest. *Journal of Forestry*. 73(special issue): 25-30.
- Del Rio, E.; Berg, A.B. 1979. Growth of Douglas-fir reproduction in the shade of a managed forest. Research Paper 40. Corvallis, OR: Forest Research Laboratory, Oregon State University. 14 p.
- Duncan, S. 2001. Invasion of the exotics: the siege of western Washington. *Science Findings* 38. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 6 p.
- Franklin, J.F. 1989. Towards a new forestry. *American Forestry*. 73 (special issue): 37-44.
- Franklin, J.F.; Hall, F.; Laudenslayer, W. [et al.]. 1986. Interim definitions for old-growth Douglas-fir and mixed-conifer forests in the Pacific Northwest and California. Research Note. PNW-RN-447. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 7 p.
- Halpern, C.B.; Spies, T.A. 1995. Plant species diversity in natural and managed forests of the Pacific Northwest. *Ecological Applications*. 5: 14-934.
- Halpern, C.B.; Evans, S.A.; Nelson, C.R. [et al.]. 1999. Response of forest vegetation to varying levels and patterns of green-tree retention: an overview of a long-term experiment. *Northwest Science*. 73 (special issue): 27-44.
- Heckman, C.W. 1999. The encroachment of exotic herbaceous plants in the Olympic National Forest. *Northwest Science*. 73: 264-276.
- Huffman, D.W.; Tappeiner, J.C., II. 1997. Clonal expansion and seedling recruitment of Oregon grape (*Berberis nervosa*) in Douglas-fir (*Pseudotsuga menziesii*) forests: comparisons with salal (*Gaultheria shallon*). *Canadian Journal of Forest Research*. 27: 1788-1793.

- Huffman, D.W.; Tappeiner, J.C., II; Zasada, J.C. 1994. Regeneration of salal (*Gaultheria shallon*) in the central Coast Range forests of Oregon. *Canadian Journal of Botany*. 72: 39-51.
- Kruger, K.W. 1960. Behavior of ground vegetation under a partially cut stand of Douglas-fir. Research Note 198. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 3 p.
- Lieffers, V.J.; Messier, C.; Stadt, K.J. [et al.]. 1999. Predicting and managing light in the understory of boreal forests. *Canadian Journal of Forest Research*. 29: 796-811.
- McComb, W.C.; Spies, T.A.; Emmingham, W.H. 1993. Douglas-fir forests: managing for timber and mature-forest habitat. *Journal of Forestry*. 91(12): 31-42.
- North, M.; Chen, J.; Smith, G. [et al.]. 1996. Initial response of understory plant diversity and overstory diameter growth to a green tree retention harvest. *Northwest Science*. 70: 24-35.
- O'Dea, M.; Zasada, J.C. 1995. Vine maple clonal development in coastal Douglas-fir forests. *Ecological Applications*. 5: 63-73.
- Soule, M.E. 1990. The onslaught of alien species, and other challenges in the coming decades. *Conservation Biology*. 4: 233-239.
- Tappeiner, J.C.; Zasada, J.C.; Ryan, P.; Newton, M. 1991. Salmonberry clonal and population structure: the basis for a persistent cover. *Ecology*. 72: 609-618.
- Thysell, D.R.; Carey, A.B. 2000. Effects of forest management on understory and overstory vegetation: a retrospective study. Gen. Tech. Rep. PNW-GTR-488. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 41 p.
- Thysell, D.R.; Carey, A.B. 2001. Manipulation of density of *Pseudotsuga menziesii* canopies: preliminary effects on understory vegetation. *Canadian Journal of Forest Research*. 31: 1513-1525.
- Wang, G.G.; Qian, H.; Klinka, K. 1994. Growth of *Thuja plicata* seedlings along a light gradient. *Canadian Journal of Botany*. 72: 1749-1757.
- Worthington, N.P.; Heebner, C.F. 1964. Light thinning of Douglas-fir does not stimulate regeneration. Research Note PNW-16. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 5 p.

## **COMPATIBILITY OF BREEDING FOR INCREASED WOOD PRODUCTION AND LONG-TERM SUSTAINABILITY: THE GENETIC VARIATION OF SEED ORCHARD SEED AND ASSOCIATED RISKS**

Randy Johnson<sup>1</sup> and Sara Lipow<sup>2</sup>

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### **ABSTRACT**

Because breeding imposes strong artificial selection for a narrow suite of economically important traits, genetic variation is reduced in seedlings derived from operational seed orchards. Both quantitative genetics theory and studies of allozyme variation show that seed orchards contain most of the genetic diversity found in natural populations, although low-frequency alleles are often absent from seed orchard populations. Because plantations established with seed orchard seed are frequently maintained for only a single generation, they do not need to preserve the low-frequency alleles that are maintained in the breeding and gene resource populations. Moreover, in the Pacific Northwest, low-frequency alleles are typically maintained in the breeding population and in *in situ* reserves that serve as gene resource populations. Our analysis of theoretical and empirical data indicates that seed orchards with 20 or more selections should provide the same level of risks as seed collected from the natural population.

**KEY WORDS:** Genetic diversity, tree breeding, seed orchards, risks.

### **INTRODUCTION**

Genetic variation is essential for populations to be able to adapt to new stresses such as disease and climate change. The amount of genetic variation required for population viability is dependent on many factors, including the expected life of the population (e.g., rotation age), the number of future generations the population is expected to produce, the environmental variation (over time and space) to which the population must adapt, and the rate that mutation and migration adds genetic variation in the future. On one extreme are agronomic crops that are planted for a single generation lasting less than a year in a relatively uniform environment. On the other extreme are natural populations of forest species that are long-lived and are expected to adapt to changes in climate and environment for many centuries. Forest plantations tend to be somewhere in the middle of this continuum; they must survive for only a single generation, but generation intervals tend to be measured in decades, during which time they experience a variety of environments.

Many forest tree species have active, ongoing tree improvement programs. Breeding activities involve selection for heritable traits such as growth and yield, crown form, and wood quality. Tree improvement enables genetic gain but also may result in undesirable erosion of genetic variation that fosters adaptation and evolutionary success (Namkoong et al. 1988). Genetic variation may be lost at several steps in the tree improvement process including during the breeding cycle and establishment of production populations (i.e., seed orchards or clonal stool beds). Therefore, a question that continues to arise with all breeding programs is: Will the use of improved varieties result in a significant loss of natural genetic variation, hence reducing the long-term sustainability of species and ecosystems that depend on them? An additional question for forest trees concerns the viability of stands produced from seed orchards: Does the stand have sufficient genetic diversity to buffer short-term environmental pressures that it will encounter throughout a typical rotation cycle?

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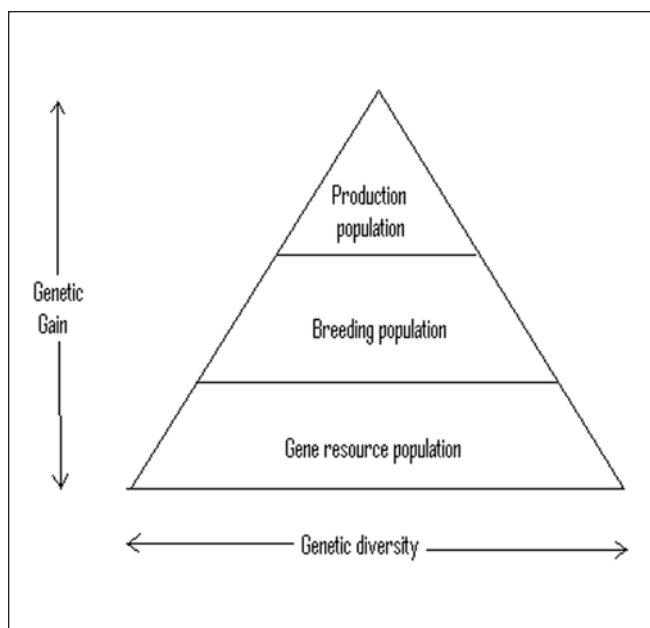


Figure 1—Conceptualization of gain versus genetic variation for a gene resource management program (from Burdon 1995<sup>3</sup>).

The issues surrounding maintenance of genetic variation differ among the three populations that one must consider in a gene resource management strategy. Rowland Burdon (1995<sup>3</sup>) developed a pyramid that conceptualizes the role of various populations to consider in gene resource management (Figure 1). The horizontal axis represents genetic diversity and the vertical axis represents genetic gain, i.e. the level of genetic improvement. Each of these populations is associated with different scales of time and area.

The gene resource population represents all of the available genetic variation that could contribute to the species in future generations. This includes native stands, provenance trials, seed orchard parents, progeny in progeny tests, and operational plantations. Ideally, there will be sufficient genetic variation at this level to maintain the species indefinitely. Because the long-term (evolutionary scale) viability of the species (i.e., the gene resource population) is a major goal, thousands of parents are recommended to maintain the genetic variation at this level (Lande 1995; Lynch 1995; Millar and Libby 1991; Yanchuk 2001).

In the Pacific Northwest, the Pacific Northwest Forest Tree Gene Conservation Group has supported an effort to document the status of the gene resource and breeding populations of eight commercially important conifers (St. Clair

and Lipow 2000). For all eight species (*Abies procera* Rehd., *Picea sitchensis* (Bong.) Carr., *Pinus ponderosa* Dougl. ex Laws., *Pinus lambertiana* Dougl., *Pinus monticola* Dougl. ex D. Don, *Pseudotsuga menziesii* (Mirb) Franco, *Thuja plicata* Donn ex D. Don, *Tsuga heterophylla* (Raf.) Sarg.), extensive and sufficient genetic resources are conserved *in situ* through much of the species regional range. However, for *Pinus monticola* and *Abies procera* there are a few local areas that may warrant additional gene conservation.

In the conceptualized gain:diversity pyramid (Figure 1), the next level is the breeding population; this group represents the individuals that will contribute their genes to the next generation in the breeding program. It tends to be more highly selected, and therefore potentially less variable, than the gene resource population. Breeding populations must have sufficient genetic variation to enable an attractive rate of progress in targeted traits for one or more generations. Suggested minimum population sizes range from tens to hundreds (see reviews by Johnson et al. 2001; and White 1992). For Douglas-fir, the predominant species being bred in the Pacific Northwest, advanced generation breeding programs are well within this range, with most breeding populations carrying over 200 individuals.

At the top of the gain:diversity pyramid is the production population, consisting of seed orchard parents or clones used for operational deployment. These genotypes are typically the best selections from the breeding population. This population must carry adequate genetic variation to sustain one rotation in an operational plantation and realize sufficient genetic gain to warrant the tree-breeding program. Because the primary purpose of the production population is to provide the best possible genetic material for operational planting, the number of selections must be limited, resulting in an unavoidable tradeoff between genetic variation and realized gain. Although maximizing genetic variation is a low priority in this population, substantial genetic variation is nearly always maintained in seed orchards, in the form of dozens or even hundreds of unrelated parent trees.

These three populations are not always different, and many species may not have active breeding and production populations. Or, for species that are in jeopardy of extinction (because of introduced pathogens or other causes), the production population may serve as the primary gene resource population.

<sup>3</sup> Presentation given at the Western Forest Genetics Association meeting, 28 August 1995, Victoria, British Columbia.

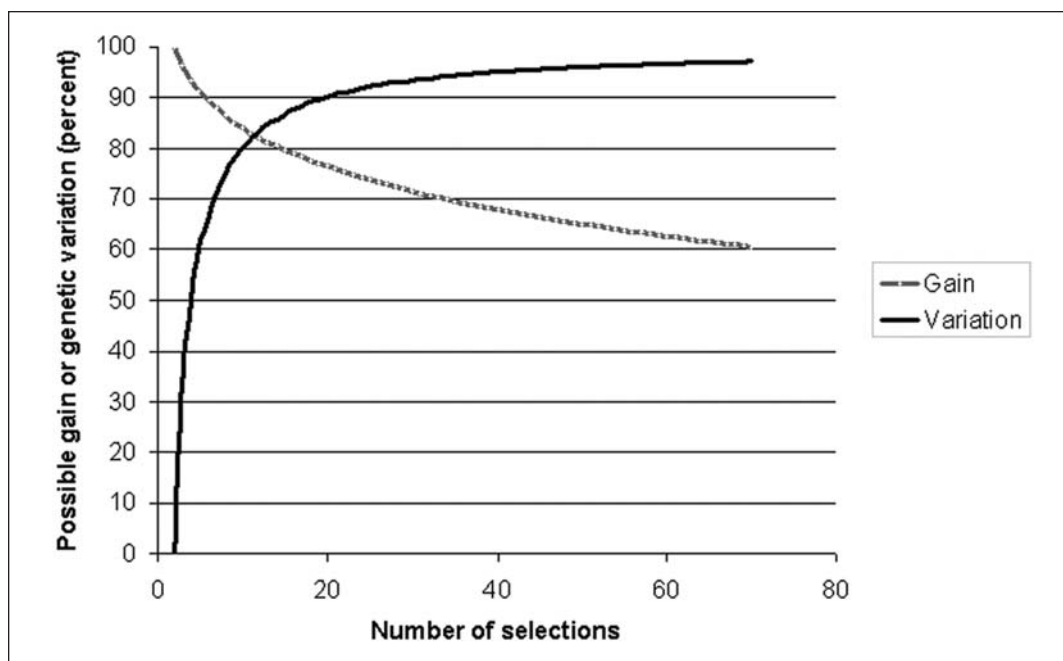


Figure 2—Example of genetic variation and genetic gain associated with seed orchards of differing numbers of clones. Genetic variation is modeled for  $N_e = N/2$ .

This paper reviews the literature that discusses the genetic variation found in seed orchards to help readers understand the risks—or lack thereof—associated with the use of genetically improved seed orchard seed.

## THEORETICAL PREDICTIONS OF GENETIC VARIATION AND CAPTURE OF LOW-FREQUENCY ALLELES

Maintenance of genetic variation in any population, including the seed orchard, primarily involves the preservation of genetic diversity (i.e., heterozygosity) and, to a lesser extent, the maintenance of low-frequency alleles. Low-frequency alleles are valuable to breeding populations but have limited benefits to plantation forests. Low-frequency alleles are usually low frequency for a reason, resulting from deleterious mutations (as suggested in Adams et al. 1998; Schmidtling et al. 1999; Skrøppa 1996), or from past negative natural or artificial selection pressure, or from random drift (a function of sampling). For a trait that is controlled by many genes, each with a small effect, alleles at low frequency contribute little to overall genetic variation because they occur in a small percentage of individuals. Even low frequency alleles with potentially major beneficial effects (e.g., those that confer disease resistance) are of little value in a seed orchard because they could only benefit a small percentage of the trees in resulting plantations.

Such alleles are of much more value in the breeding population where their frequency can be increased to the benefit of future production populations.

### Theoretical Calculation of Genetic Variation

Population genetics theory makes it possible to predict how well a given number of selections capture the genetic variation of a given population. Additive genetic variation is that portion of the total genetic variation that responds to natural and artificial selection. In forest trees, additive genetic variation makes up the largest component of the total genetic variation and is more affected by population size than by nonadditive genetic variation; therefore, a reduction in additive genetic variation provides a conservative estimate of the reduction in the total genetic variation. The formula to calculate the percentage of total additive genetic variation ( $\%V_A$ ) in a seed orchard relative to the natural population from which it is derived is:

$$\%V_A = 100 \times [1 - 1/(2N)],$$

where  $N$  is the number of selections. For obligate outcrossing and monoecious species the equation is modified to:

$$\%V_A = 100 \times [1 - 1/(N)]$$

(Johnson 1998).

Studies indicate that truly random mating (panmixis) does not happen in the seed orchard, because 80 percent of the seed is typically produced by 20% of the clones (Anon. 1976). Although various factors contribute to the unequal reproductive contribution of parents (reviewed by El-Kassaby 2000), they all reduce overall genetic variation in the resulting seed orchard seed. This reduction can be evaluated by examining the effective population size in the seed orchard. Effective population size ( $N_e$ ) is defined as the number of individuals that would give rise to the genetic variance or inbreeding coefficient if mating were actually panmictic (Falconer and Mackay 1996). Estimates of the effective population sizes of seed orchards relative to the census number of clones ( $N$ ) or families vary widely, making it difficult to generalize as to the extent to which genetic variation in the seed orchard crop is reduced relative to the orchard selections. Most of estimates do suggest that the ratio of  $N_e/N$  is greater than 0.5, although within an orchard, there appears to be considerable variation among years (El-Kassaby and Askew 1991; Kjaer 1996). By assuming  $N_e = N/2$ , and substituting  $N_e$  in the above equation, we can obtain a conservative estimate of the additive genetic variation coming from a seed orchard (Figure 2). A seed orchard with 25 unrelated selections contains about 92 percent of the genetic variation of the natural population. In short, theory suggests that seed derived from an orchard of reasonable size (20 or more clones) will harbor most of the genetic variation found in the native population.

Figure 2 demonstrates the relation between genetic gain and genetic diversity for an obligate outcrossing species after substituting  $N$  with an estimate of  $N_e$  (where  $N_e = N/2$ ). Gain increases sharply as selection numbers fall below 30 and genetic diversity increases sharply up to about 20 selections. This tradeoff must be considered when planning a seed orchard.

**Probability of capturing rare alleles**—The probability rare alleles will be lost in a seed orchard with a given number of selections can be calculated. For an outcrossing species, the probability that an allele of frequency  $p$  found in the natural population does not occur in the orchard is  $(1-p)^{2N}$ , where  $N$  equals the number of clones in the orchard. This equation suggests that, in general, a seed orchard with 25 clones will include all alleles with frequency  $> 0.05$  with a 92 percent probability. Again, theory predicts that most alleles will be included in a seed orchard of moderate size.

#### Direct Measures of Genetic Variation Coming from Seed Orchards

Despite the theoretical predictions that a seed orchard contains a representative portion of the genetic variation

found in natural populations, the concern that diversity in seed orchards may be compromised under intense breeding and selection schemes has impelled several empirical studies (Table 1). These studies compare genetic variation within seed orchards with genetic variation found in natural populations from the same or a larger source region. They evaluate presumably neutral allozyme loci and then estimate several population genetic statistics that allow for comparison (Berg and Hamrick 1997). These include:

- Percentage of polymorphic loci (%P)—the percentage of loci that have more than one detected allele. The %P is partly a function of the population sample size, because low-frequency alleles are more likely to be observed in larger samples.
- Allelic diversity—the mean number of alleles ( $A$ ) and the mean number of alleles per polymorphic locus ( $A_p$ ).
- Expected proportion of heterozygous loci per individual ( $H_e$ )—reflects the heterozygosity that would be expected in a population experiencing Hardy-Weinberg equilibrium. It is a function of the proportion of polymorphic loci, the number of alleles per polymorphic locus, and the evenness of allele frequencies within population. It is computed as

$$H_e = 1 - \sum p_i^2,$$

where  $p_i$  is the mean frequency of the  $i$ th allele and is averaged over all loci.

- Observed heterozygosity ( $H_o$ ) is a related statistic. It is figured directly from observed genotype frequencies and thus is affected by inbreeding and other evolutionary processes.

#### Studies Confirm Similar Genetic Variation in Seed Orchards and Natural Populations

Table 1 summarizes values of %P,  $A_p$ ,  $A$ ,  $H_e$ , and  $H_o$  from 14 allozyme studies comparing genetic variation between first-generation seed orchards and natural populations. The general conclusion from these studies is that seed orchards retain most of the genetic variation present in the natural populations from which they were derived, although, as predicted, some low-frequency alleles or alleles that were restricted to only one or a few populations are not included.

In most studies, the values of %P and allelic diversity ( $A$  and  $A_p$ ) did not differ substantially between the means of the natural populations and the seed orchards. This is exactly as theory predicts. Moreover, the capture of genetic variation in the seed orchards was likely enhanced by

differences in sampling methods between the natural populations and the seed orchards. Sampling of natural populations was typically restricted to a single stand, whereas the selections in seed orchards were usually chosen from numerous stands, adding additional opportunities for picking up alleles. Indeed, when selections in a Sitka spruce orchard were sampled across an atypically large area, the %P and A were actually higher in the orchard than in any one sampled natural population (Chaisurisri and El-Kassaby 1994). Additionally, contamination by alien pollen led to higher allelic diversity in the seed produced by an interior spruce orchard relative to the mean of the natural populations (Stoehr and El-Kassaby 1997). Pollen contamination also may have been responsible for the novel alleles detected in the seed orchards of the other species (El-Kassaby and Ritland 1996b; Godt et al. 2001).

When pooled results from natural populations were examined, as opposed to mean values, overall reduced allelic diversity (%P, A, and  $A_p$ ) in the seed orchard selections relative to the source region was revealed; however, measures of heterozygosity ( $H_e$  and  $H_o$ ) were still similar. The reduction in allelic diversity is not surprising as the number of samples from the pooled natural populations were, on average, twice the number of selections from the orchards. The few cases of lower  $H_e$  in the orchard were ascribed to missing low-frequency alleles (Knowles 1985; Moran and Bell 1987; Stoehr and El-Kassaby 1997). Despite some slight variations in patterns of heterozygosity, these combined results again confirm that only a minor reduction of genetic diversity results when selections are chosen for a seed orchard.

### Genetic Diversity in Rogued First-Generation and Advanced-Generation Seed Orchards

Genetic testing in tree improvement enables the breeding values of selections in a breeding population to be determined. Once breeding values have been calculated, first-generation seed orchards can be rogued to leave only the best selections, or second-generation seed orchards can be developed. This process leads to a reduction in the number of parent trees within the seed orchard and, unavoidably, the loss of some genetic variation.

Only one study has directly compared genetic variation in seed orchards at various stages of improvement. El-Kassaby and Ritland (1996b) examined allozyme diversity in 12 first-generation Douglas-fir seed orchards before and after roguing, as well as in four second-generation seed orchards. They report that  $H_e$ , %P, and A did not differ significantly among the various orchard populations. Nevertheless, at each stage in the domestication process,

some rare and local alleles were lost. These results are backed up by two studies of simulated roguing of first-generation seed orchards (Godt et al. 2001; Stoehr and El-Kassaby 1997), both of which show that expected heterozygosity remains high even if up to 50 percent of the orchard parents are removed. The number of alleles per locus drops more rapidly with roguing than does expected heterozygosity, as would be expected with any genetic bottleneck.

### RISKS

A reduced range of genetic variation could potentially result in incremental damage and mortality in plantations if the genes “lost” or under-represented are related to traits that turn out to be important in the environments that the plantation has to face over its lifetime—although the “low-frequency” alleles typically lost would be unlikely to have this kind of substantive effect. Still, with the advent of clonal forestry operations, analyses have been made to estimate the risk potential caused by decreased genetic diversity in clonally propagated plantations. Several assumptions are involved in these estimates, but in general, the number of clones needed to give levels of risk similar to natural populations ranged from 17 to 40, depending on the analysis (Bishir and Roberds 1995; Hühn 1986; Libby 1982; Roberds and Bishir 1997; Roberds et al. 1990). These analyses indicate there should be little increase in risk associated with the level of genetic variation in seed lots from most orchards.

An argument is also sometimes made that the faster growing families typically represented in a seed orchard, although adapted to the climate of the planting zone, may be less resistant to diseases and pests. This argument is based on the premise that there is a physiological tradeoff between growth and defense (Herms and Mattson 1992), and has been demonstrated in comparisons among some species. However, this trend has not been established when one looks at families within a breeding zone. Typically, the opposite is true: empirical studies frequently show that the faster growing families tend to be the healthier families. In Douglas-fir, favorable genetic associations have been shown for growth and resistance to Swiss needle cast (Johnson and Temel 1998), and for growth and terpene content (Kimball et al. 1999), a deterrent to bear damage. Other resistant traits having favorable genetic (or family mean) correlations with growth include: foliage disease (*Cyclaneusma minus* (Butin) Di Cosmo, Peredo and Minter) in *Pinus radiata* D. Don (King et al. 1998), fusiform rust (*Cronartium quercuum* (Berk) Miyabe ex Shirai f. sp. *fusiforme*) (McKeand and Bridgewater 1995) and tip moth

Table 1—Means and population ranges (in parenthesis) of percentage of polymorphic loci (%P), mean number of alleles (A), mean number of alleles per polymorphic locus ( $A_p$ ), expected proportion of heterozygosity ( $H_e$ ), and observed heterozygosity ( $H_o$ ) from seed orchards (SO) and the natural populations (NP). (continued on next page)

| Species                                    | Population  | Number of sample trees (N) | %P               | A                   | $A_p$               | $H_e$                  | $H_o$                  | Citation                                                 |
|--------------------------------------------|-------------|----------------------------|------------------|---------------------|---------------------|------------------------|------------------------|----------------------------------------------------------|
| <i>Picea abies</i> (L.) Karst              | 1 SO        | 45                         | 88               | 2.37                |                     |                        | 0.23                   | Bergmann and Ruetz 1991                                  |
|                                            | 3 NP pooled | 60                         | 100              | 2.5                 |                     |                        | 0.32                   |                                                          |
|                                            | 3 NP mean   | 60                         | 83.7<br>(75-88)  | 2.21<br>(2.0-2.37)  |                     |                        | 0.33<br>(0.22-0.24)    |                                                          |
| <i>Picea glauca</i> (Moench) Voss          | 1 SO        | 40                         | 50               | 1.72                | 2.44                | 0.157                  |                        | Godt et al. 2001                                         |
|                                            | 7 NP pooled | ~336                       | 55.6             | 2.17                | 3.1                 | 0.164                  |                        |                                                          |
|                                            | 7 NP mean   | ~336                       | 46.8<br>(44-56)  | 1.72<br>(1.61-1.83) | 2.55<br>(2.38-2.88) | 0.161<br>(0.157-0.166) | 0.163<br>(0.153-0.181) |                                                          |
| <i>Picea glauca</i> x <i>engelmanni</i>    | 1 SO        | 100                        | 64.7             | 2.4                 |                     | 0.207                  | 0.194                  | Stoehr and El-Kassaby 1997                               |
|                                            | 9 NP pooled | 360                        | 64.7             | 2.7                 |                     | 0.21                   | 0.189                  |                                                          |
|                                            | 9 NP mean   | 360                        | 62.73<br>(53-71) | 2.16<br>(1.9-2.1)   |                     | 0.203<br>(0.154-0.223) | 0.189<br>(0.150-0.226) |                                                          |
| <i>Picea mariana</i> (Mill) Britton et al. | 1 SO        | 58                         | 100              | 2.8                 |                     | 0.327                  | 0.272                  | Knowles 1985                                             |
|                                            | 2 NP mean   | 201<br>(100-101)           | 100              | 2.9<br>(2.8-3.0)    |                     | 0.329<br>(0.321-0.336) | 0.32<br>(0.296-0.345)  |                                                          |
| <i>Picea sitchensis</i> (Bong) Carriere    | SO          | 134                        | 100              | 2.77                |                     | 0.229                  |                        | Chaisurisri and El-Kassaby 1994; Yeh and El-Kassaby 1980 |
|                                            | 10 NP mean  | 782                        | 66.92<br>(54-85) | 1.82<br>(1.62-2.00) |                     | 0.183<br>(0.159-0.207) |                        |                                                          |

Table 1 (continued)—Means and population ranges (in parenthesis) of percentage of polymorphic loci (%P), mean number of alleles (A), mean number of alleles per polymorphic locus ( $A_p$ ), expected proportion of heterozygosity ( $H_e$ ), and observed heterozygosity ( $H_o$ ) from seed orchards (SO) and the natural populations (NP) (continued on next page)

| Species                                           | Population               | Number of sample trees (N) | %P           | A                | $A_p$               | $H_e$               | $H_o$               | Citation                                      |
|---------------------------------------------------|--------------------------|----------------------------|--------------|------------------|---------------------|---------------------|---------------------|-----------------------------------------------|
| <i>Pinus banksiana</i> Lamb.                      | SO                       | 31                         | 44           | 1.67             | 2.5                 | 0.114               |                     | Godt et al. 2001                              |
|                                                   | 5 NP pooled              | ~240                       | 59.3         | 2.04             | 2.75                | 0.114               |                     |                                               |
|                                                   | 5 NP mean                | ~240                       | 46.7 (41-52) | 1.66 (1.59-1.74) | 2.41 (2.33-2.50)    | 0.112 (0.097-0.127) |                     |                                               |
| <i>Pinus caribaea</i> Morelet var <i>caribaea</i> | 1 Seed Orchard           | 109                        | 62.5         | 2.3              |                     | 0.274               |                     | Zheng and Ennos 1999                          |
|                                                   | 5 NP mean                | 80                         | 60.0 (50-75) | 2.26 (2.1-2.3)   |                     | 0.272 (0.250-0.297) |                     |                                               |
| <i>Pinus palustris</i> Mill                       | 3 Seed Orchards - mean   | 30                         | 57.6 (45-68) | 1.88 (1.59-2.05) |                     | 0.112 (0.101-0.129) | 0.111 (0.096-0.122) | Schmidtling and Hipkins 1998                  |
|                                                   | 20 NP plus the 3 SO mean | 618                        | 62.1 (50-86) | 1.92 (1.50-2.27) |                     | 0.105 (0.075-0.147) | 0.103 (0.072-0.144) |                                               |
|                                                   | 20 Seed Orchard pooled   | 162                        | 77.4         | 2.16             |                     | 0.092               |                     | Moran and Bell 1987                           |
| <i>Pinus radiata</i> D. Don                       | 20 Seed Orchard mean     | 162                        | 48.4 (39-55) | 1.58 (1.45-1.65) | 0.091 (0.083-0.097) | 0.089 (0.079-0.097) |                     |                                               |
|                                                   | 5 NP pooled              | a                          | 87.1         | 2.39             |                     | 0.117               |                     |                                               |
|                                                   | 5 NP mean                | a                          | 56.8         | 1.79             |                     | 0.098               |                     |                                               |
| <i>Pinus sylvestris</i> L.                        | 2 Seed Orchards - pooled |                            |              | 3.7              |                     | 0.37                |                     | Rudin et al. 1974 and Rudin and Lindgren 1977 |

Table 1 (continued)—Means and population ranges (in parenthesis) of percentage of polymorphic loci (%P), mean number of alleles (A), mean number of alleles per polymorphic locus ( $A_p$ ), expected proportion of heterozygosity ( $H_e$ ), and observed heterozygosity ( $H_o$ ) from seed orchards (SO) and the natural populations (NP) (continued on next page)

| Species                                                      | Population                             | Number of sample trees (N) | %P                | A    | $A_p$               | $H_e$                  | $H_o$                  | Citation                            |
|--------------------------------------------------------------|----------------------------------------|----------------------------|-------------------|------|---------------------|------------------------|------------------------|-------------------------------------|
|                                                              | 2 Seed Orchards - mean                 |                            |                   | 3.5  |                     | 0.36                   |                        | compared in Adams 1981              |
|                                                              | 3 NP pooled                            |                            |                   | 5.3  |                     | 0.38                   |                        |                                     |
|                                                              | 3 NP mean                              |                            |                   | 4.3  |                     | 0.37                   |                        |                                     |
| <i>Pinus sylvestris</i> L.                                   | 3 SO mean                              | 1227 <sup>b</sup>          |                   |      | 2.66<br>(2.38-2.92) | 0.276<br>(0.258-0.305) | 0.229<br>(0.214-0.245) | Szmidi and Muona 1985               |
|                                                              | 3 NP mean                              | 401 <sup>b</sup>           |                   |      | 2.84<br>(2.69-2.92) | 0.294<br>(0.257-0.316) | 0.249<br>(0.237-0.262) |                                     |
| <i>Pseudotsuga menziesii</i> (Mirb.) Franco Oregon           | 1 SO                                   | 77                         |                   | 3    | 0.247               |                        |                        | Adams 1981                          |
|                                                              | 4 NP pooled                            | 97                         |                   | 3.1  |                     | 0.233                  |                        |                                     |
| <i>Pseudotsuga menziesii</i> (Mirb.) Franco Washington       | 1 SO                                   | 79                         |                   | 2.8  |                     | 0.239                  |                        | Adams 1981                          |
|                                                              | 4 NP pooled                            | 88                         |                   | 3    | 0.249               |                        |                        |                                     |
| <i>Pseudotsuga menziesii</i> (Mirb.) Franco British Columbia | 12 Seed Orchards pooled                | 936                        | 62.5 <sup>c</sup> | 2.28 |                     | 0.172                  |                        | El-Kassaby and Ritland 1996a, 1996b |
|                                                              | (1 <sup>st</sup> generation, unrogued) | (54-114)                   |                   |      |                     |                        |                        |                                     |
|                                                              | 12 SO pooled                           | 731                        | 60.4              | 2.24 | 0.173               |                        |                        |                                     |
|                                                              | (1 <sup>st</sup> generation rogued)    | (37-94)                    |                   |      |                     |                        |                        |                                     |

Table 1 (continued)—Means and population ranges (in parenthesis) of percentage of polymorphic loci (%P), mean number of alleles (A), mean number of alleles per polymorphic locus ( $A_p$ ), expected proportion of heterozygosity ( $H_e$ ), and observed heterozygosity ( $H_o$ ) from seed orchards (SO) and the natural populations (NP)

| Species | Population                   | Number of sample trees (N) | %P           | A                | $A_p$ | $H_e$               | $H_o$ | Citation |
|---------|------------------------------|----------------------------|--------------|------------------|-------|---------------------|-------|----------|
|         | 4 SO pooled                  | 223                        | 56.3         | 2.25             |       | 0.163               |       |          |
|         | (2 <sup>nd</sup> generation) | (40-85)                    |              |                  |       |                     |       |          |
|         | 49 NP pooled                 | 2497                       | 85           | 3.05             |       | 0.163               |       |          |
|         | 49 NP mean                   | 2497                       | 52.6 (40-70) | 2.14 (1.75-2.35) |       | 0.171 (0.122-0.198) |       |          |
|         |                              | (43-61 per population)     |              |                  |       |                     |       |          |

<sup>a</sup> 300 progeny per population with 50 families X 6 progeny.

<sup>b</sup> In Szmidt and Muona 1985 embryos and not adult tissue were examined in both the SO and NP. Also, 3 seed crops from 3 different years were studied per SO.

<sup>c</sup> El-Kassaby and Ritland (1996a, 1996b) considered a locus to be polymorphic only if the frequency of the most common allele was less than 0.95.

(*Rhyacionia frustrana* Zimm.) tolerance (Hedden et al. 2001) in *Pinus taeda* L. and weevil (*Pissodes strobi* (Peck)) resistance in a British Columbia population of interior spruce (*Picea* sp.) (King et al. 1997). (Care must be taken, however, to consider adaptive traits [such as cold and drought hardiness] when selecting from outside of established seed or breeding zones.) Again, the potential impact of genetic variation lost through selection does not appear to increase risk in use of improved orchard progeny.

## CONCLUSION

The theoretical and measured amounts of genetic diversity coming from seed orchards are in agreement. Although seed orchards do not capture all the low-frequency alleles in a population, they do have most of the genetic variation. Both for loss of random genetic diversity (reduction in numbers) and for diversity lost through directional selection, a seed orchard population size of 20 or greater will have over 90 percent of the genetic variation found in the entire population. When used in their native breeding zone (or even when used after testing outside their breeding zone), progeny from seed orchards should have risk properties comparable to natural populations.

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## LITERATURE CITED

- Anonymous. 1976. Twentieth annual report on cooperative tree improvement and hardwood research program. Raleigh, NC: North Carolina State University.
- Adams, W.T. 1981. Population genetics and gene conservation in Pacific Northwest conifers. In: Scudder, G.G.E.; Reveal J.L., eds. Evolution today, proceedings of the second international congress on systematic and evolutionary biology. 401-405.
- Adams, W.T.; Zuo, Z.; Shimizu, J.Y.; Tappeiner, J.C. 1998. Impact of alternative regeneration methods on genetic diversity in coastal Douglas-fir. *Forest Science*. 44: 390-396.
- Berg, E.E.; Hamrick, J.L. 1997. Quantification of genetic diversity at allozyme loci. *Canadian Journal of Forest Research*. 27: 415-424.

- Bergmann, F.; Ruetz, W. 1991. Isozyme genetic variation and heterozygosity in random tree samples and selected orchard clones from the same Norway spruce populations. *Forest Ecology and Management*. 46: 39-47.
- Bishir, J.; Roberds, J. 1995. Analysis of failure time in clonally propagated plant populations. *Mathematical Biosciences*. 125: 109-125.
- Chaisurisri, K.; El-Kassaby, Y.A. 1994. Genetic diversity in a seed production population vs natural population of Sitka spruce. *Biodiversity and Conservation*. 3: 512-523.
- El-Kassaby, Y.A. 2000. Effect of forest tree domestication on gene pools. In: Young, A.; Boshier, D.; Boyle, T., eds. *Forest conservation genetics, principles and practice*. Collingwood, VIC, Australia: CSIRO Publishing: 197-213.
- El-Kassaby, Y.A.; Askew, G.R. 1991. The relation between reproductive phenology and output in determining the gametic pool profile in a Douglas-fir seed orchard. *Forest Science*. 37: 827-835.
- El-Kassaby, Y.A.; Ritland, K. 1996a. Genetic variation in low elevation Douglas-fir of British Columbia and its relevance to gene conservation. *Biodiversity and Conservation*. 5: 779-794.
- El-Kassaby, Y.A.; Ritland, K. 1996b. Impact of selection and breeding on the genetic diversity in Douglas-fir. *Biodiversity and Conservation*. 5: 795-813.
- Falconer, D.S.; Mackay, T.F.C. 1996. *Introduction to quantitative genetics*. 4<sup>th</sup> edition. Essex, England: Longman Group Ltd.: 464 p.
- Godt, M.J.W.; Hamrick, J.L.; Edwards-Burke, M.A.; Williams, J.H. 2001. Comparison of genetic diversity in white spruce (*Picea glauca*) and jack pine (*Pinus banksiana*) seed orchards with natural populations. *Canadian Journal of Forest Research*. 31: 943-949.
- Hedden, R.; Cameron, S.; Cunningham, M.; Nelson, C.D. 2001. Tolerance to tip moth attack in loblolly pine families. In: *Proceedings of the 26<sup>th</sup> biennial southern forest tree improvement conference*. Southern Forest Tree Improvement Committee Publication No. 48: 147-153.
- Herms, D.A.; Mattson, W.J. 1992. The dilemma of plants: to grow or defend. *Quarterly Review of Biology*. 67: 283-335.
- Hühn, M. 1986. Theoretical studies on the necessary number of components in mixtures. 3. Number of components and risk considerations. *Theoretical and Applied Genetics*. 72: 211-218.
- Johnson, G.R.; Temel, F. 1998. Genetics of Swiss needle cast tolerance—early screening and field results. In: Filip, G., ed. *Swiss Needle Cast Cooperative annual report, 1999*. Corvallis, OR: Oregon State University, College of Forestry: 10-11.
- Johnson, R. 1998. Breeding design considerations for coastal Douglas-fir. Gen. Tech. Rep. PNW-GTR-411. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 34 p.
- Johnson, R.; St. Clair, B.; Lipow, S. 2001. Genetic conservation in applied tree breeding programs. In: Thielges, B., ed. *Proceedings, international conference on ex situ and in situ conservation of commercial tropical trees*. Yogyakarta, Indonesia: Faculty of Forestry, Gadjah Mada University: 215-230.
- Kimball, B.A.; Johnson, G.R.; Nolte, D.L.; Griffen, N.L. 1999. An examination of the genetic control of Douglas-fir vascular tissue phytochemicals: Implication for black bear foraging. *Forest Ecology and Management*. 123: 245-251.
- King, J.N.; Carson, M.J.; Johnson, G.R. 1998. Analysis of half diallels mating designs II—results from a third generation progeny test of the New Zealand radiata pine improvement programme. *Silvae Genetica*. 47: 80-87.
- King, J.N.; Yanchuk, A.D.; Kiss, G.K.; Alfaro, R.I. 1997. Genetic and phenotypic relationships between weevil (*Pissodes strobi*) resistance and height growth in spruce populations of British Columbia. *Canadian Journal of Forest Research*. 27: 737-739.
- Kjær, E.D. 1996. Estimation of effective population number in a *Picea abies* (Karst.) seed orchard based on flower assessment. *Scandinavian Journal of Forest Research*. 11: 111-121.
- Knowles, P. 1985. Comparison of isozyme variation among natural stands and plantations: jack pine and black spruce. *Canadian Journal of Forest Research*. 15: 902-908.

- Libby, W.J. 1982. What is a safe number of clones per plantation? In: Heybroek, H.M.; Stephan, B.R.; von Weissenberg, K., eds. Resistance to disease and pests in forest trees; proceedings of the third international workshop on the genetics of host-parasite interactions in forestry. Wageningen, Netherlands: Centre for Agricultural Publishing and Documentation: 342-360.
- Lande, R. 1995. Mutation and conservation. *Conservation Biology*. 9: 782-791.
- Lynch, M. 1995. A quantitative-genetic perspective on conservation issues. In: Avise, J.C.; Hamrick, J.L., eds. Conservation genetics: case histories from nature. New York: Chapman and Hall: 471-501.
- McKeand, S.; Bridgewater, F. 1995. Variance component and genetic gain estimates from 6-year-old diallel tests of loblolly pine. In: Proceedings, 23<sup>rd</sup> Southern forest tree improvement conference. Southern Forest Tree Improvement Committee Publication No. 23: 197-203.
- Millar, C.J.; Libby, W.J. 1991. Strategies for conserving clinal, ecotypic, and disjunct population diversity in widespread species. In: Falk, D.A.; Holsinger, K.E., eds. Genetics and conservation of rare plants. New York: Oxford University Press: 149-170.
- Moran, G.F.; Bell, J.C. 1987. The origin and genetic diversity of *Pinus radiata* in Australia. *Theoretical and Applied Genetics*. 73: 616-622.
- Namkoong, G.; Kang, H.C.; Brouard, J.S. 1988. Tree breeding: principles and strategies. New York: Springer-Verlag, Inc. 180 p.
- Roberds, J.H.; Bishir, J.W. 1997. Risk analyses in clonal forestry. *Canadian Journal of Forest Research*. 27: 425-432.
- Roberds, J.H.; Namkoong, G.; Skroppa, T. 1990. Genetic analysis of risk in clonal populations of forest trees. *Theoretical and Applied Genetics*. 79: 841-848.
- Rudin, D.; Eriksson, G.; Ekberg, I.; Rasmuson, M. 1974. Studies of allelic frequencies and inbreeding in Scots pine populations by aid of the isozyme technique. *Silvae Genetica*. 23: 10-13.
- Rudin, D.; Lindgren, D. 1977. Isozyme studies in seed orchards. Stockholm: Swedish College of Forestry. 23 p.
- Schmidtting, R.C.; Hipkins, V. 1998. Genetic diversity in longleaf pine (*Pinus palustris*): influence of historical and prehistorical events. *Canadian Journal of Forest Research*. 28: 1135-1145.
- Schmidtting R.C.; Carroll, E.; LaFarge, T. 1999. Allozyme diversity of selected and natural loblolly pine populations. *Silvae Genetica*. 48: 35-45.
- Skroppa, T. 1996. Diallel crosses in *Picea abies* II. Performance and inbreeding depression of selfed families. *Forest Genetics*. 3: 69-79.
- St. Clair, B.; Lipow, S. 2000. Pacific Northwest tree gene conservation group. *Western Forester*. 45(2): 17.
- Stoehr, M.U.; El-Kassaby, Y.A. 1997. Levels of genetic diversity at different stages of the domestication cycle of interior spruce in British Columbia. *Theoretical and Applied Genetics*. 94: 83-90.
- Szmidt, A.E.; Muona, O. 1985. Genetic effects of Scots pine (*Pinus sylvestris* L.) domestication. *Lecture Notes Biomathematics*. 60: 241-252.
- White, T. 1992. Advanced-generation breeding populations: size and structure. In: Proceedings: IUFRO conference S2.02-08, breeding tropical trees—Resolving tropical forest resource concerns through tree improvement, gene conservation and domestication of new species. Raleigh, NC: CAMCORE: 208-222.
- Yanchuk, A.D. 2001. A quantitative framework for breeding and conservation of forest tree genetic resources in British Columbia. *Canadian Journal of Forest Research*. 31: 566-576.
- Yeh, F.C.; El-Kassaby, Y.A. 1980. Enzyme variation in natural populations of Sitka spruce (*Picea sitchensis*). 1. genetic variation patterns among trees from IUFRO provenances. *Canadian Journal of Forest Research*. 10: 415-422.
- Zheng, Y-Q.; Ennos, R.A. 1999. Genetic variability and structure of natural and domesticated populations of Caribbean pine (*Pinus caribaea* Morelet). *Theoretical and Applied Genetics*. 98: 765-771.

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*SECTION E*  
**NONTIMBER  
FOREST PRODUCTS**

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## **ASSESSMENT OF WESTERN OREGON FOREST INVENTORY FOR EVALUATING COMMERCIALLY IMPORTANT UNDERSTORY PLANTS**

Nan Vance<sup>1</sup>, Andrew Gray<sup>2</sup>, and Bob Haberman<sup>3</sup>

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### **ABSTRACT**

The plant species that furnish nontimber forest products (NTFP) are an under-assessed but ubiquitous resource in the Pacific Northwest. This study addresses the relation between these understory species and the forest overstory by examining forest inventory data to determine its appropriateness for building predictive models linking forest management and conditions to the abundance and distribution of understory plants. Data from the 1995 inventory of western Oregon, conducted by Forest Inventory and Analysis (FIA), were analyzed to determine if forest condition and environmental variables provide useful correlations with the abundance and cover of NTFP plant species. An assessment of representative NTFP plant species of the Pacific Northwest provided a list of 76 species for the analysis. Of 55 NTFP species found in the database, 14 occurred with plot frequency high enough for statistical analysis. Frequency was significantly correlated with several environmental and forest condition variables. The sampling methodology tended to exclude less abundant and smaller plant species and may not be appropriate for narrowly distributed species.

**KEY WORDS:** Forest inventory, nontimber forest products, understory, plants, FIA, Oregon.

### **INTRODUCTION**

A variety of understory plant species native to Pacific Northwest forests are nontimber forest product (NTFP) resources that are harvested from Pacific northwestern forests and sold in various markets. They are collected for subsistence, education, research, and recreation. These species are well represented in various forest plant communities influenced by land management practices and environmental disturbances that change forest structure and habitat. Harvest practices directly affect populations of particular species. In some cases harvesting has been so heavy that it may have altered abundance and cover. Harvest activities for particular species have increased in the past decade (Vance et al. 2001). But other than permitting reports, little information is available on species distribution, abundance, and location and amount of harvest. Inventories, monitoring, or tracking protocols could quantify trends in species abundance, harvesting, and changes in environmental and forest stand conditions, greatly aiding the sustainable management of these resources.

Broad-scale inventories can provide usable data for evaluating the compatibility of multiple forest values with commodity production. Many understory plant species, especially herbaceous plants, make up a group of forest resources under-valued and not well studied. Yet they are important constituents of biological diversity; many are bio-indicators of ecological landscape units; and numerous species add significant educational, recreational, esthetic, and commercial value to the forest when viewed in resource terms. The many species that furnish nontimber forest products (NTFP) in the Pacific Northwest comprise an important subset of those understory species. Several broad-scale inventories and assessments that sample forested lands include understory vegetation in the sampling process. One such national inventory program that develops forest resource information at the state level is the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forest Inventory and Analysis program (FIA).

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The Forest Service has conducted resource assessments for over 60 years mandated by the McSweeney-McNary Forest Research Act of 1928. Authorized by Congress to inventory the forest resources of the United States, the FIA program, under the Deputy Chief for Research and Development, completed at least one inventory of forest resources for each of the 48 conterminous states. Focusing primarily on the timber resource, statewide inventories were conducted over varying intervals averaging about 10 years nationwide until the 1960s and 1970s. In response to the need for more frequent inventories that provide information about other resources besides timber, the 1974 Resources Planning Act and the 1978 Resources Research Act began to change inventory scope and frequency.

Long term trends defined in the 1990s and continuing today are the rising recreational uses, changes in environmental health, and changes in the broad spectrum of commodities and non-market goods and services demanded of forests (USDA, Forest Service 1992). Broadening forest resource and environmental assessments would increase the information base needed, for programs such as the Resource Planning Act (RPA) assessments and status reports on Criteria and Indicators (C&I) for the Conservation and Sustainable Management of Boreal and Temperate Forests (U.S. Department of Agriculture, Forest Service 1997). Analyses produced from such inventories would help determine the direction of C&I trends. One such effort is the examination of the compatibility of timber harvest with forest health/integrity by evaluating C&I using the FIA database (Donnegan, n.d.). To meet the broader scope of the FIA, a new program will incorporate the plot portion of the Forest Health Monitoring program, including sub-sampling ecosystem attributes such as soil, lichen communities, total vegetative profiles, crown conditions, and surveys for ozone damage (Gillespie and Smith 2000).

The broadening forest uses, multiple values, and the complexity of forest management objectives are increasingly relying on a single inventory that now has over 100 parameters that must be measured and recorded to meet a variety of needs and expectations. The purpose of this study is to determine if the FIA inventory is appropriate for analyzing trends in a set of understory plant species that provide a suite of NTFPs. Analyses may help to define the limitations of the plot data in making population estimates for species underrepresented in the database and in detecting significant trends in species with adequate representation.

## BACKGROUND

Authorized by Congress to inventory the forest resources of the United States, the FIA program at the Pacific Northwest Research Station has completed expanded inventories of forest resources of five western states, Oregon, Washington, California, Alaska, Hawaii, and the Pacific Islands. The Oregon Department of Forestry has conducted an assessment of state lands to document trends in forest resources (Oregon Department of Forestry 1999). The latest inventory conducted by the PNW FIA program has broadened the assessment of forest conditions on state and private lands to address a range of resource issues in the Pacific Northwest (Azuma et al., in press). The 1995-1997 western Oregon inventory represented the fourth visit to a permanent grid of established field plots. Each inventory has been modified to include more resource information.

The FIA inventory of Oregon is used to provide information for resource planners, policy analysts, and others involved in forest resource decision-making. Analyzed collected data provide information on forestland ownership classes and degree of urbanization; timber volume, mortality, and removals, potential forest productivity; opportunities for silvicultural treatment; and kind and area of wildlife habitats. The inventory design is based on a modified double sample for stratification (Woudenberg and Farrenkopf 1995). The inventory data can be stratified into forest types, political boundaries, and ecologically based sub-units. The stratification reduces overall variance, resulting in more precise estimates of forest area and volume statistics. Information can be generated from over 100 variables calculated from data collected on inventory field plots. These include forest type, environmental parameters (slope, aspect, etc), tree volume, basal area, stocking and biomass estimates, coarse woody debris, and understory vegetation, including species and growth form cover.

Forest Inventory and Analysis plot data is effective when used with other resource inventories to fill in sampling gaps and broaden the scope of information (Ohmann and Spies 1998). The data have been used (about one third of all the plots used) with other resource inventory data from sampled plots on Bureau of Land Management (BLM) districts and national forests to develop regional-scale patterns of woody plant community structure (Ohmann and Spies 1998). The authors demonstrated that, despite some limitations in direct gradient analyses, multivariate analysis of the data enabled the quantification and mapping of regional ecological patterns of a subset of forest vegetation. The FIA data were also used to develop predictive models

for the distribution and abundance of shrubs (Kerns 2001). Explanatory variables differed by land ownership (public, private industrial, private non-industrial); nevertheless trends in shrub abundance in relation to stand closure and different successional stages were found. Environmental variables also were correlated with deciduous shrub abundance. Kerns concluded that on FIA surveyed lands, variable site and disturbance histories, and other factors precluded developing strong regression models of shrub abundance based on the forest stand data used in the analysis. For selected understory species, life form, or functional groups, data produced under the sampling protocol is perhaps not sufficient for statistical analyses to make reliable inferences or predictive models.

The structure of herbaceous or small shrub layers in relation to stocking, stand structure, and overstory canopy conditions of forests in various successional stages has been described by McKenzie et al. (2000); Klinka et al. (1996); Halpern and Spies (1995). It is well understood that the overstory can exert a strong influence on the composition and cover of understory plant communities; however, it would be useful if a broad scale forest sampling could suggest how different land ownerships, environmental conditions, development and structure of coniferous or mixed hardwood and conifer stands, and their interactions may influence specific plants in the understory. Examining a database of many samples taken across a large sampling area at one point in time might also provide information based on the ability to capture the variation of forest conditions that occur over time. However, caution is necessary when working with a database developed primarily for a large resource inventory. The most important criteria that determine how sampling should proceed should address the primary question and the scale at which to answer it (Dale 1999). Once a sampling design is in place, how do we determine if the question and the scale are appropriate? When analyzing understory species using a dataset developed through a pre-existing sampling design developed primarily for large scale resource questions, it is appropriate to understand what inferences to make for species distributed across a vegetative layer that may vary widely under a given set of forest conditions and for which finer scale sampling is more appropriate.

A multiple regression approach used on the database assumes that correlations between independent and dependent variables, such as stocking and species cover, are derived from a sampling scheme that represents the range of stocking in which the species is found. It also requires a sufficient number of plot samples to span a range of environmental

and forest stand-specific variables, such as stocking conditions, within the species' range. In addition, stratification by such factors as stand type or ownership may reduce variation, but meaningful analysis requires that each factor be sufficiently distributed across the sampled landscape to include enough variation in forest conditions and a large enough range of environmental values for correlating with abundance and cover.

## METHODS AND APPROACH

Between 1995 and 2001, biological, ecological, and use information was collected and compiled on about 76 vascular plant species identified as NTFP resources (Vance et al. 2001). The list of plant species evolved out of five years of research on plant resources in the Pacific Northwest including northern California. The information was acquired and organized in multiple stages. First, a selection process was developed for including species; second, information categories were defined and refined; and third, information was collected and carefully documented for each of the species.

The species list was compiled first from permit lists obtained from the U.S. Department of Agriculture, Forest Service and U.S. Department of Interior, Bureau of Land Management. These lists provided the names of species for which permits were obtained in the U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. Additional species were added based on recommendations from harvesters and business owners who knew that other products were being collected.

Information, which included species description, ecology, biology, cultivation, harvest techniques, uses, and markets, was gathered from a variety of documents. Important sources of unpublished information were provided from people with experience or knowledge of particular species with regard to harvesting or processing. Information was also referenced against several lists including threatened and endangered species lists, regional sensitive plant species lists, United Plant Savers, and lists of seeds commercially available or plants in commercial cultivation. From this process, a list of 76 herb, shrub, and tree species found in western Oregon was generated for which comprehensive information was gathered.

Most of the herbaceous species generally are not yet mapped at a statewide level or inventoried using a broad, systematic sampling scheme. It was an appropriate next step to determine if the FIA program's inventory data for western Oregon forests was appropriate for creating reliable

**Table 1—Height and frequency of 55 herbaceous and woody plant species found in western Oregon; height used as an indicator of size**

| Plant Height Range<br>(cm) | Mean Number of Occurrences |
|----------------------------|----------------------------|
| 1,000-2,000                | 222                        |
| 500-999                    | 192                        |
| 100-499                    | 122                        |
| 1-99                       | 12                         |

**Table 2—List of shrub and herbaceous understory plant species harvested for non-timber forest products with highest plot frequency in western Oregon Forest Inventory and Analysis (FIA) 1995-1997 database, life form, number of occurrences in plots, and frequency (total plots = 1,125)**

| Common name            | Botanical name              | Lifeform | Plots<br>number | Frequency<br>% |
|------------------------|-----------------------------|----------|-----------------|----------------|
| Western sword fern     | <i>Polystichum munitum</i>  | fern     | 824             | 73.0           |
| Salal                  | <i>Gaultheria shallon</i>   | shrub    | 551             | 48.8           |
| Vine maple             | <i>Acer circinatum</i>      | shrub    | 534             | 47.3           |
| Bracken fern           | <i>Pteridium aquilinum</i>  | fern     | 516             | 45.7           |
| Dwarf Oregon grape     | <i>Berberis nervosa</i>     | shrub    | 513             | 45.5           |
| Buckthorn              | <i>Frangula purshiana</i>   | shrub    | 371             | 32.9           |
| Elderberry             | <i>Sambucus racemosa</i>    | shrub    | 263             | 23.3           |
| California huckleberry | <i>Vaccinium ovatum</i>     | shrub    | 146             | 12.9           |
| Oregon grape           | <i>Berberis aquifolium</i>  | shrub    | 87              | 7.7            |
| Beargrass              | <i>Xerophyllum tenax</i>    | herb     | 56              | 5.0            |
| Devil's club           | <i>Oplopanax horridum</i>   | shrub    | 53              | 4.7            |
| Stinging nettle        | <i>Urtica dioica</i>        | herb     | 43              | 3.8            |
| Pipsissewa             | <i>Chimaphila umbellata</i> | herb     | 39              | 3.5            |
| St. John's wort        | <i>Hypericum perforatum</i> | herb     | 33              | 2.9            |

species distribution maps and modeling the relationship of these species to forest conditions on a broad scale. The western Oregon FIA inventory used for analysis was conducted between 1995 and 1997 on state and privately owned forestlands. Forestland is defined as land that had, or previously had, at least 10 % tree canopy cover and was not developed for non-forest use, e.g. parks, urban uses, grazing, or agriculture. Because the inventory included taking plot data of herbaceous species presence and cover, the frequency and cover of certain understory plants, particularly those of commercial value, may be related to other environmental and stand variables.

The field plot sample design consists of a systematic grid with 5.4 km spacing (one point per 3,000 ha). At each forest grid location, sample plots were installed by systematically installing (or remeasuring) five subplots placed over a two ha area. Understory vegetation was sampled on five m radius plots around each subplot center. All species of shrubs, and of trees <2.5 cm DBH ("seedlings") were recorded; "herb" species (forbs, graminoids, and ferns) were recorded if present at >3 % cover. Overstory trees were sampled with variable radius plots on the same subplots, and tree canopy cover was measured using line-intercept transects (51 m per subplot).

Species sampled were categorized by life form (e.g. *Alnus rubra* was sampled as a tree, *Alnus sinuata* was sampled as a shrub). Crews were instructed to collect samples of unknown species and attempt to identify them in the evenings. Generic or unknown records for sampled plants were allowed. Generally, one could expect very good taxonomic ability for trees, moderate for shrubs, adequate for the most common forbs and ferns, and limited for graminoids.

Because the subplots were systematically placed, they often sampled different forest types, stand age classes, or land types, termed "conditions" (e.g. clearcut and pole stand, road and forest). Obvious differences in vegetation types were distinguished and mapped, and all collected data were individually identified as to its vegetation type. It is possible that for forest "conditions" the area sampled could be considerably less than the standard five subplots. Where multiple conditions occurred in the same subplot, understory vegetation was only recorded for the condition at subplot center.

For the statistical analyses, the first step was to fit linear models to the frequency and cover data using environmental variables (e.g. precipitation, elevation, aspect, slope). Logistic regression was used for the frequency data, using

the odds ratio for each plot (number of subplots with species/number of subplots sampled). Stepwise regression was used for the cover data, using the average cover of a species on a plot across all subplots sampled (subplots without the species were given a cover of zero). The best models were chosen for each species using the criteria of the best fit of significant variables to the data (a manual stepwise procedure was used for the logistic regression). Tree canopy cover was then added to the model to determine whether, given the effect of environment, canopy cover was significant and least-squared means were computed.

## DISCUSSION

The frequency of occurrence (constancy) on plots out of a total of 1,127 was analyzed for 55 NTFP plant species identified in the western Oregon FIA database. The frequency of occurrence for most plant species was too low to subject to further regression analysis. The 10 species with the lowest frequency (appeared once) were primarily herbs while the 10 plants highest in frequency were mostly shrubs and small trees. This suggests that sampling method (plants were recorded only if > 3 % in cover), size (Table 1), and probably distribution pattern influence frequency. Using a criterion for a species to have a minimum plot frequency of 30 for inclusion in the analysis, 14 herb and shrub species were analyzed from 55 in the database out of the original 76 plant species documented as being harvested for nontimber forest products in the Pacific Northwest (Table 2).

By definition, a comprehensive inventory encompasses large variation. To reduce variation, the data were stratified by forest types. Forest types were based on the dominant species on a plot, and were lumped into forest type groups (Table 3). The non-stocked type was a previously-forested site that had few or no trees present. Because most of the species used in the analysis are found primarily in the wet conifer and wet hardwood types, data gathered from plots in these types were used in the analysis.

Initial regression analysis indicated that stand age, canopy cover, and ownership were correlated with frequency of occurrence for many but not all species. However the results are to be interpreted with caution. A systematic inventory is not a balanced design. For example, the plots with the oldest stand age tend to occur in the southern part of the inventory area, and the private non-industrial ownership are found primarily in the lower-elevation valley margins. Environmental variables precipitation and elevation were correlated with plot frequency of most species.

**Table 3—Number of plots in each forest type with dominant tree species from western Oregon Forest Inventory and Analysis (FIA) 1995-1997 database; species listed from most abundant to least; forest types with less than one plot not shown**

| Forest Type          | Botanical name                  | Number |
|----------------------|---------------------------------|--------|
| Dry Conifer type     |                                 |        |
| Grand fir            | <i>Abies grandis</i>            | 45     |
| Incense cedar        | <i>Calocedrus decurrens</i>     |        |
| White fir            | <i>Abies lasiocarpa</i>         |        |
| Lodgepole pine       | <i>Pinus contorta</i>           |        |
| Ponderosa pine       | <i>Pinus ponderosa</i>          |        |
| Dry hardwood type    |                                 | 144    |
| Oregon white oak     | <i>Quercus garryana</i>         |        |
| Pacific madrone      | <i>Arbutus menziesii</i>        |        |
| Tanoak               | <i>Lithocarpus densiflorus</i>  |        |
| California black oak | <i>Quercus kelloggii</i>        |        |
| Canyon live oak      | <i>Quercus chrylosepis</i>      |        |
| Wet type conifer     |                                 | 732    |
| Douglas-fir          | <i>Pseudotsuga menziesii</i>    |        |
| Western hemlock      | <i>Tsuga heterophylla</i>       |        |
| Sitka spruce         | <i>Picea sitchensis</i>         |        |
| Western red cedar    | <i>Thuja plicata</i>            |        |
| Noble fir            | <i>Abies procera</i>            |        |
| Pacific silver fir   | <i>Abies amabilis</i>           |        |
| Port-Orford cedar    | <i>Chamaecyparis lawsoniana</i> |        |
| Wet hardwood type    |                                 | 180    |
| Red alder            | <i>Alnus rubra</i>              |        |
| Bigleaf maple        | <i>Acer macrophyllum</i>        |        |
| Black cottonwood     | <i>Populus trichocarpa</i>      |        |
| Oregon ash           | <i>Fraxinus latifolia</i>       |        |
| Willows              | <i>Salix species</i>            |        |
| California laurel    | <i>Umbellularia californica</i> |        |
| Non-stocked          |                                 | 26     |

For species with sufficiently high plot frequency, maps showing plot distribution across public and private ownerships are often useful and can be generated. The map of total number of plots across ownerships shows the distribution of the ownerships (Figure 1). For the total analysis, interpretation of the data would proceed with attention to the caveats described in this paper.

A major consideration when using selected plant species rather than large vegetative groupings is their distribution and abundance over the sampled landscape. A predictive

model would have the highest reliability for large herbaceous species, such as *Polystichum munitum*, that are common and widely dispersed. Despite significant correlations of frequency with factors used in the analysis, sampling error for species less widely distributed, but abundant, may produce spurious results. Systematic sampling allows an accurate, unbiased description of forest resource conditions over large areas. However, since the number of sample plots is directly proportional to aerial extent, forest types that cover relatively small areas are sampled by relatively few plots. Within a plot, plants with small dimensions and low cover are under-sampled in a sampling scheme that does not

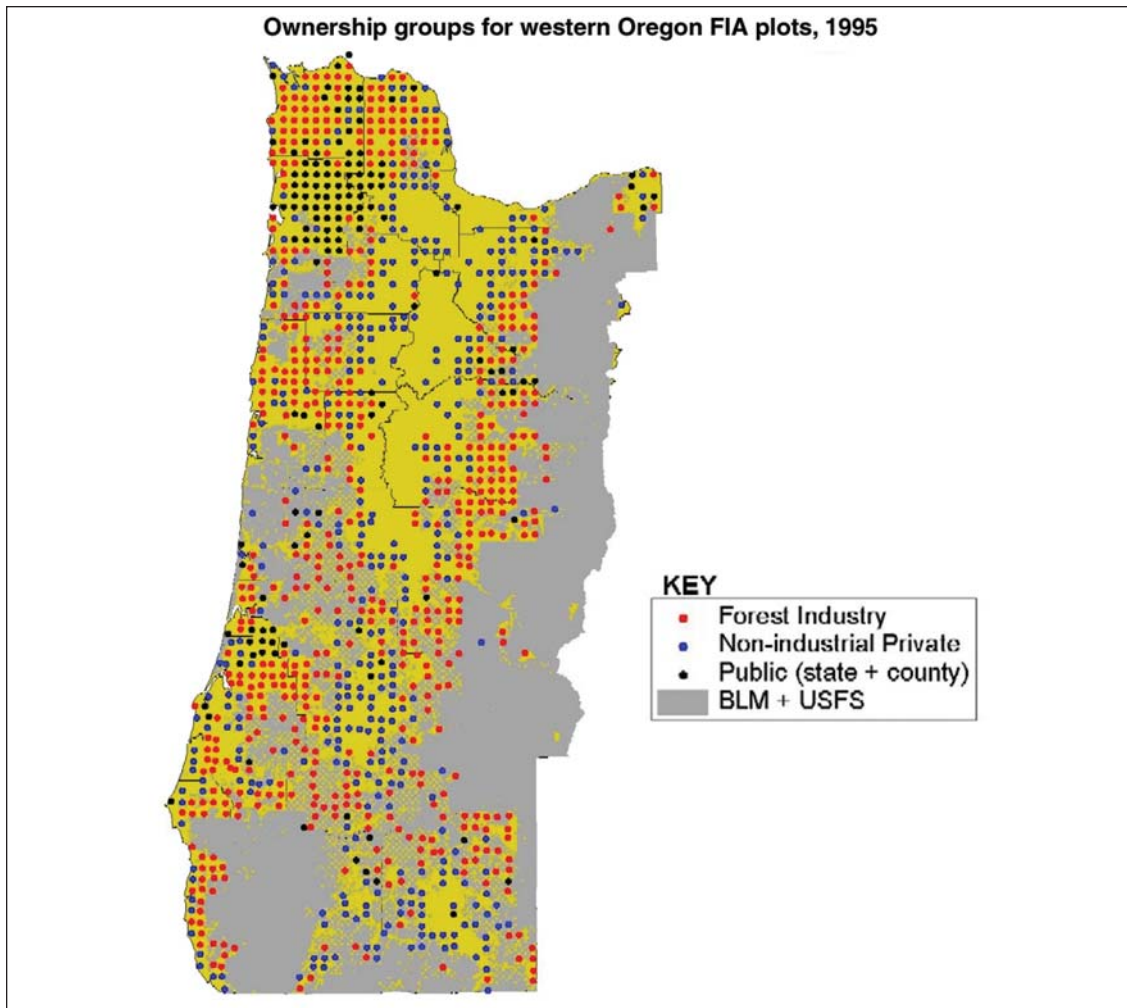


Figure 1—Map of Forest Inventory and Analysis (FIA) plots by land ownership groups in western Oregon.

include species with less than 3% cover. As data are subdivided into smaller areas, sampling errors increase and the reliability of estimates decreases (Woudenberg and Farrenkopf 1995).

## CONCLUSIONS

The various sampling methods, design, and sampling error, and the size and distribution of the species discussed above are important considerations for building a reliable predictive model or making inferences based on statistical correlations. Such broad-scale inventories are useful for coarse vegetative groupings, or for common and large species where the correlation of vegetation and environment increases with increasing grain size or scale (Dale 1999). However, they are limited for most herbaceous species in western Oregon outside of broad vegetational groupings.

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## LITERATURE CITED

- Azuma, D.L.; Bednar, L.F.; Hiserote, B.A.; Veneklase, C.A. [In press]. Timber resource statistics for western Oregon. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
- Dale, M.R.T. 1999. Spatial pattern analysis in plant ecology. Cambridge University Press, Cambridge, England. 326 p.

- Donnegan, J. [N.d.] Trends in Criteria and Indicators for Forested Lands in the Pacific States. [Manuscript in preparation]. On file with: Joe Donnegan, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forest Science Laboratory, P.O. Box 3890, Portland OR 97208.
- Gillespie, A.J.R.; Smith, W.B. 2000. Introduction to the Forest Inventory and Analysis Program. <http://fia.fs.fed.us>. USDA Forest Service, National FIA program Staff, Washington, D.C. Updated 10/2000. (5 November 2001).
- Halpern, C.B.; Spies, T.A. 1995. Plant species diversity in natural and managed forests of the Pacific Northwest. *Ecological Applications* 5: 913-934.
- Kerns, B.K. 2001. Factors that Influence the Distribution and Abundance of Shrubs in Coastal Oregon Forests (Abstract). Poster presented at 86th Annual Meeting, Ecological Society of America, Madison WI.
- Klinka, K.; Chen, H.Y.H.; Wang, Q.; de Montigny, L. 1996. Forest canopies and their influence on understory vegetation in early-seral stands on west Vancouver Island. *Northwest Science*. 70: 193-200.
- McKenzie, D.; Halpern, C.B.; Nelson, C.R. 2000. Overstory influences on herb and shrub communities in mature forests of western Washington, U.S.A. *Canadian Journal of Forest Resources*. 30: 1655-1666.
- Oregon Department of Forestry. 1999. Oregon's Forests at the Millennium: First Approximation Report. State of Oregon, Salem, OR. <http://www.odf.state.or.us/rp/FAR/intro.asp>. (5 November 2001).
- Ohmann, J.L.; Spies, T.A. 1998. Regional gradient analysis and spatial pattern of woody plant communities of Oregon forests. *Ecological Monographs*. 68: 151-182.
- U.S. Department of Agriculture, Forest Service. 1992. Forest Service resource inventories: an overview. Forest Inventory, Economics, and Recreation Research staff. Washington, DC. 39 p.
- U.S. Department of Agriculture, Forest Service. 1997. Report of the United States on the criteria and indicators for the sustainable management of temperate and boreal forests. U.S. Department of Agriculture, Forest Service, Washington, DC. 211 p.
- Vance, N.C.; Borsting, M.; Pilz, D.; Freed, J. 2001. Special forest products: species information guide for the Pacific Northwest. Gen. Tech. Rep. PNW-GTR-513, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 169 p.
- Woudenberg, S.W.; Farrenkopf, T.O. 1995. The Westside Forest inventory database: user's manual. <http://www.srsfia.usfs.msstate.edu/wwman.htm>. (19 October 2001).

## ASSESSING COMMERCIAL UNDERSTORY SPECIES: QUANTITY, QUALITY, SUPPLY AND DEMAND

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### ABSTRACT

To provide information for compatible commercial understory species and timber management approaches, our study focused on the following questions. Do suitable methods or databases exist to assess commercial understory species quantity and quality? Can we determine how timber management, specifically overstory manipulations, impacts commercial understory species quantity and quality? To address the first question, we conducted a synthesis of current inventory methods and databases for understory species and the adequacy of these methods and databases to provide appropriate information about commercial quantity and quality. We found that sampling methods exist or are being developed that can be applied to NTFP species for inventory and monitoring purposes. However, information and methodology regarding commercial quality and quantity are lacking. Current forest resource surveys frequently do not provide appropriate spatial and temporal resolution for local information needs and commercial quantity and quality data are lacking. To address the second question, we conducted two studies in western Oregon. Our results showed that understory development and relationships with overstory variables have deterministic components that can help guide compatible management; but, to best determine how silvicultural treatments might affect commercial understory species supply, it is important to take into account product attributes, species and site specific responses.

**KEY WORDS:** Nontimber forest products, inventory methods, forest structure, understory, overstory, inventory databases.

### INTRODUCTION

Nontimber forest products (NTFP) are derived from biological resources collected in forests and grasslands for personal, educational, commercial, cultural, recreational and scientific use. Examples include foods such as huckleberries (*Vaccinium membranaceum*), floral greenery such as salal (*Gaultheria shallon*), and medicinal products like cascara (*Rhamnus purshiana*). In the Pacific Northwest, the harvest and sale of understory species is a multimillion-dollar commercial industry that employs over 10,000 persons in seasonal and permanent positions in this region (Blatner and Alexander 1998; Schlosser et al. 1991). For example, since 1992, the value of U.S. moss and lichen exports has been increasing steadily, with as much as \$13 million worth of moss and lichens exported from the Pacific Northwest in 1998. The greatest value in U.S. foliage exports comes from fresh foliage; salal is one of the most significant wild-

harvested understory species exported from the Pacific Northwest. Because many of these exports are wild-growing, mostly native species (Alexander et al. 2002, Vance et al. 2001), exact amounts are often difficult to calculate from U.S. Census export data.

There are many knowledge gaps concerning commercial understory species in the Pacific Northwest. Harvesters, biologists, and the general public have expressed concern about commercial harvest of NTFP, particularly those for which little biological information exists. Information about what is being harvested, and in what quantities, future demand trends, and the impact of timber management on species are often incomplete and not integrated across disciplines. In order to provide information for compatible commercial understory species and timber management approaches, our study focused on the following questions. Do suitable methods or databases exist to assess commercial

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understory species quantity and quality? Can we determine how timber management, specifically overstory manipulations, impacts commercial understory species quantity and quality? To address the first question, we conducted a synthesis of current inventory methods and databases for understory species and the potential adequacy of these methods and databases to provide appropriate information about commercial quantity and quality. To address the second question, we conducted two studies in western Oregon. We discuss and synthesize our results below.

## **NONTIMBER FOREST PRODUCTS INVENTORY ASSESSMENT**

Inventory and monitoring are critical to assess resource sustainability, determine product economic value and marketability, and decide whether appropriate management is to emphasize conservation, use, or enhancement of the resource. Inventory data is available from a number of sources, or a combination thereof, including local and indigenous knowledge, existing forest resource inventories, statistically designed inventories, scientific investigations (hypothesis testing), and holistic studies embracing social, political and biophysical processes. The type, relevance and cost of information provided by each of these approaches differ considerably, so managers, stakeholders and policy makers will benefit from understanding the strengths and limitations of various strategies used to assess resource conditions and trends. We conducted a synthesis of nontimber forest product inventory methods to provide detailed, but relatively nontechnical information regarding methodologies and issues to consider when designing and implementing an inventory and monitoring program, examining or analyzing existing data, or formulating policies based on a resource assessment. A more exhaustive analysis is in Kerns et al. (2002).

### **Inventory and Monitoring Methodology**

To inventory a resource is “to account quantitatively for goods on hand or provide a descriptive list of articles giving, at a minimum, the quantity or quality of each” (Lund and Thomas 1989). Inventories provide a snapshot of the resource at a single point in time. In contrast, resource monitoring is a dynamic activity that has temporal elements: “the process of observing and measuring over a period of time to detect change or to predict trends” (Lund and Thomas 1989).

Strategies used to assess resource conditions and trends can be broken into three key areas: (1) descriptive and nonstatistical, (2) statistical, scientific and research (hypothesis

testing), and (3) holistic. Descriptive and nonstatistical approaches include using local knowledge, ethnographic methods, species checklists (presence/absence) and historical photos. For example, in an ethnobotanical study, a researcher might conduct interviews to compile a list of plants used by local people that occur in a particular area. Some biodiversity assessments, such as Conservation International’s Rapid Assessment Program (e.g., Killeen and Schulenberg 1999), include only species’ presence and absence because quick assessment of an unknown area is the primary goal. Historical photos and repeat photography are commonly used to document vegetation change (Hall 2001; Hasting and Turner 1965). Descriptive and nonstatistical inventories yield important information regarding species distribution and abundance, are generally relatively inexpensive to conduct, and provide a context for local use, history and customs. These types of studies provide limited or no information for specific objectives such as quantitative biometric analyses and predictive modeling.

Statistical inventories can include a single species or multiple species and resources. Although properly conducted statistical assessments are often more expensive and time consuming than descriptive methods, they often provide more specific information for assessing resource conditions, estimating commercial productivity, sustainability, species response to harvest and management, and are necessary for most monitoring activities. Issues such as specific sampling designs, selection of sampling units, replication, and sample independence need to be evaluated carefully. It is important to develop and assess sampling methods considering the spatial and temporal distribution; size, life and growth form; and biological traits of the species and product of interest (Elzinga et al. 1998; Kent and Coker 1992). For instance, edible fungi are nontimber products that exhibit a wide range of spatial and temporal variability and present unique sampling challenges (Amaranthus and Pilz 1996; Arnolds 1992; Castellano and Trappe in press; O’Dell et al. 2000; Pilz et al. 1998a, 1998b; Pilz and Molina 2002). Although many sampling methods exist for nontimber product species, these methods are largely focused on answering biological and ecological questions. Methods for assessing product quality and quantity attributes are being developed for some NTFP (e.g. fungi, Pilz and Molina 2002); however, for many other products, such methods are lacking (Kerns et al. 2002).

For monitoring activities, sampling designs and measurement techniques should be selected so that error values are low. This is particularly true when it is important to detect small changes. Monitoring also requires that accurate measurements be made on plant species or products to

detect changes that are biologically, ecologically and/or socioeconomically significant. Consultation with a statistician is highly recommended before starting a new monitoring project. Additional information on monitoring is in Ferriss-Kaan and Petterson (1992), Goldsmith (1991); Elzinga and Evenden (1997); and Elzinga et al. (1998).

For nontimber forest product species, holistic approaches can provide very useful information that a statistical approach would not (Kerns et al. 2002). Holistic methods collect information on the biophysical status of natural resources plus the social, political and economic contexts in which management decisions are made. Interdisciplinary natural resource assessments are part of a larger effort to integrate human dimensions—the social, political, and economic processes and data—biophysical factors (Cordell et al. 1999; Endter-Wada et al. 1998). For example, a team of scientists used an interdisciplinary effort to determine the impacts of chanterelle mushroom harvests on humans and natural systems in the Pacific Northwest (Liegel et al. 1998a, 1998b; Love et al. 1998; McLain et al. 1998; Pilz et al. 1998a, 1998b). Not only were multiple stakeholders involved in study conception, implementation, data analysis, synthesis and report writing, but economic and social studies were also included and integrated into a holistic guide for managing chanterelle mushrooms. Although holistic efforts require complex planning and a significant investment of human and financial resources, the integrated knowledge gained can be well worth the cost.

### Using Existing Databases

Inventory and monitoring of forested lands in the United States have been conducted at various scales primarily by three different programs: USDA-FS Forest Inventory and Analysis (FIA), USDA-FS Forest Health Monitoring (FHM), and the USDA National Forest System Resource Inventories (NFS). These programs were established primarily as statistical inventories to estimate the productivity and health of timber and associated resources. However, statutory requirements, coupled with recent environmental concerns such as species biodiversity and emphasis on an ecosystem management paradigm, have refocused federal inventory planning. The result has included a broader range of data collection measures and information on nontimber species.

The 1998 Agricultural Research, Extension, and Education Reform Act contained several mandates that directed the USDA Forest Service FIA Program to make

significant changes in inventory methods, including switching to annual surveys, developing a core program that will be implemented consistently across the USA, including the USDA National Forests, and producing comprehensive state reports at five-year intervals (Gillespie 1999). Achieving consistency and linking databases in federal agency resource monitoring programs is now a high priority (Olsen et al. 1999). In the Pacific Northwest, implementation and merging of FIA/FHM and NFS inventories is currently underway.

It is unclear how long it will take to merge FIA/FHM/NFS forest resource inventories, but it will likely be years before data are available that represent new standards for consistent and linked databases. Presently, using inventory data across all western Oregon forested lands (multiple land-owners) involves obtaining several data sources, sampling designs, and methodologies (Kerns and Ohmann, N.d.<sup>5</sup>, Ohmann and Spies 1998). For example, FIA ground samples are located 5.5 km apart along a systematic grid and cover of understory species was recorded by layers (shrub and herb) by species on all subplots (<http://fia.fs.fed.us/>, accessed 02/2002). Species with less than 3% cover are not recorded. The Region 6 (Oregon and Washington) USDA-NFS resource inventory (Current Vegetation Survey (CVS)) <http://www.fs.fed.us/r6/survey/>, accessed 02/2002) uses a more intensive spatial grid of 2.7 km (wilderness and USDI-BLM lands used a 5.5 km grid) and understory species were recorded only if they are an indicator species specific to each vegetation association and district. Inclusion of research (e.g. USDI-BLM Forestry Intensive Research Program), USDA-FS Area Ecology Program, and other data sources can provide additional information, but sampling designs and methodologies will not be consistent.

Rapid growth in harvesting of nontimber forest species has prompted some NFS land managers to establish inventory and monitoring programs for particular products (Peck 1998; Pilz and Molina 2002). Most national forests can provide summary information, such as species frequency and cover, by vegetation association. Such information can be used to examine potential communities where products might be present or abundant. For example, Schlosser et al. (1991) used plant association data gathered by the USDA-Forest Service in the Pacific Northwest to estimate the occurrence of several important floral greenery species. If inventory information is linked to a geospatial database (GIS), it is possible to target specific areas on the ground.

<sup>5</sup> Kerns, B. K.; and J. Ohmann. [N.d.]. Shrub abundance in coastal Oregon forests: influence of forest structure, disturbance, and environment. In review: *Journal of Vegetation Science*. Manuscript on file with senior author.

Although federal inventory data is somewhat limited for use in local planning efforts due to inherently coarse spatial and temporal scales, it is possible to examine landscape trends for common species distribution and abundance in relation to vegetation association, overstory, environmental, and disturbance factors. For example, Kerns and Ohmann (N.d.)<sup>5</sup> are using FIA, CVS, and research plot data to model shrub abundance in the Oregon Coast Range. However, existing databases lack information regarding commercial quantity and quality. For example, for floral greenery products, numerous factors such as temporal changes in foliage age and color, overstory stand conditions, disease, and site quality determine market quality.

The U.S. Department of the Interior, Bureau of Land Management (USDI-BLM) has stressed the need to inventory, monitor and conduct research on nontimber forest products and some districts have special forest product programs (U.S. Department of the Interior, Bureau of Land Management 1993). The USDI-BLM has recommended addressing NTFP inventory and monitoring issues, in part, following these procedures:

- Conduct market surveys to determine which NTFP's are present and have future economic importance.
- Adopt a broad level plant classification system including herb, shrub, and tree species to predict overall distribution of various products.
- After analyzing feasibility and importance, modify existing data collection procedures to include nontimber species.
- Evaluate current data analysis, storage, and mapping capabilities for modification needed to include nontimber products.
- Train personnel and initiate interagency coordination to ensure consistency and sharing of information.

Additional information is in U.S. Department of the Interior, Bureau of Land Management (1993).

## FOREST MANAGEMENT, SILVICULTURE AND UNDERSTORY SPECIES

In general, studies have shown that understory species' response to stand thinning is generally characterized by increased biomass and cover, particularly for clonal species and woody shrubs. However, Alaback and Herman (1988) found that most of the understory species that colonized thinned plots at Cascade Head, in the central Coast Range of Oregon, were shade-tolerant and had animal dispersed seeds such as fleshy berries. Ferns and graminoids can also show large positive responses to stand thinning (Bailey et al. 1998; Thomas et al. 1999). Examples of nontimber forest product species from Douglas-fir forests of the Pacific Northwest that respond favorably to thinning include salal (*Gaultheria shallon* Pursh), vine maple (*Acer circinatum* Pursh), and salmonberry (*Rubus spectabilis* Pursh) (Bailey et al. 1998, Huffman et al. 1994; O'Dea et al. 1995, Tappeinner et al. 1991).

We conducted two studies in western Oregon to examine how management prescriptions might impact NTFP species abundance, product supply and demand. This first study (Kerns et al. N.d.)<sup>6</sup> focused on three species of shrubs that are used in floral, medicinal and food markets. We examined differences in *Vaccinium ovatum*, *V. parvifolium* and *V. membranaceum* frequency and abundance using data from old-growth, and young thinned and unthinned Douglas-fir stands from western Oregon. Results indicated that the collection and use of *Vaccinium* plants in the Pacific Northwest are economically and culturally important to local communities and that forest management treatments, such as stand thinning, can potentially influence supply. However, to fully assess the effects of forest management on these species as nontimber forest products, linkages between biological abundance and commercial productively are needed. Additional studies are also needed to address the unique questions, issues and sites relevant to these species as commercial forest products. However, except for *V. membranaceum*, we found little market evidence for supply concerns or motivation for forest management to increase supply of these species.

In our second study (Kerns and Ohmann N.d.)<sup>5</sup> we conducted a landscape-scale study of relationships between shrub abundance and stand structure, site history, disturbance and environment. We used data acquired from forest

<sup>6</sup> Kerns, B.K.; Alexander, S.J.; Bailey, J.D. [N.d.]. Nontimber forest products and Douglas-fir stand conditions in western Oregon: ecology and economics of huckleberry species. Manuscript on file with the senior author.

inventories and research programs, coupled with mapped climatic and topographic data to explore relationships and develop predictive models and maps using multiple regression and regression tree analysis.

Although variables associated with forest structure, rather than environment, were the most important for explaining both total and deciduous shrub abundance, all models displayed weak predictive power. This may be because many common shrubs can persist and maintain consistent cover under a variety of forest stand and environmental conditions. Stochastic elements reflecting site history and variation in disturbance are also present. Predicting shrub abundance in this highly managed variable landscape is inherently problematic, and predicting commercial attributes will be even more difficult.

## CONCLUSIONS

Although many inventory and monitoring methods and databases exist for nontimber forest species, several key issues and knowledge gaps have emerged from our synthesis and studies.

A critical inventory issue is that current guidelines lack methods, and available resource databases do not include attributes that assign economic value to harvestable products (Kerns et al. 2002). While many methods exist for determining biological productivity, few assess economic or commercial productivity. For some species, existing databases can be used to develop models relating stand level characteristics to biological productivity (cover, density or biomass). However, the weak link in these models is relating stand level characteristics and biological productivity to commercial productivity or quality. Establishing economically based empirical relationships will require additional research and novel sampling designs. Studies are needed to determine appropriate quality attributes and yield functions across multiple landscape positions.

Achieving consistency among and linking databases in federal agency resource monitoring programs is another high priority issue and is currently in progress. Yet it is unclear if this will be cost-effective for the type of nontimber information that is collected (Kerns et al. 2002). Federal resource inventories contain limited or no information on temporally and spatially ephemeral species such as edible mushrooms, bryophytes and lichens, many herbaceous species, and rare and low cover species. Moreover, data are not currently collected regarding product quality

and spatial grids and temporal scales are frequently inadequate for local planning efforts. Lack of fine scale inventory and monitoring data, coupled with complex social and biological interactions that are poorly understood, currently hampers the development of both local and broadscale measures for nontimber products.

As previously noted, a major gap in our current knowledge is how harvesting practices affect resource productivity. Research studies, as well as small-scale monitoring projects for specific products or groups of products, would allow development and testing of sustainable harvest practices and monitoring protocols. This is particularly critical for species that are now intensively harvested and in immediate need of management guidelines. Information from research studies and small-scale monitoring projects for specific products could provide more useful information for stakeholders than existing regional federal surveys and databases. Moreover, with such information, broadscale measures for assessing harvesting of nontimber forest resources could be developed.

Our results regarding compatible commercial understory species and timber management suggest that understory development and relationships with overstory variables have deterministic components that can help guide management and promote complementary or synergistic resource use. For example, many understory species can potentially be managed sustainably while managing for wood production. Certain forest management activities, such as silvicultural thinnings, can enhance understory species production. Other management activities, such as clear-cut logging, will adversely affect some species or their commercial characteristics. Therefore, the ecology, biology, and characteristics of the species (commercial or other characteristics) are important to consider. Understory responses cannot be generalized for species or systems for which we have little or no information. In addition, stochastic elements reflecting site history and variation in disturbance also influence understory development (Halpern 1989). Therefore, to best determine how management prescriptions might affect the supply of commercial understory species, we should take into account species and site specific responses.

## LITERATURE CITED

- Alaback, P.B.; Hermman, F.R. 1988. Long-term response of understory vegetation to stand density in *Picea-Tsuga* forests. *Canadian Journal of Forest Research*. 18: 1522-1530.

- Alexander, S.J.; Weigand, J.F.; Blatner, K.A. 2002. Nontimber forest products commerce. In: Jones, E.T.; McLain, R.J.; Weigand, J.F. eds. Nontimber forest products in the United States. Lawrence, Kansas: Lawrence University Press of Kansas: 115-150
- Amaranthus, M.; Pilz, D. 1996. Productivity and sustainable harvest of wild mushrooms. In: Pilz, D.; Molina, R. eds. Managing forest ecosystems to conserve fungus diversity and sustain wild mushroom harvests. Gen. Tech. Rep. PNW-GTR-371. Portland, OR: U. S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 42-61.
- Arnolds, E. 1992. Mapping and monitoring of macromycetes in relation to nature conservation. *McIlvanea*. 10(2): 4-27.
- Bailey, J.D.; Mayrsohn, C.; Doescher, P.S. [et al.]. 1998. Understory vegetation in old and young Douglas-fir forests of western Oregon. *Forest Ecology and Management*. 112: 289-302.
- Blatner, K.A.; Alexander, S. 1998. Recent price trends for nontimber forest products in the Pacific Northwest. *Forest Products Journal*. 48: 28-33.
- Castellano, M.A.; Trappe, J.M. In press. Survey, inventory and monitoring of sequestrate fungi. In: Mueller, G.M.; Bills, G.F.; Foster, M.S. eds. Measuring and monitoring biological diversity: standard methods for fungi. Washington, D.C.: Smithsonian Institution Press.
- Cordell, H.K.; Hoover, A.P.; Super, G.R.; Manning, C.H. 1999. Adding human dimensions to ecosystem-based management of natural resources. In: Cordell, H.K.; Bergstrom, J.C. eds. Integrating social sciences with ecosystem management. Champaign, IL: Sagamore Publishing: 1-12.
- Elzinga, C.L.; Evenden, A.G. 1997. Vegetation monitoring: an annotated bibliography. Gen. Tech. Rep. INT-GTR-352. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 184 p.
- Elzinga, C.L.; Salzer, D.W.; Willoughby, J. 1998. Measuring and monitoring plant populations. *BLM Technical Reference 1730-1*. 477 p.
- Endter-Wada, J.; Blahna, D.; Krannich, R.; Brunson M. 1998. A framework for understanding social science contributions to ecosystem management. *Ecological Applications*. 8: 891-904.
- Ferris-Kaan, R.; Petterson, G.S. 1992. Monitoring vegetation changes in conservation management of forests. *Forestry Commission Bulletin* 108. 30 p.
- Gillespie, A.J.R. 1999. Rationale for a national annual forest inventory program. *Journal of Forestry*. 97: 16-20.
- Goldsmith, B. ed. 1991. Monitoring for conservation and ecology. London: Chapman and Hall. 275 p.
- Hall, F.C. 2001. Ground-based photographic monitoring. Gen. Tech. Rep. PNW-GTR-503. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 340 p.
- Halpern, C.B. 1989. Early successional patterns of forest species: interactions of life history trait and disturbance. *Ecology* 70(3): 704-720.
- Hasting, J.R.; Turner R.M. 1965. The changing mile: an ecological study of vegetation change with time in the lower mile of an arid and semiarid region. Tucson, AZ; University of Arizona Press. 317 p.
- Huffman, D.W.; Tappeiner, J.C.; Zasada, C. 1994. Regeneration of salal (*Gaultheria shallon*) in the central Coast Range forests of Oregon. *Canadian Journal of Botany*. 72: 39-51.
- Kent, M.; Coker, P. 1992. Vegetation description and analysis. London: Belhaven Press. 363 p.
- Kerns, B.K.; Liegel, L.; Pilz, D.; Alexander, S.J. 2002. Biological inventory and monitoring. In: Jones, E.T.; McLain, R.T.; Weigand, J. eds. Nontimber forest products in the United States. Lawrence, KS; University Press of Kansas: 237-269.
- Killeen, T.J.; Schulenberg, T.S., eds. 1999. A biological assessment of the parque Nacional Noel Kempff Mercado, Bolivia. RAP Working Papers, #10. Chicago, IL; University of Chicago Press. 200 p.
- Liegel, L.; Pilz, D.; Love, T. 1998a. The MAB mushroom study: background and concerns. *Ambio Special Report*. 9:3-7.

- Liegel, L.; Pilz, D.; Love, T.R.; Jones, E. 1998b. Integrating biological, socioeconomic, and managerial methods and results in the MAB mushroom study. *Ambio Special Report*. 9: 26-33.
- Love, T.R.; Jones, E.; Liegel, L. 1998. Valuing the temperate rainforest: wild mushrooming on the Olympic Peninsula. *Ambio Special Report*. 9: 16-25.
- Lund, H.G.; Thomas, C.E. 1989. A primer on stand and forest inventory designs. Gen. Tech. Rep. WO, 54. Washington, DC: U.S. Department of Agriculture, Forest Service. 96 p.
- McLain, R.; Jones, E.; Liegel, L. 1998. The MAB mushroom study as a teaching case example of interdisciplinary and sustainable forestry research. *Ambio Special Report*. 9: 34-35.
- O'Dea, M.E.; Zasada, J.C.; Tappeiner, J.C. 1995. Vine maple clone growth and reproduction in managed and unmanaged coastal Douglas-fir forests. *Ecological Applications*. 5: 63-73.
- O'Dell, T.E.; Ammirati, J.F.; Schreiner, E.G. 2000. Species richness and abundance of ectomycorrhizal basidiomycete sporocarps on a moisture gradient in the *Tsuga heterophylla* zone. *Canadian Journal of Botany*. 77: 1699-1711.
- Ohmann, J.L.; Spies, T.A. 1998. Regional gradient analysis and spatial pattern of woody plant communities of Oregon forests. *Ecological Monographs*. 68: 151-182.
- Olsen, A.R.; Sedransk, J.; Edwards, D., [et al.]. 1999. Statistical issues for monitoring ecological and natural resources in the United States. *Environmental Monitoring and Assessment*. 54: 1-45.
- Peck, J. 1998. Update to the moss harvesting monitoring plan. Unpublished report on file with the Siuslaw National Forest. Corvallis, OR. [Unknown pagination]
- Pilz, D.; Brodie, F.D.; Alexander, S.J.; Molina, R. 1998a. Relative value of chanterelles and timber as commercial forest products. *Ambio Special Report*. 9: 14-15.
- Pilz, D.; Molina, R. 2002. Commercial harvests of edible mushrooms from the forests of the Pacific Northwest United States: issues, management, and monitoring for sustainability. *Forest Ecology and Management*. 155: 3-16.
- Pilz, D.; Molina, R.; Liegel, L. 1998b. Biological productivity of chanterelle mushrooms in and near the Olympic Peninsula Biosphere Reserve. *Ambio Special Report*. 9: 8-13.
- Schlosser, W.; Blatner, K.; Chapman, R.C. 1991. Economic and marketing implications of the special forest products harvest in the Coastal Pacific Northwest. *Western Journal of Applied Forestry*. 6: 67-72.
- Tappeiner, J.; Zasada, J.; Ryan, R.R.; Newton, M. 1991. Salmonberry clonal and population structure: the basis for persistent cover. *Ecology*. 72: 609-618.
- Thomas, S.; Halpern, C.C.; Falk, D.A. [et al.] 1999. Plant diversity in managed forests: understory responses to thinning and fertilization. *Ecological Applications*. 9: 864-879.
- U.S. Department of the Interior, Bureau of Land Management. 1993. Managing special forest products in Oregon and Washington: A BLM final task force report. Portland, OR. [Irregular pagination].
- Vance, N.C.; Borsting, M.; Pilz, D.; Freed, J. 2001. Special forests products: species information guide for the Pacific Northwest. Gen. Tech. Rep. PNW-GTR-513. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 169 p.

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## **SILVISHROOMS: PREDICTING EDIBLE ECTOMYCORRHIZAL MUSHROOM PRODUCTIVITY**

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Susan Alexander<sup>6</sup>, Daniel Luoma<sup>7</sup>, Kermit Cromack<sup>8</sup>, and Charles Lefevre<sup>9</sup>

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### **ABSTRACT**

The value of edible forest mushrooms harvested from the Pacific Northwest exceeds several hundred million dollars annually and provides self-employment income for various individuals and ethnic groups. Picking mushrooms has little impact on subsequent fruiting, but forest management critically influences their productivity because many edible mushrooms grow symbiotically with host trees. Landscape-scale silvicultural experiments are costly and have a limited range of inference; hence our goal is to develop quantitative models for predicting mushroom productivity under a broad range of stand conditions or alternate silvicultural choices. One purpose is to enhance the ability of managers and policy analysts to provide sustainable forest mushroom harvesting opportunities within the context of managing forests for wood fiber production. We outline a theoretical model of factors affecting edible ectomycorrhizal mushroom productivity, describe proposed research to quantify the model and incorporate economic analyses, and discuss how the model could be applied on scales ranging from stands to regions. The proposed research would expand on the goals of the Wood Compatibility Initiative by providing one of the first broadly applicable quantitative models of how silvicultural choices for wood production are likely to influence the productivity of a nontimber forest product.

**KEY WORDS:** Mushrooms, productivity, silviculture, economic, model.

### **INTRODUCTION**

Edible mushrooms have been harvested from forests for as long as humans have foraged in woodlands, but in the later part of the 20th century, commerce in forest mushrooms became global, and annual international trade is now worth billions of U.S. dollars. A large portion of this trade is derived from the sporocarps (fruiting bodies) of fungi that grow symbiotically with trees by forming ectomycorrhizae (Figure 1), a nutrient and water exchange structure consisting of fine tree roots and an enclosing sheath of fungal tissue. Ectomycorrhizal (EM) fungi act as an extended fine root system for trees and, in return, they obtain carbohydrates from host tree photosynthesis. These carbohydrates

are one reason that EM fungi can fruit copiously each year if weather is favorable. Depending on the species, sporocarps of EM fungi can be mushrooms that fruit above ground or truffles that fruit below ground. Well-known edible EM fungi include chanterelles, matsutake, boletes, and truffles. Some edible EM fungi occur in the tropics and in inoculated plantations in the Southern Hemisphere, but most grow in temperate and boreal forests of the Northern Hemisphere with tree species in the Pinaceae and Fagaceae. Work is underway to cultivate edible EM fungi in plantations (Hall et al. 1998), but inoculation and establishment of most EM species has proven difficult (Danell 1994). Even if widely cultivated, forest mushrooms are likely to remain a viable commercial product for the foreseeable future.

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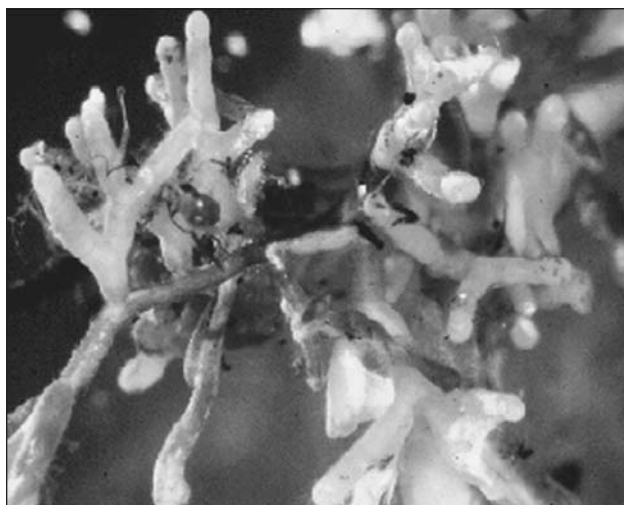


Figure 1—Chanterelle ectomycorrhizae. Photo by Eric Danell.



Figure 2—Young stand thinning operations in chanterelle habitat.

**Table 1—Discounted present net worth in perpetuity for chanterelles and Douglas-fir timber under two timber harvest regimes on Site Index 130 lands (base age 50 years) on the Olympic Peninsula, Washington**

| Types and amounts                                       | 50-year rotation -<br>no commercial<br>thinning | 80-year rotation -<br>commercial thinning<br>at ages 35 and 55 |
|---------------------------------------------------------|-------------------------------------------------|----------------------------------------------------------------|
| U.S. dollars per hectare per year <sup>a</sup>          |                                                 |                                                                |
| Chanterelles (2 kg ha <sup>-1</sup> yr <sup>-1</sup> )  | 29                                              | 34                                                             |
| Chanterelles (5 kg ha <sup>-1</sup> yr <sup>-1</sup> )  | 73                                              | 86                                                             |
| Chanterelles (20 kg ha <sup>-1</sup> yr <sup>-1</sup> ) | 292                                             | 343                                                            |
| Douglas-fir timber                                      | 8,420                                           | 7,049                                                          |

<sup>a</sup> Values are adjusted to year 2000 values. Multiply by 0.4 to obtain U.S. dollars per acre per year. See Pilz et al. (1998) for assumptions inherent in this analysis.

**Table 2—Return from timber and American matsutake for three management and productivity scenarios**

| Products                                       | Alternative 1: timber<br>harvest and 100%<br>increase in matsutake<br>productivity | Alternative 2: timber<br>harvest, constant<br>matsutake productivity | Alternative 3: no timber<br>harvest; constant<br>matsutake productivity |
|------------------------------------------------|------------------------------------------------------------------------------------|----------------------------------------------------------------------|-------------------------------------------------------------------------|
| U.S. dollars per hectare per year <sup>a</sup> |                                                                                    |                                                                      |                                                                         |
| Timber                                         | 1,317                                                                              | 1,317                                                                | 0                                                                       |
| Matsutake<br>(50% harvest cost)                | 1,537                                                                              | 1,145                                                                | 1,145                                                                   |
| Matsutake<br>(90% harvest cost)                | 434                                                                                | 358                                                                  | 358                                                                     |

<sup>a</sup>Adjusted to year 2000 U.S. dollars.  
See Pilz et al. (1999) for assumptions inherent in this analysis.

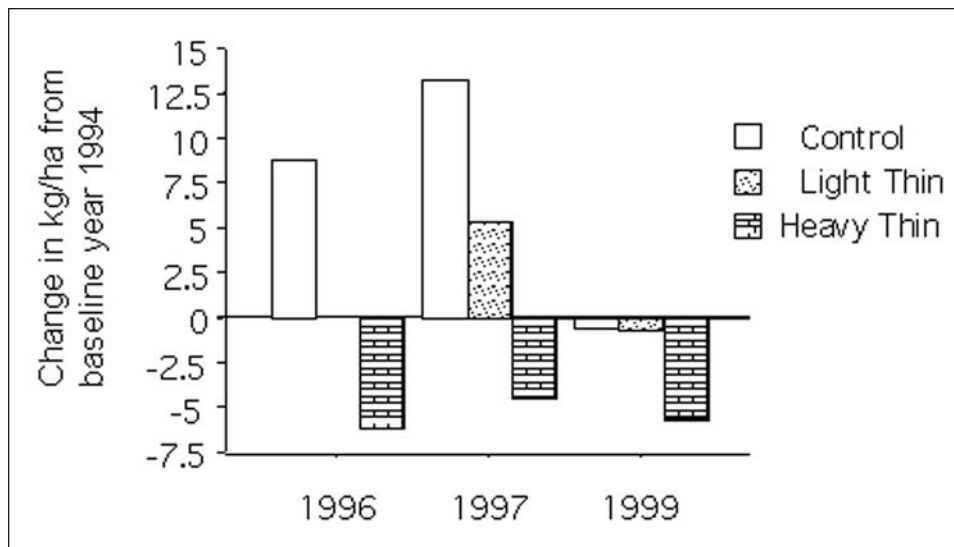


Figure 3—Change in chanterelle productivity for 3 of 4 years after thinning young Douglas-fir stands.

The increase in harvesting of forest mushrooms and truffles has engendered concerns about whether the harvest is sustainable. Egli et al. (1990) and Norvell (1995) suggest that picking mushrooms per se has no discernable impact on subsequent fruiting in small areas over periods of a decade or two. Pilz and Molina (1998) have described a three-pronged regional research and monitoring program for tracking potential long-term or broad-scale mushroom harvest impacts in the forests of the Pacific Northwestern United States. Here we describe in detail our pursuit of the research component of this regional program.

Sustaining appropriate forest habitat is essential for sustaining associated EM mushroom crops. Ectomycorrhizal fungi exhibit varying degrees of specificity for arboreal host species; the tree species growing in a stand dictate the range of associated fungi that can occur in the stand. Clearcutting a forest interrupts the fruiting of edible EM fungi for 1 to 3 decades as the new stand becomes established. Although mushroom productivity is still poorly understood, we are starting to acquire knowledge about how site conditions (soil fertility or climate), stand conditions (age, density, or growth rate) and management activities (commercial thinning or fertilization) affect mushroom productivity over time, and how mushroom values compare to timber or other resource values. Because many mushroom crops are harvested from the same forests that are managed for timber or other forest products and amenities, forest managers need a better understanding of how their choices will influence the size and value of mushroom crops if they are to optimally manage for multiple resource values (Table 1 and 2).

Biological, ecological, and physiological research has provided hypotheses for the influence of factors affecting mushroom productivity. For instance, the young stand thinning and diversity study on the Willamette National Forest in Oregon (Figure 2) is an example of a silvicultural experiment, replicated across a national forest landscape, that has shown dramatic declines in chanterelle fruiting for up to 4 years following heavy thinning (Figure 3). Nevertheless, testing landscape-scale hypotheses with replicated sets of stand treatments is expensive, and inferences derived from the results are limited to the forest types where the experiments were conducted. Development of a quantitative ecosystem process model that predicts mushroom productivity over a broad range of forest types, stand conditions, and site factors is much more cost-effective and broadly applicable approach. Fortunately, we believe that a confluence of scientific advances in carbon allocation modeling and immunoassay techniques has made development of such a model possible.

**CENTRAL HYPOTHESIS** (See Figure 4 for definitions and acronyms)

Average (5 to 10 years) site productivity of selected edible EM mushroom species can be predicted by two factors:

- 1 The amount of net primary productivity (NPP) allocated below ground by EM trees in a forest stand.
- 2 The occupancy of that site or stand by the fungus of interest.

- **Gross primary productivity (GPP):** Total quantity of carbon fixed through photosynthesis in the form of carbohydrates or other metabolic compounds.
- **Net primary productivity (NPP):** Net quantity of carbon available to the tree or its mycorrhizal fungus partners for growth or other functions after subtracting the amount used for tree respiration (maintenance metabolism). NPP is a relatively constant 47% of gross primary productivity across a wide range of forest types and conditions.
- **Belowground allocation:** The proportion or amount of net primary productivity that the tree allocates for large structural roots, fine feeder roots, and mycorrhizal symbionts.
- **Fruiting potential:** The maximum productivity that is possible on a given site in a given year if weather is favorable for mushroom development during the fruiting season.
- **Average site productivity:** The average mushroom productivity (kg per ha per yr) of a site over 4 to 10 years. This variable provides a mean of expressed fruiting potential by averaging across years with variation in weather patterns during the fruiting seasons. Conversely, 4 to 10 years is a sufficiently short interval so that natural changes in stand conditions should not unduly interfere with deriving correlations for our model.
- **Site occupancy:** The percentage of potential habitat that is occupied by the edible EM fungal species of interest relative to competing ectomycorrhizal (EM) fungi as measured by the percentage of EM root tips colonized by the species of interest or by the spatial extent of its mycelium.

Figure 4—Definitions and acronyms.

## CARBON ALLOCATION MODELING

One scientific development that makes our proposed model possible is the recent development of a simplified carbon allocation model. The acronym 3PG stands for physiological principles predicting growth. It is a generalized forest carbon allocation model, Landsberg and Waring (1997), that works with any forest biome and can be run as an Excel<sup>10</sup> spreadsheet by practicing foresters given a few days of training. The model uses relatively simple and readily available inputs such as species growth tables, latitude, aspect, weather records, edaphic variables, stand age, and stand density to derive monthly estimates of gross primary productivity, carbon allocation, and stand growth. The model has the capacity for specifying thinning regimes, although the function needs further refinement. In recent iterations, the 3PG model has been linked to satellite

imagery of canopy photosynthetic capacity to model forest growth across landscapes (Coops et al. 1998). Intended as a practical management tool, the model is under constant revision to incorporate new research data, simplify application, and broaden its usefulness. Belowground processes and allocation are one of the least developed aspects of this model, and our envisioned research will contribute to the model's development and range of applicability. Web sites discussing the model and current applications are listed in the acknowledgment section.

Various factors are known to influence the allocation of carbon below ground. For instance, trees are known to allocate a larger proportion of their NPP below ground on infertile sites than on fertile sites (Perry 1994). Much of this allocation goes to mycorrhizal fungi to enhance their ability to obtain nutrients. This is true of old forests, and

<sup>10</sup> 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.

- Modify rotations, thinning densities, thinning intervals, or tree species selection to retain or enhance mushroom productivity in forests predominantly managed for timber production.
- Manage stands in areas with convenient access for mushroom picking to enhance long-term mushroom production.
- Lengthen rotations or refrain from harvesting timber in areas identified as having low timber value and high mushroom productivity.
- Manage stand conditions to promote mushroom production in forests not intended for timber production (for example, carbon sequestration).
- Provide continuous mushroom harvesting opportunities across watersheds, land ownerships, or bioregions as the mosaic of forest conditions and age classes shifts across the landscape.
- Maintain mushroom harvesting opportunities in the coming centuries by anticipating the shifts in forest biomes as they respond to global warming or other human caused factors.

Figure 5—Potential applications for predicting how environmental factors, stand conditions, and forest management choices influence the size and value of mushroom crops.

of boreal or high-elevation forests growing on cold soils; under these conditions, nutrients are often tightly bound in accumulated organic matter; hence trees allocate more carbon to mycorrhizae to access the scarce nutrients, especially nitrogen. Drought-related stress also can influence below-ground carbon allocation when trees provide more carbohydrates to roots and mycorrhizae to obtain scarce water. In some cases, drought-related stress can be influenced by tree size because tall trees experience greater hydraulic resistance moving water to a more distant canopy, and small trees might not fully exploit available soil water (Pothier et al. 1989).

Most factors that limit tree growth also increase the proportion of NPP allocated below ground. It is possible that mushroom productivity will be significantly correlated with a simple integrative measure of growth constraints such as site index (the ratio of tree height to age), and this hypothesis also will be tested. Our hypothesis states, however, that mushroom productivity is correlated with the amount (kg per ha per yr) of NPP allocated below ground, not the proportion. Because NPP is a relatively constant fraction of gross primary productivity (GPP), the quantity of NPP allocated below ground is a function of GPP as well as the proportional allocation of NPP. In other words, although growth constraints cause trees to allocate a greater proportion of their food resources below ground, they have less available food to begin with because they are growing more slowly.

One of the more important questions we will address with our research is how the quantity of food available to mycorrhizal fungi varies across gradients of site fertility, soil temperatures, and stand age.

Of the NPP allocated below ground, the proportion allocated to large structural roots is about 25% of the NPP allocated to stem wood. The remainder is available for fine roots and mycorrhizae. Although carbon allocation patterns are relatively well known for most structural and functional components of tree growth and metabolism, the allocation and use of NPP among fine roots and mycorrhizae is not yet well quantified. Likewise, we have little information about how EM fungi compete for arboreal photosynthates or how various species of EM fungi allocate acquired carbon to growth, metabolism, function, or the production of sporocarps. Because so little quantitative information exists about carbon allocation in this realm, we start with two simplifying assumptions: (1) the amount of carbon each EM species obtains from trees in the stand will be correlated with site occupancy of that EM species, and (2) site occupancy will be correlated with average site productivity for each EM species. Although we expect these correlations to be robust, we also expect parameter values for the correlations to vary between fungus species.

Several species of chanterelles (*Cantharellus* species, Figure 6) and matsutake (*Tricholoma* species, Figure 7) will be the first EM species modeled because they are



Figure 6—Chanterelle (*Cantharellus formosus* Corner).



Figure 7—American matsutake (*Tricholoma magnivelare* (Peck) Redhead).

among the most widely collected and traded mushrooms in international commerce, and both are widely distributed in temperate and boreal forests of the Northern Hemisphere (Bergius and Danell 2000; Danell 1999). They occur in sufficient abundance to facilitate site selection and to reliably sample. We have used these species for comparative evaluations of mushroom and timber values, so economic analyses can be readily extrapolated to mushroom and timber productivity estimates derived from our model.

## METHODS

### Estimating Site Occupancy

We envision the application of several alternate or complementary techniques for estimating the occupancy of a site or stand by the EM fungus species of interest, namely immunoassays of ectomycorrhizal root tips derived from soil cores, olfactory surveys of matsutake mycelia in mineral soil horizons, and the spatial distribution of sporocarps in a stand.

In collaboration with Dr. Eric Danell, we anticipate contracting with immunoassay development companies to develop monoclonal antibody reagents (Miller et al. 1988; Neuner-Plattner et al. 1999) that will allow us to quickly assay the percentage of ectomycorrhizae in stands colonized by the edible mushroom species of interest. Immunoassays for chanterelles will be designed for specificity to the genus *Cantharellus* because all the species in the genus are edible and commercially collected. For matsutake we plan to develop reagents specific to methyl cinnamate (Yajima et al. 1981), the unique odor molecule produced by the several species of *Tricholoma* that are harvested as “matsutake” around the world.

Successful development of immunoassay reagents for chanterelles and matsutake will provide useful tools for sampling stands for potential mushroom productivity even when the mushrooms are not fruiting. They also can be used to verify fungal persistence in plantations of trees inoculated with these species.

Chanterelle mycelia grow diffusely in the soil, so directly estimating their mass or volume is not currently feasible. Matsutake mycelia, however, grow in dense mats near the surface of the mineral soil, and the mats exude the distinctive odor of matsutake. Charles LeFevre, as a part of his graduate thesis, has developed, tested (Figure 8), and refined olfactory sampling procedures for estimating the areal extent of matsutake mycelia in a forest stand.

As a backup to both of these approaches to estimating site occupancy, we plan to sample mushroom productivity by using many systematically located small plots. The percentage of plots that are occupied by either chanterelles or matsutake will give us a less direct, but we hope still useful, estimate of the site occupancy for each species.

### Field Sites

We plan to select field sites that cover the range of climatic and edaphic conditions that we hypothesize are important to mushroom productivity. Factors driving site selection will include:

- At least some fruiting of chanterelles or matsutake so that productivity and site occupancy can be estimated.
- High fertility versus low fertility soils.

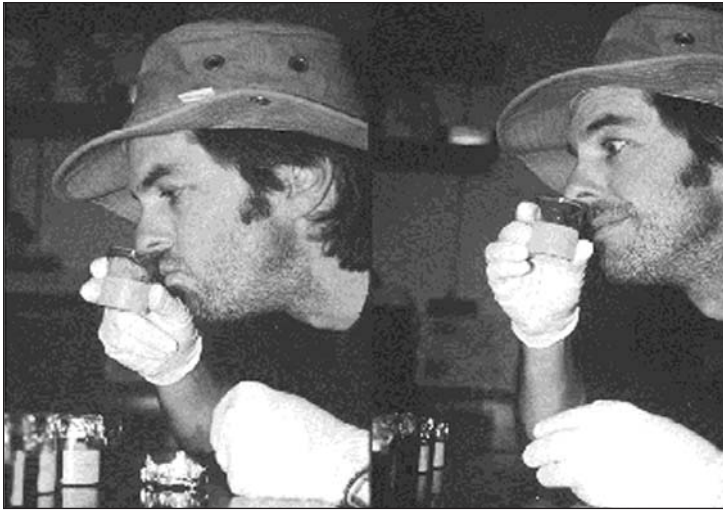


Figure 8—Tom Horton testing olfactory methods for detecting *Tricholoma magnivelare* mycelium in soil.

- Temperate versus cold (boreal or alpine) climates.
- Forests with tall trees versus forests with short trees.

In addition to sampling *C. formosus*, *C. subalbidus*, and *T. magnivelare* on sites in the Pacific Northwest, *C. cibarius* and *T. nauseosum* (syn. *T. matsutake*) will be sampled on sites in Sweden to broaden the applicability of the model to coniferous forest biomes throughout the Northern Hemisphere. Actual carbon budgets will be calculated for each site, annual mushroom productivity will be averaged over 4 or more years, and site occupancy estimated. The amount of carbon allocated below ground to fine roots and mycorrhizae will be modified by the percentage of occupancy of chanterelles or matsutake and then correlated with average mushroom productivity recorded on the site. The correlations we develop and the predictions of our resulting model will be tested on other sites where long-term mushroom productivity estimates already exist. For example, the young stand thinning and diversity study has 12 stands where chanterelle productivity has been sampled for more than 5 years. We also have at least nine other sites in the Pacific Northwest where 2 or more years of chanterelle or matsutake productivity have been sampled and where the model's predictions could eventually be tested.

## FUTURE ITERATIONS

Current iterations of the 3PG model are designed to work with forest stands of a single tree species and uniform age. Given that the most abundant fruiting of chanterelles and matsutake often occurs in young stands, early versions

of our modified model might be most applicable to recently regenerated forest stands that have timber production as one of their goals. Future revisions of the 3PG model are likely to incorporate multiple tree species of nonuniform age. Our aim is to use tree species ratios (host/nonhost tree species for each EM fungus) and dominance by those tree species (photosynthetic capacity) to modify our predictions of the amount of carbon allocated to the mushroom species of interest. These versions of the SilviShroom 3PG model would then be more applicable to natural or diverse forest stands.

Our core modeling efforts will not provide estimates of the fruiting potential of a stand in any given year, only multiyear averages. Physiological evidence exists, however, that seasonal weather patterns likely influence the amount of carbon allocated below ground immediately prior to and during the mushroom fruiting season. If the effects of weather patterns on seasonal carbon allocation are further elucidated, the information might provide a means for predicting fruiting potential in a given year. We will test this hypothesis with actual carbon allocation budgets developed for each stand in the study.

## Economic Valuation

Timber values are thoroughly understood, but mushroom values are harder to estimate and most attempts are relatively recent (Alexander et al. 2002; Pilz et al. 1998, 1999). Preliminary analyses illustrated in Tables 1 and 2 include many economic assumptions about mushroom prices and harvester costs, but they also include uncertain assumptions about how timber management choices affect

mushroom productivity. Coupling analyses of mushroom values with predictions of mushroom productivity under different forest management scenarios will allow managers to better evaluate resource tradeoffs and synergies.

### Scaling from Stands to Landscapes

Evaluating commercial mushroom crops and their values at the scale of landscapes would enable planners or policy analysts to anticipate how regional mushroom crops might be influenced by changes in climate, pollution, exotic forest pests, forest age class distributions, timber management regimes, or land-use patterns. Satellite sensing of canopy conditions to use in scaling the 3PG model to landscape estimates of mushroom productivity will be ineffective, however, unless we better understand the range and habitat preferences of the modeled mushroom species. After the core modeling research is underway, we plan to survey mushroom experts (mycology club members, agency botanists, and commercial mushroom harvesters) about the habitat preferences of commercially harvested mushroom species. By incorporating summaries of this habitat information into geographic information system (GIS) databases, we will be able to select appropriate habitat strata for application of remotely sensed canopy data. This approach will allow us to more accurately estimate mushroom productivity and crop values at watershed, landscape, or regional scales.

### CONCLUSIONS

The research outlined in this paper seeks to build on our current understanding of the influence of forest management on mushroom productivity (Pilz and Molina 2002). By elucidating the processes that influence edible mushroom productivity, we will better understand the relative importance of site conditions and silvicultural choices for sustaining or enhancing the production of this valued forest resource. Regardless of forest management goals for any given landowner, the model we propose should enable foresters to evaluate a range of management options for those that best meet their objectives. Additionally, this approach should prove feasible across a broad range of forest types and scales of analysis. Although useful as an instrument for ecosystem research, the model we propose to develop is specifically intended as a practical management tool and will be developed with ease of application as a primary goal. As managers struggle with the complexity of applying theories of ecosystem management, sustaining the production of multiple resources, and preserving or restoring forest health, tools such as these hold promise for enhancing the ability of our forests to meet our needs and those of generations to come.

### ACKNOWLEDGMENTS

More individuals have contributed to the conception of this proposed research than it is possible to list here. The authors are those who have been most directly involved and who expressed interest in continued cooperation if funding and institutional support can be arranged to pursue the project. Funding for development of the conceptual model and this research proposal has been provided in part by two research programs of the PNW Research Station: the Wood Compatibility Initiative and the Sustainable Management Strategies. A PNW Research Station (Forest Mycology Team) web site that mirrors this paper can be found at <http://www.fs.fed.us/pnw/mycology/>

This proposed research project would not be possible without decades of research that have quantified forest ecosystem processes and the integration of that research into a process-based quantitative carbon allocation model designed for use by practicing foresters. Web sites that discuss the 3PG model and some of its applications include the following:

- Landsberg Consulting (Download 3PG program in Excel format) <http://www.landsberg.com.au/>
- Physiological Principles for Predicting Growth from Satellites <http://www.ffp.csiro.au/nfm/mdp/pgs/pgshome.htm>
- 3PG in SW Oregon <http://www.ffp.csiro.au/nfm/mdp/bevr/home1.html>
- 3PG in New Zealand [http://www.ffp.csiro.au/nfm/mdp/nz/nz\\_fram.htm](http://www.ffp.csiro.au/nfm/mdp/nz/nz_fram.htm)

### LITERATURE CITED

- Alexander, S.J.; Pilz, D.; Weber, U.S. et al. 2002. Mushrooms, trees, and money: value estimates of commercial mushrooms and timber in the Pacific Northwest. *Environmental Management* 30: 129-141.
- Bergius, N.; Danell, E. 2000. The Swedish matsutake (*Tricholoma nauseosum* syn. *T. matsutake*): distribution, abundance, and ecology. *Scandinavian Journal of Forest Research*. 15: 318-325.

- Coops, N.C.; Waring, R.H.; Landsberg, J.J. 1998. Assessing forest productivity in Australia and New Zealand using a physiologically-based model driven with averaged monthly weather data and satellite derived estimates of canopy photosynthetic capacity. *Forest Ecology and Management*. 104: 113-127.
- Danell, E. 1994. Formation and growth of the ectomycorrhiza of *Cantharellus cibarius*. *Mycorrhiza*. 5: 89-97.
- Danell, E. 1999. *Cantharellus*. In: Cairney, J.W.G.; Chambers, S.M., eds. Ectomycorrhizal fungi: key genera in profile. Springer-Verlag. Berlin: 253-267. Chapter 10.
- Egli, S.; Ayer, F.; Chatelain, F. 1990. Der Einfluss des Pilzsammelns auf die Pilzflora. *Mycologia Helvetica*. 3: 417-428.
- Hall, I.; Buchanan, P.K.; Yun, W.; Cole, A.L.J. 1998. Edible and poisonous mushrooms: an introduction. Christchurch, NZ: New Zealand Institute for Crop and Food Research Limited. 189 p.
- Landsberg, J.J.; Waring, R.H. 1997. A generalized model of forest productivity using simplified concepts of radiation use efficiency, carbon balance and partitioning. *Forest Ecology and Management*. 95: 209-228.
- Miller, S.A.; Rittenburg, J.H.; Peterson, F.P.; Grothaus, G.D. 1988. Application of rapid, field usable immunoassays for the diagnosis and monitoring of fungal pathogens in plants. In: Brighton Crop Protection Conference, Pests and Diseases. Surrey, UK: British Crop Protection Council: 795-803.
- Norvell, L. 1995. Loving the chanterelle to death? The ten-year Oregon chanterelle project. *McIlvainea*. 12: 6-25.
- Neuner-Plattner, I.; Grabher, T.; Hall, I.R. [et al.]. 1999. A comparison of immunological assays for the identification of *Tuber* spp. and other edible EM fungi. *Mycological Research*. 103(4): 403-412.
- Perry, D.A. 1994. Forest ecosystems. London: John Hopkins Press, Ltd. 649 p.
- Pilz, D.; Molina, R. 1998. A proposal for regional monitoring of edible forest mushrooms. *Mushroom, The Journal of Wild Mushrooming*. 16(3): 19-23.
- Pilz, D.; Brodie, F.D.; Alexander, S.; Molina, R. 1998. Relative value of chanterelles and timber as commercial forest products. In: Liegel, L.H., comp. The biological, socioeconomic, and managerial aspects of chanterelle mushroom harvesting: the Olympic Peninsula, Washington State, U.S.A. *Ambio, A Journal of the Human Environment*. Stockholm, Sweden: Royal Swedish Academy of Sciences. Special Report Number 9: 14-15.
- Pilz, D.; Smith, J.; Amaranthus, M.P. [et al.]. 1999. Mushrooms and timber: managing commercial harvesting in the Oregon Cascades. *Journal of Forestry*. 97(3): 4-11.
- Pilz, D.; Molina, R. 2002. Commercial harvests of edible mushrooms from the forests of the Pacific Northwest United States: issues, management, and monitoring for sustainability. *Forest Ecology and Management*. 155: 3-16.
- Pothier, D.; Margolis, H.A.; Waring, R.H. 1989. Patterns of change of saturated sapwood permeability and sapwood conductance with stand development. *Canadian Journal of Forest Research*. 19: 432-439.
- Yajima, I.; Yanai, T.; Nakamura, M. [et al.]. 1981. Volatile flavor compounds of matsutake-*Tricholoma matsutake* (Ito et Imai) Sing. *Agricultural and Biological Chemistry*. 45(2): 373-377.

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## **INVOLVING STAKEHOLDER COMMUNITIES IN RESEARCH ON NONTIMBER FOREST PRODUCTS**

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### **ABSTRACT**

The premise behind this work is that Forest Service research and land management that involve user groups will more likely result in products and activities that meet stakeholder perceived problems and needs and also increase public support for management and research programs. Through this research, we develop and illustrate processes for involving stakeholders and conducting research relevant to identified stakeholder interests and needs. The process involved engaging commercial and noncommercial harvesters and resource managers in discussions about conservation, management, and use of nontimber forest products (NTFP). Data were collected from dialogues with stakeholders and from comments at public meetings in several communities. Research topics were identified and considered in light of criteria including the likelihood of significant harvester involvement in the research and benefits to stakeholder communities coming from successful completion of the research. Ongoing research studies supported by this effort include studies of medicinal plants, noble fir boughs, beargrass, and salal.

**KEY WORDS:** Research, stakeholder, nontimber forest products, community.

### **INTRODUCTION**

It does not take a trained observer to conclude that indifference or active opposition frustrates many plans and management activities that the Forest Service attempts to implement. This is despite the fact that the concept of 'ecosystem management' has gained broad public acceptance over the past decade (Bengston et al. 2001). While some individual U.S. Department of Agriculture, Forest Service (Forest Service) activities may have broad stakeholder community support, on a continuum from active support with no opposition to gridlock, Forest Service programs, in general, are closer to gridlock than active support.

Collaborative approaches to ecosystem management between federal agencies and locality-based groups or user groups are rapidly forming across the United States (Gray et al. 2001; Moote et al. 2000; Weber 2000). Manifested as partnerships, community-based collaboratives, watershed councils, and more, these multi-party groups often emerge out of mutual interest to manage natural resources in ways

that integrate ecological, social, and economic objectives and to escape the paralysis of agency planning followed by stakeholder litigation. Similar logic led us to the primary premise of this pilot project; involvement of stakeholder communities in selection, design, and implementation of follow-up research projects will result in management actions that better meet the needs of stakeholder communities and reduce the amount of resistance to project implementation.

### **WHY NTFP MANAGEMENT**

Characteristics of NTFP use and management make it an ideal venue for exploring alternative approaches to research and management. Where traditional methodologies for researching problems may not adequately address the complexity of contemporary resource management dilemmas (Cortner et al. 1996), new approaches must acknowledge the human dimensions of management choices and build understanding, support, and ownership of collective choices (Wondolleck and Yaffee 2000). At first glance, the NTFP sector possesses many disparate and potentially

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problematic characteristics. Yet research and management activities that tap into these characteristics with intention and creativity may make effective contributions to biological integrity and social and economic well-being. The diverse NTFP sector (1) involves non-traditional forest resource stakeholders, also known as ‘underserved populations’; (2) involves many small communities of place and interest that are scattered throughout the region (Carroll et al. in press); (3) plays a role in small business/cottage industry (Emery 2001); (4) has social, economic, cultural, and biological tensions (Hansis et al. 2001), where efforts to reduce conflict are needed; (5) involves a vast, diverse, and largely unorganized group of personal-use gatherers; (6) has a long history as part of indigenous and immigrant ways of life in the PNW (Emery and O’Halek 2001; Hansis 1996; Turner and Cocksedge 2001; Yamane 1997); and, (7) represents a management dilemma faced by many Forests with decreasing staffs and budgets and increasing responsibilities (Cortner and Moote 1999). In other words, NTFP management is biologically complex and rich in sometimes-conflicting cultural and economic traditions. It abounds with diverse stakeholder groups that have the potential to become active participants in knowledge development and coalition building needed to inform public policy. As such, it is ripe for creativity and innovation in research and management approaches.

Recognizing that NTFP management is a complex undertaking, we set out to understand user values and concerns, identify management barriers and opportunities, clarify knowledge gaps, and develop collaborative research activities. Our hope was that a better understanding of how the public values forest resources would assist resource managers and policymakers in developing resource management approaches that are socially and politically acceptable as well as biologically sound (Bengston 1994). This is in response to evidence that people often measure their interactions with forest agencies by the extent to which their values, ideas, and concerns are given consideration in decisionmaking, rather than being eclipsed by agency politics or the national debate (Shindler 1997). Understanding and acknowledging values and concerns became a core focus of this project. To the extent possible, we hope that follow-up projects will contribute understanding of both the scientific and social basis of complex resource management problems and will lead to better understanding of human-natural resource relations that are relevant to forest users (Shindler and Cramer 1999).

## APPROACH

This project involved stakeholders in five geographic communities that are in close proximity to national forests. Interests and concerns were solicited from both commercial and non-commercial harvesters and managers of NTFP.<sup>4</sup>

- The full pilot project involved the following steps:
- Identify target NTFP stakeholder communities
- Identify stakeholder interests and concerns
- Develop research project areas addressing the interests and concerns
- Match project areas with scientists interested in conducting follow-up projects
- Participating scientists involve stakeholders in research design and implementation where possible
- Request proposals from interested scientists
- Evaluate and provide initial funding to projects that fit criteria
- Pursue opportunities to develop funding proposals around coalitions of interested parties

## IDENTIFICATION OF STAKEHOLDER INTERESTS AND CONCERNS

Five locations were identified from which data on stakeholder interests and concerns were collected. Selection was based on criteria including: proximity to Forest Service lands, evidence of prior NTFP activity, representation of Oregon and Washington, representation of Native Americans and other ethnic groups, feasibility of gathering data given time and budget constraints, and more. We conferred with a review committee made up of state and federal agency personnel, social and biological scientists and others familiar with the NTFP industry about site selection and research objectives. The five study sites were Siuslaw National Forest-Lincoln County area, OR; Willamette National Forest, Linn-Lane County, OR; Gifford Pinchot National Forest, WA; Confederated Tribes of the Grande Ronde Community, OR; and Confederated Tribes of the Siletz Indians, OR.

Once the sites were selected, we began to identify stakeholders through a snowball sampling approach. Social scientists from the USDA Forest Service’s PNW Research Station conducted one-on-one dialogues with non-commercial NTFP gatherers. Cooperators from the Pinchot Institute

<sup>4</sup> Catherine Mater, Senior Fellow, Pinchot Institute for Conservation conducted dialogues with commercial harvesters. Pacific Northwest Research Station researchers and research associates conducted dialogues with non-commercial harvesters. Mary Mitsos and Will Price of the Pinchot Institute for Conservation facilitated community meetings.

for Conservation talked with commercial harvesters.<sup>5</sup> We also talked with resource managers about permitting procedures and management concerns and issues. Some key issues that emerged from the dialogues with the non-commercial harvesters included concern about fads, publicity and rapid changes associated with commercial harvesting, lack of clarity about the personal use permit system, concern about firewood supply, concern about access, desire for more educational information, importance of cultural revitalization and sustaining culturally important resources, and more. A separate manuscript on the dynamics of non-commercial harvesters by Donoghue is forthcoming.<sup>6</sup> On the commercial side, some of the key issues that emerged included resource theft, volatile interaction among groups of harvesters, concern for over-harvesting, diminished resource quality, issues pertaining to enforcement, issues pertaining to the permit structure, impact of local communities, issues of access, and more.<sup>7</sup>

## PROCESSING THE INFORMATION AND DEVELOPING RESEARCH PROJECTS

A list of prospective research topics emerged from this long list of NTFP management issues. Some topics related specifically to harvesting methods and issues of resource quality and quantity. Other topics focused on historic use, traditional knowledge, emerging markets, education and training, and ecological change. A series of community forums and feedback sessions occurred in which project topics were presented to stakeholders for feedback, further fleshing out, and solicitation of potential collaborators. Another step involved linking PNW Station researchers with the topic areas and participant collaborators. Research proposals were developed and four projects were funded on the topics of: (1) biology and ecology of beargrass (*Xerophyllum tenax*) and effects of harvesting on plants and populations in the Willamette National Forest, (2) interaction of forest dynamics and medicinal plant harvesters, (3) developing and evaluating Noble Fir bough management scenarios for public and private lands, and (4) participatory research on the impacts of harvesting intensity on salal, *Gaultheria shallon*, in Mason County, Washington. These studies are currently underway and results will be forthcoming. Although these projects maintain varying degrees of collaboration with harvesters and managers, they remain consistent with key issues that resulted from the stakeholder dialogues.

## CONCLUSIONS

This pilot project provided an opportunity to subjectively evaluate a stakeholder-involved research process as an approach that could be applied in other places and circumstances. The process was successful at gathering information about harvester and manager's concerns and issues pertaining to NTFP management. It solicited feedback from interested community members and gained their participation in the identification of priority research projects. We were able to match interested scientists with priority research areas. In some of the projects, we were able to have direct involvement of one or more members of a stakeholder community. Results on these follow-up research projects are forthcoming.

## LITERATURE CITED

- Bengston, D.N. 1994. Changing forest values and ecosystem management. *Society and Natural Resources*. 7(6): 515-533.
- Bengston, D.N.; Xu, G.; Fan, D.P. 2001. Attitudes toward ecosystem management in the United States, 1992-1998. *Society and Natural Resources*. 14(6): 471-487.
- Carroll, M.S.; Blatner, K.A.; Cohn, P. [in press]. Social embeddedness and the spectrum of wild edible huckleberry harvest and use. *Rural Sociology*.
- Cortner, H.; Shannon, M.; Wallace, M. [et al.]. 1996. Institutional barriers and incentives for ecosystem management: a problem analysis. Gen. Tech. Rep. PNW-GTR-354. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 35 p.
- Cortner, H.J.; Moote, M.A. 1999. The politics of ecosystem management. Washington, DC: Island Press. 179 p.
- Emery, M.R. 2001. Nontimber forest products and livelihoods in Michigan's Upper Peninsula. In: Davidson-Hunt, I.; Duchesne, L.C.; Zasada, J.C., eds. *Forest communities in the third millennium: linking research, business, and policy toward a sustainable nontimber forest product sector*. Gen. Tech. Rep. NC-217. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 151 p.

<sup>5</sup> We recognize that many of the values and concerns about NTFP management transcend any type of distinction between commercial vs. non-commercial harvesters. The distinction was made here to facilitate the data collection process between two separate teams.

<sup>6</sup> Donoghue, E.M. [N.d.] Personal-use harvesters of nontimber forest products in the Pacific Northwest. Manuscript in preparation.

<sup>7</sup> Report titled "USFS SFP Collaborative Project: Mater Dialogues Issues Analysis," August 31, 1999. On file with: the Pinchot Institute for Conservation, 1616 P Street NW, Suite 100, Washington, DC 20036.

- Emery, M.R.; O'Halek, S.L. 2001. Brief overview of historical nontimber product use in the U.S. Pacific Northwest and Upper Midwest. *Journal of Sustainable Forestry*. 13(3/4): 25-30.
- Gray, G.J.; Enzer, M.J.; Kusel, J., eds. 2001. Understanding community based ecosystem management in the United States. New York: Hawthorne Press. 447 p.
- Hansis, R. 1996. The harvesting of special forest products by Latinos and Southeast Asians in the Pacific Northwest: preliminary observations. *Society and Natural Resources*. 9: 611-615.
- Hansis, R.; Jones, E.T.; McLain, R.J. 2001. Recent trends: nontimber forest product pickers in the Pacific Northwest. *Journal of Sustainable Forestry*. 13(3/4): 141-146.
- Moote, A.; Conley, A.; Firehock, K.; Dukes, F. 2000. Assessing research needs: a summary workshop on community-based collaboratives. Udall Center Publications 00-5. Udall Center for Studies in Public Policy, The University of Arizona. 20 p.
- Shindler, B. 1997. Public participation in forest planning: 8 attributes of success. *Journal of Forestry*. 95(1): 17-19.
- Shindler, B.; Cramer, L.A. 1999. Shifting public values for forest management: making sense of wicked problems. *Western Journal of Applied Forestry*. 14(1): 28-34.
- Turner, N.J.; Cocksedge, W. 2001. Aboriginal use of non-timber forest products in Northwestern North America: applications and issues. *Journal of Sustainable Forestry*. 13(3/4): 31-57.
- Weber, E.P. 2000. A new vanguard for the environment: grass-roots ecosystem management as a new environmental movement. *Society and Natural Resources*. 13(3): 237-259.
- Wondolleck, J.M.; Yaffee, S.L. 2000. Making collaboration work: lessons from innovation in natural resource management. Washington, DC: Island Press. 277 p.
- Yamane, L. 1997. Ancient heritage: keeping an art alive. *Inner Voice*. 9(2) March/April: 19-21.



*SECTION F*  
**SOCIAL/ECONOMIC  
STUDIES**

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## LOGIC MODELS AS FRAMEWORKS FOR THINKING ABOUT COMPATIBILITY

Keith M. Reynolds<sup>1</sup>

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### ABSTRACT

Numerous efforts around the world are underway to apply the Montreal criteria and indicators to assess the sustainability of temperate and boreal forests. This 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.

**KEY WORDS:** Montreal Process, forest, ecosystem, sustainability, criteria and indicators, logic, model, knowledge base, decision support, compatibility.

### INTRODUCTION

The 1992 Earth Summit (Rio de Janeiro, Brazil) enunciated principles for sustainable development of the world's forest resources (United Nations 1992). Subsequently, the 11 signatory nations to the 1995 Santiago Declaration, representing about 90% of the world's boreal and temperate forest cover, affirmed the recommendations of the Montreal Process (WGCICSMTBF 1995) that prescribed a set of seven criteria and 67 indicators for evaluating sustainable forest management (SFM).

#### Criteria, Indicators and Measurement Endpoints

Prabhu et al. (2001) describe criteria and indicators (C&I) as "information tools in the service of forest management" in the sense that they "can be used to conceptualize, evaluate, implement, and communicate sustainable forest management." For this paper, I follow the definitions of C&I given by Prabhu et al. (1999a):

**Indicator:** *An indicator is any variable or component of the forest ecosystem ... used to infer attributes of the sustainability of the resource and its utilization. Indicators should convey a 'single meaningful message.' This 'single message' is termed information. It represents an aggregate of one or more data elements with certain established relationships.*

**Criterion:** *A standard that a thing is judged by. Criteria are the intermediate points to which the information provided by the indicators can be integrated and where an interpretable assessment crystallizes. Principles [e.g., sustainability] form the final point of integration. Criteria should be treated as reflections of knowledge... It can be viewed as a large-scale selective combination ... of related pieces of information.*

In addition to C&I, it is also necessary for subsequent discussion to define measurement endpoints. Some Montreal indicators are simple; their definition suggests an obvious one-to-one correspondence between an indicator and a metric for that indicator. However, definitions of some Montreal indicators are more complex in the sense that they represent a synthesis of two or more data elements, which I refer to as measurement endpoints

#### Balancing Services, Uses, and Values

People have worried about the sustainability of their forests for hundreds, if not thousands, of years. Until recently, efforts to sustain forests and their benefits have focused largely on maintaining a sustained yield of timber harvest (Davis et al. 2001). Maintaining a sustained yield of timber volume of individual ownerships or administrative units was thought to maintain desirable ecological,

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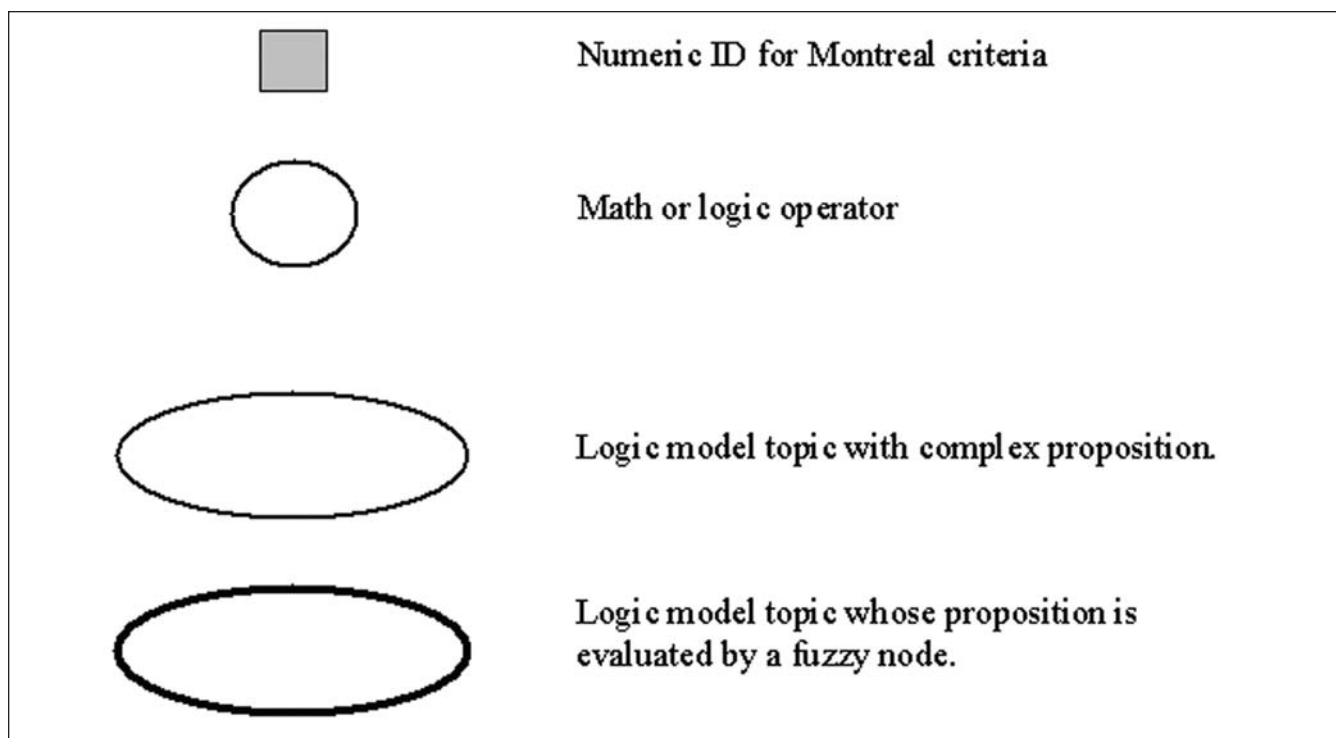


Figure 1—Key to logic symbols used in subsequent figures.

economic, and social conditions. As part of this approach, native forest was transformed into plantations to maintain a high level of growth into the future.

In the early 1990s, this concept came under attack for its neglect of species dependent on native forest, especially the old growth forests of the Pacific Northwest. Thus, the Pacific Northwest became a crucible for rethinking our approach to ensuring the sustainability of forests and their benefits. Driven by concerns over threatened and endangered species, such as the northern spotted owl and Pacific salmon, the federal lands of the Pacific Northwest shifted their assessment of sustainability from the harvest rate of commercial timber products to the level of protection for native species. In the process, federal foresters also began to rethink how to maintain desirable economic, social, and institutional conditions through time.

### Objectives

Any indicator or criterion implies a model and set of assumptions that relates the indicator to more complex phenomena and comes with an obligation to make explicit both the metric and the underlying model (Hammond et al. 1995; Adriaanse 1993). Relatively little research to date has focused on developing formal representations of indicators and their interrelations as a basis for actually evalu-

ating SFM despite recent widespread interest in developing and applying C&I for evaluating SFM (Prabhu et al. 2001). However, a few efforts, primarily associated with the Center for International Forest Research (CIFOR), have been experimenting with use of semantic networks and similar types of representation (Colfer et al. 1996; Haggith et al. 1998; Prabhu et al. 1999b). This paper continues that general line of investigation, considering the use of a fuzzy-logic based network representation for evaluation of the Montreal C&I at national and regional scales. Use of fuzzy logic networks is demonstrated as a way to accommodate the vagueness and imprecision inherent in natural language descriptions (Zadeh 1976).

This study has two objectives: (1) to illustrate a logic-based approach to evaluating the sustainability of forests and their benefits per the Montreal C&I, and (2) to provide some initial insight into the potential range of possibilities for representing tradeoffs and compatibilities among attributes of sustainability.

## ANALYSIS

### Montreal Criteria and Indicators

The Montreal specifications provide relatively clear definitions of biophysical, socioeconomic, and framework attributes requiring evaluation (WGCICSMTBF 1995).

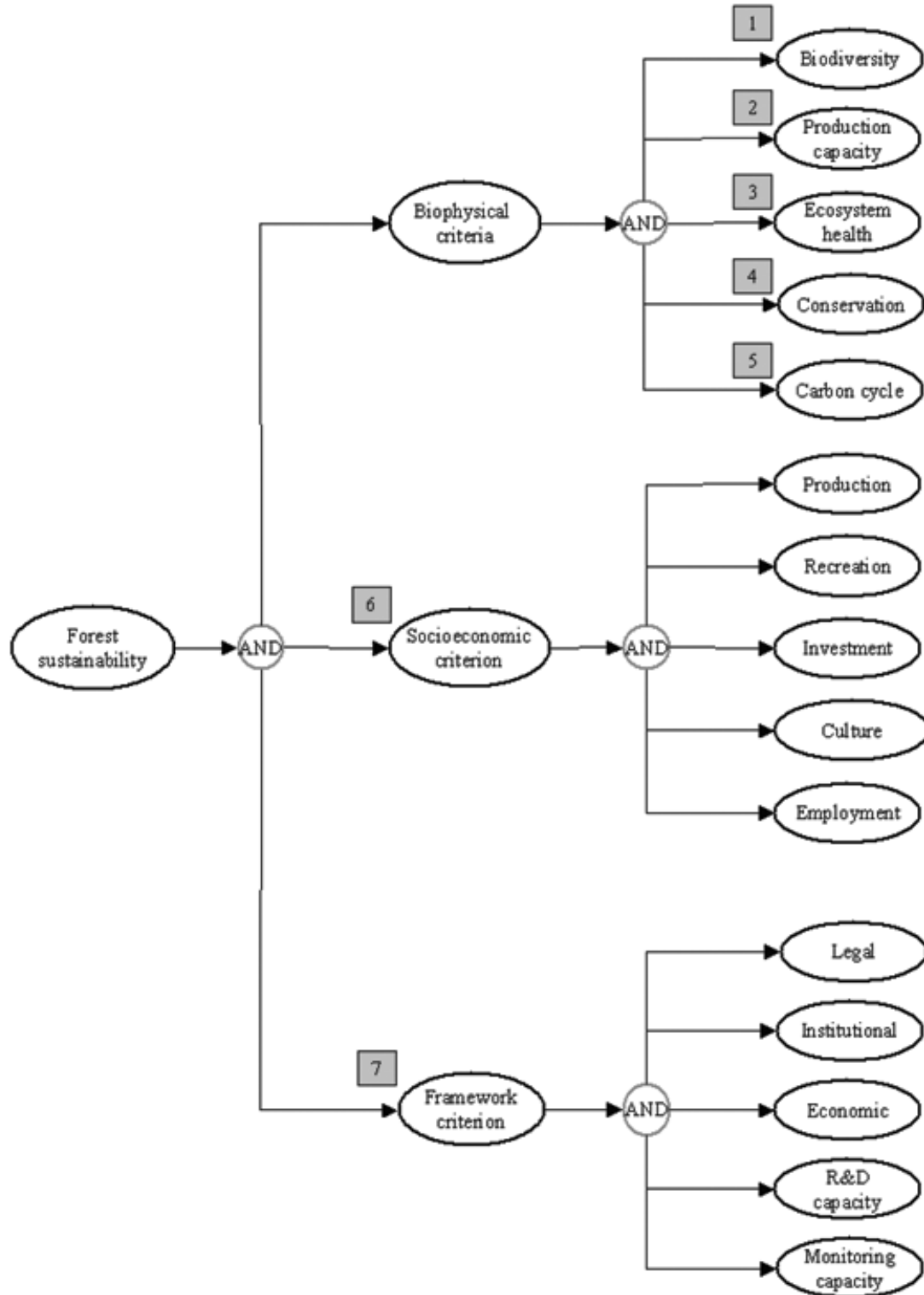


Figure 2—Partial logic specification for evaluating sustainability of a forest ecosystem. Each premise has its own logic specification that may extend many more levels. NetWeaver knowledge bases are graphically built from modular components like this, simplifying incremental development of complex models. Only the first three levels of network structure are illustrated.

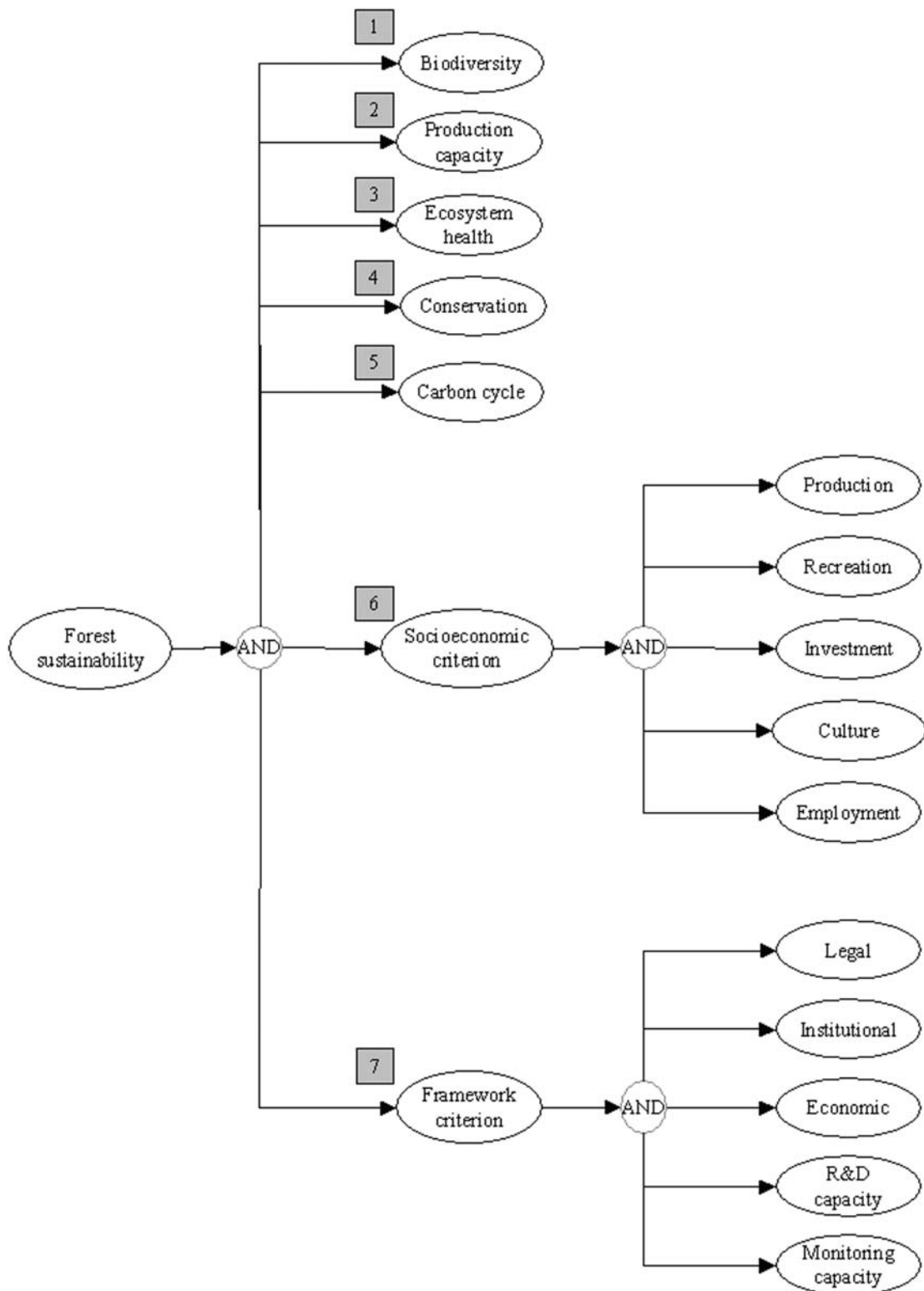


Figure 3—An alternative (partial) logic specification for evaluating sustainability of a forest ecosystem. In this representation, biophysical criteria assume more importance compared to Figure 2.

However, design of evaluation procedures that allow interpretation of the Montreal C&I is one of the major technical issues that remain to be resolved (Raison et al. 2001). The design of any model that purports to evaluate sustainability with respect to a set of criteria and indicators must incorporate value judgments and other subjective elements (Prabhu et al. 2001). This is no less an issue for biophysical aspects as it is for socioeconomic ones (Lélé and Norgaard 1996). Some specific examples of subjective design elements in the context of logic models are discussed in the section, *Model Design Issues*.

### Logic Models as Design Frameworks

Logic models, often referred to as knowledge bases, provide a formal specification for organizing and interpreting information, and are a form of meta database - they are data about data. In the design of a specification for evaluating SFM, Reynolds et al. (in review) used the NetWeaver Developer system (Rules of Thumb, North East, PA)<sup>2</sup> that represents a problem in terms of propositions about topics of interest and their logical interrelations. In design of a NetWeaver model, a topic for analysis is translated into a testable proposition. For example, if the topic is forest sustainability, the associated proposition might be as simple as "The forest ecosystem is sustainable." The statement of the proposition by itself is inherently ambiguous because sustainability is an abstract concept. However, the full formal logic specification underlying a proposition makes the semantic content of the proposition clear and precise (Figure 1 and 2). The biophysical, socioeconomic and framework topics (Figure 2) are logical premises of forest sustainability. The proposition about forest ecosystem sustainability evaluates as *true to the degree that* the biophysical environment, socioeconomic conditions, and the institutional framework are in suitable condition.

The phrase, "true to the degree that," is intended to emphasize that strength of support for propositions in NetWeaver models is evaluated by what might be termed "evidence-based reasoning." More specifically, this form of reasoning is implemented in NetWeaver with fuzzy math (Reynolds 1999), a branch of applied mathematics that implements qualitative reasoning as a method for modeling lexical uncertainty (fuzzyTech 1999):

*Stochastic uncertainty deals with the uncertainty of whether a [particular] event will take place and probability theory lets you model this. In contrast, lexical uncertainty deals with the uncertainty of the*

*definition of the event itself. Probability theory cannot be used to model this [because] the combination of subjective categories in human decision processes does not follow its axioms...Even though most concepts used are not precisely defined, humans can use them for quite complex evaluations and decisions that are based on many different factors.*

The logical discourse on forest ecosystem sustainability is extended by providing a logic specification for each premise. Each iteration of discourse extends the logic structure another level deeper by defining a logic specification for each topic in the level above. The pattern of discourse generally proceeds from abstract to concrete propositions, with a tendency for premises of a particular proposition to be less abstract than that proposition. Eventually, each logic pathway terminates in a premise, or set of premises, each of which can be evaluated by reference to data. Logic pathways in a knowledge base can thus be construed as a mental map of the problem that provides a formal data specification. The specification not only describes what data are to be evaluated, but how the data are to be interpreted to arrive at conclusions.

### Model Design Issues

**Basic model organization**—Basic organization of topics within the current Montreal design specification has important policy implications. For example, most science colleagues consulted so far find the highest-level organization (Figure 2) quite acceptable, but alternative representations are quite possible, and these alternative representations of sustainability could, in general, produce very different evaluations. The five biophysical criteria in the current specification are subsumed under the biophysical topic (Figure 2). Assuming for the moment that all topics in the model carry default weights of 1, the current specification effectively asserts that the collective evidence from all biophysical criteria is equal, in terms of strength of evidence for sustainability, to the collective evidence from criterion 6 or criterion 7. One alternative representation (Figure 3) puts much greater emphasis on the biophysical criteria, asserting that the collective evidence of each biophysical criterion (1-5) is equal to that for criterion 6 or criterion 7.

**Integration of information**—Evaluation of any criterion for SFM involves multiple indicators. Therefore, the definition of a criterion (Prabhu et al. 1999a) stresses the need for integration of information in evaluating any SFM criterion. In the case of the Montreal C&I, integration of information

<sup>2</sup> 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.

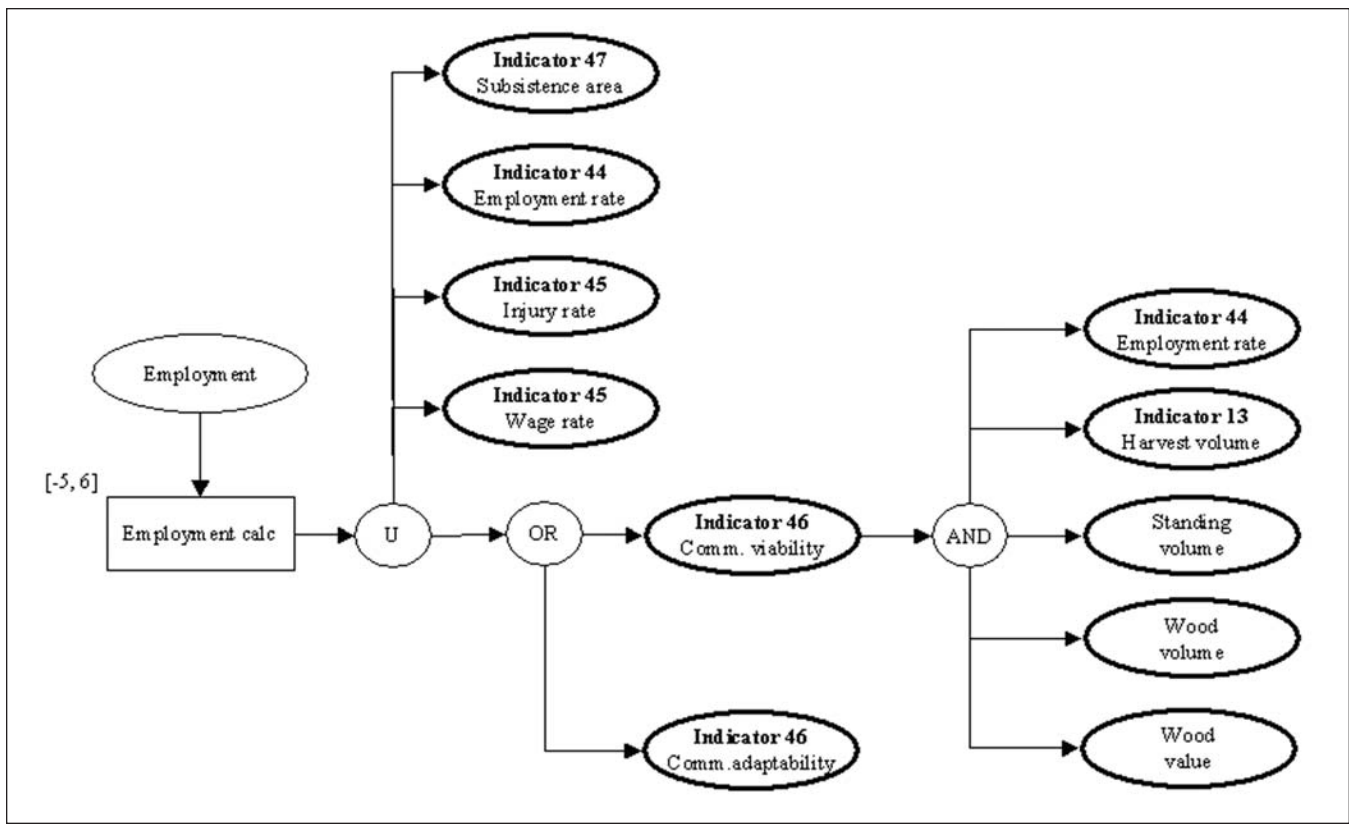


Figure 4—Logic specification for evaluation of the employment topic under the socioeconomic criterion (criterion 6). Community viability depends on (e.g., is cross-linked to) indicators 13 and 44 as well as data elements of other biophysical indicators related to wood production (indicators 29 and 31) and production capacity (indicators 11 and 12).

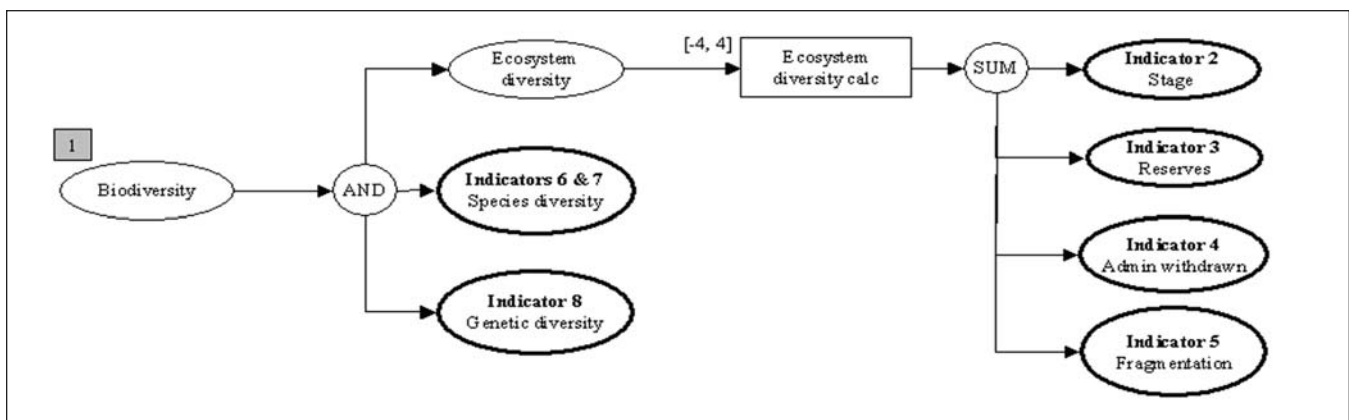


Figure 5—Additional level of detail of the logic specification for the biodiversity criterion, illustrating the AND and UNION operators which represent different philosophies about how information combines.

may, in fact, extend many levels deep (e.g., Figure 2 and 3). The specifications of the employment topic (Figure 4) and biodiversity (criterion 1, Figure 5) illustrate another design issue with significant policy implications - the choice of how to integrate information. The most commonly used

logical operators for combining elements in NetWeaver are AND, OR, and UNION. The fact that the logic model requires us to explicitly assign an operator at each step of integration reveals critical information that is often undefined in less rigorous descriptions.

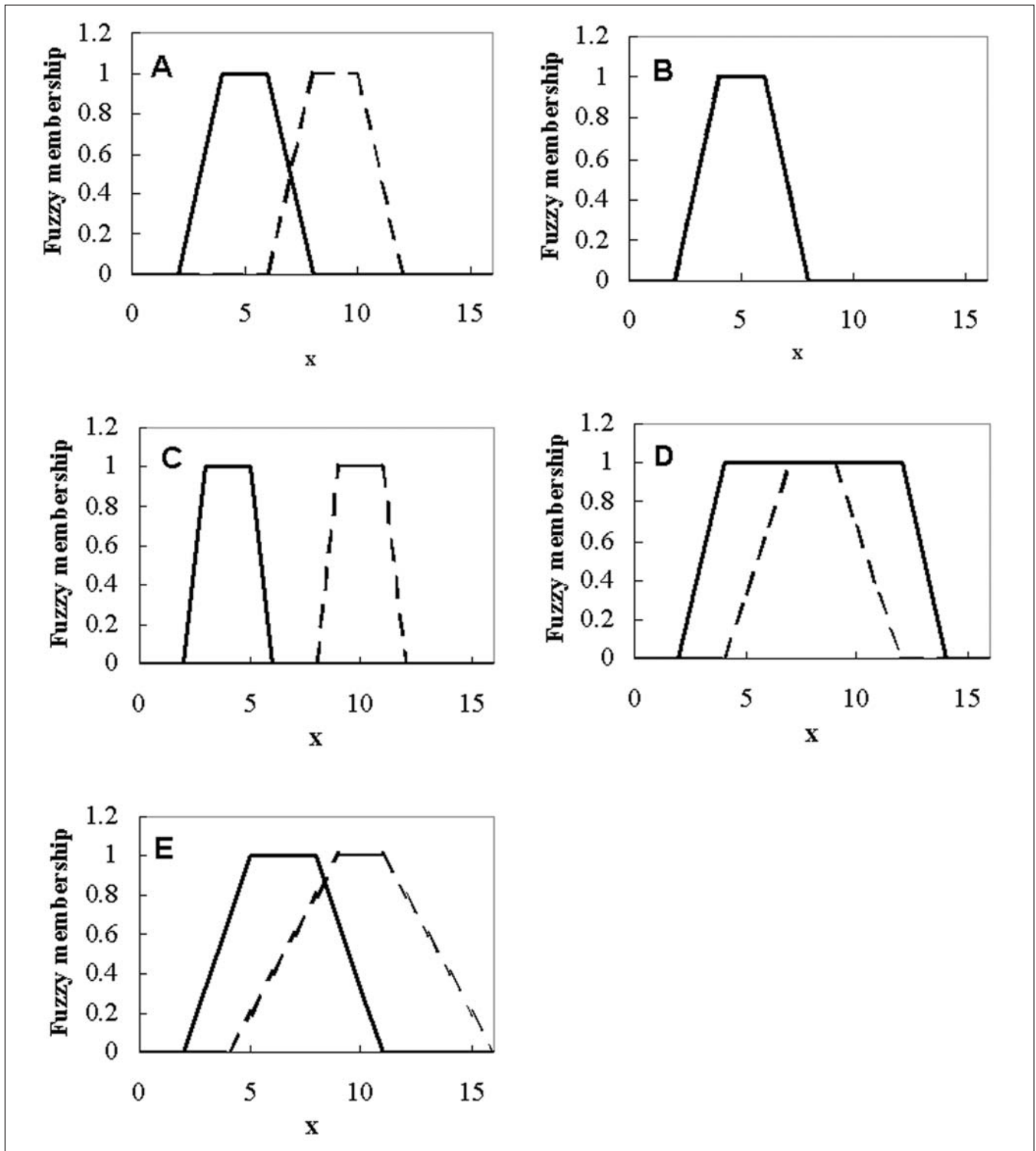


Figure 6—Prototypical relations between two fuzzy membership functions,  $f_A(x)$  (solid line) and  $f_B(x)$  (dashed line), for two elementary topics, A and B, respectively, illustrating trade-offs, compatibilities, and hybrid relations: A, pure trade-off; B, complete compatibility ( $f_A(x) \downarrow f_B(x)$ ); C, complete incompatibility; D, potential compatibility; and E, partial trade-off/partial compatibility.

The computation implemented by the NetWeaver AND operator effectively evaluates the set of topics that are arguments to the operator as limiting factors. The result of the AND operation is constrained by the least favorable component. A three-legged stool is a useful visual analogy to the AND operator. If one leg is removed (a line of evidence evaluates as fully false), the stool topples.

The U operator, commonly associated with calculations in the Montreal logic model, calculates a weighted average of a set of topics, and effectively asserts that the topics in the set of arguments to the U operator can partially compensate for one another. For example, in the evaluation of the ecosystem diversity topic (Figure 5), if the proposition for indicator 2 evaluates as fully false, but propositions for indicators 3, 4, and 5 evaluate as fully true, then the proposition of suitable ecosystem diversity evaluates to 75% true.

The OR operator is the functional opposite of AND. In this case, the three-legged stool is magical and will continue to support weight as long as any one of the legs is functional. Figure 4 uses an OR operator to combine community viability with community adaptability. Socioeconomic goals are likely to be met if the community can either continue sustainably as it is or successfully adapt to new conditions.

The choice of operator depends not only on inherent relationships among topics, but also on the overall purpose of the evaluation. A more regulatory approach, where all conditions must be met to some minimum standards, would be more likely to use AND operators, whereas U operators might be preferable if the goal were to compare relative performance.

**Tradeoffs and compatibilities**—Most representations of C&I for evaluating SFM are arranged hierarchically (Prabhu et al. 2001), which is true in the case of the Montreal C&I (WGCICSMTBF 1995). However, Prabhu et al. (2001) emphasize the value of a more general network representation, such as that used in NetWeaver, which allows cross-linkage among indicators and perhaps other intermediate topics. In the current prototype of the Montreal C&I logic, for example, evaluation of community viability (indicator 46) depends on indicators 13 and 44 as well as data elements related to other indicators (Figure 4). Although the logic specification for community viability is the only significant example of networked relations in the current prototype model, it is very likely that additional networked

relations within and between the biophysical and socioeconomic criteria will emerge in the continuing evolution of the design.

Indeed, the example (Figure 4) inspired a more general inquiry into the types of relations that might be accommodated. Let us first consider the simplest possible case in which two topics, A and B, are related through fuzzy membership functions,  $f_A(x)$  and  $f_B(x)$  respectively, that each evaluate the variable  $x$ . The function  $f_A(x)$ , for example, evaluates the degree to which the observed value of  $x$  supports the proposition of topic A (conversely,  $f_A(x)$  can be thought of as expressing the affinity of the observed value of  $x$  for the proposition of topic A). Five prototypical cases (Figure 6) illustrate some of the possible relations between topics A and B, including pure tradeoff (Figure 6A), complete compatibility (Figure 6B), complete incompatibility (Figure 6C), potential compatibility (Figure 6D), and partial tradeoff/partial compatibility (Figure 6E). Additional variations on the basic prototypes (Figure 6) could easily be generated, for example, by considering different functional forms such as  $f_A(w, x, y)$  and  $f_B(y, z)$ .

At a higher level of logic abstraction, we can now consider prototypical networks of relations between topics A and B (Figure 7), in which topic A is evaluated with respect to two premises, represented by topics C and D. Topic B is evaluated with respect to four premises, represented by topics D, E, F, and G. In all four examples (Figure 7), topics A and B are related through a shared dependence on the premise associated with topic D. The first three examples illustrate partial compatibility between topics A and B that is manifested in varying degrees, depending on intrinsic weight specifications on a premise and number of premises per topic (Figure 7A) and on the logic operator (Figure 7B and 7C). The third example is interesting in that, whereas topic D is evaluated as a limiting factor with respect to topic A, topic B is conditionally independent of topic D, depending on the states of topics E, F, and G. The final example (Figure 7D) illustrates a tradeoff relation between topics A and B, based on mutual dependence on topic D, but modified by the influence of other participating premises.

## CONCLUSIONS

Historically, managers, scientists and the public have tended to think in terms of tradeoffs among natural resource values and uses. More recent thought has emphasized a search for compatibility among values and uses in the hope

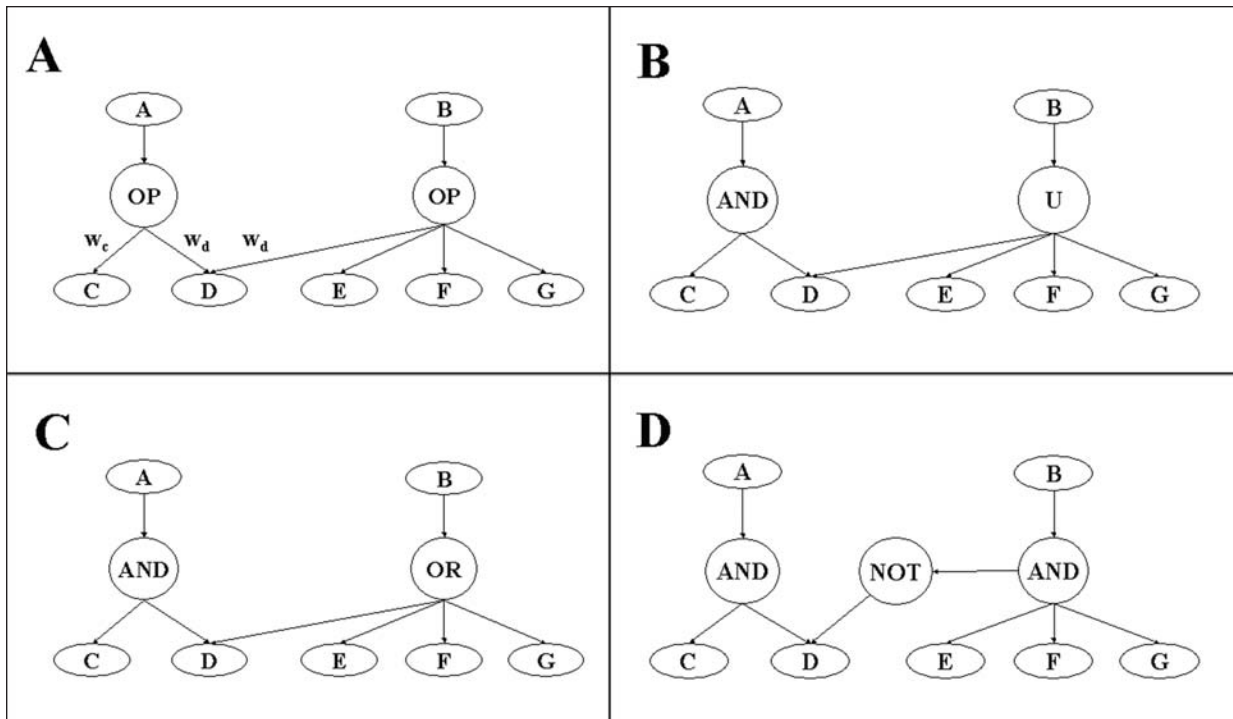


Figure 7—Prototypical relations between two topics, A and B, whose logic specifications share a common premise (topic D). A, topics A and B are compatible with respect to topic D, but topic D may have a differential effect on the two topics due to different numbers of premises or different weights applied to references to topic D (OP indicates a generic logic operator); B, topics A and B are compatible with respect to topic D, but topic A evaluates topic D as a limiting factor, while topic B evaluates topic D as an incremental contribution; C, topics A and B are potentially compatible, but topic B may be independent of topic D given the evaluated states of topics E, F, or G; and D, topics A and B are incompatible with respect to topic D, but the trade-off relation is modified by other premises.

that a dialogue on resource management started from this perspective will be more conducive to collaborative problem solving and, at the same time, less prone to the sorts of adversarial stand-offs that have often paralyzed resource management over the past few decades.

Evaluating individual attributes of a problem with fuzzy membership functions is very similar to the use of utility functions in utility theory (Edwards 1977; Edwards and Newman 1982). At the level of individual functions, there is little practical distinction between the two methods; both map results into a dimensionless response space that facilitates comparing apples and oranges when no common metric otherwise exists as a basis for comparison. Furthermore, if fuzzy membership functions are construed as a type of utility function, then a logic model can be viewed as a generalization of utility theory with the added virtue that a large number of relations can be organized relatively easily within the logic structure.

Reynolds et al. (in review) began the process of looking for networked relations between SFM topics in the course of designing the current logic model for evaluation of the

Montreal C&I (Figure 4). Results of the initial inquiry prompted the general treatment presented in Figures 6 and 7. Although the examples are limited in number and are relatively simple, perhaps the most important conclusion to be drawn is that many “real world” interdependencies among SFM or other natural resource management topics probably cannot be adequately represented by simple trade-off and compatibility relations. Instead, many relations probably will reflect variations on the basic concepts of tradeoff and compatibility relations along the lines suggested here, including variants in which both types of relation may be expressed. Fortunately, logic representation of natural resource evaluations potentially can accommodate a wide array of subtle variations on the basic concepts of tradeoffs and compatibility.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Adriaanse, A. 1993. Policy performance indicators. SDU Publishers, The Hague. 124 p.
- Colfer, C.J.P.; Woelfel, J.; Wadley, R.L.; Harwell E. 1996. Assessing people's perceptions of forests in Danau Sentarum Wildlife Reserve. CIFOR Working Paper No. 13. CIFOR, Bogor, Indonesia. 18 p.
- Davis, L.; Johnson, K.N.; Bettinger, P.; Howard, T. 2001. Forest Management (4<sup>th</sup> edition). McGraw Hill, New York. 804 p.
- Edwards, W. 1977. How to use multi-attribute utility measurement for social decision making. *IEEE Transactions on Systems, Man, and Cybernetics*. 7: 326-340.
- Edwards, W.; Newman, J. R. 1982. Multi-attribute evaluation. Sage, Beverly Hills, CA. 166 p.
- fuzzyTech, 1999. fuzzyTech user guide. fuzzyTech, Berlin. [unpaged]
- Haggith, M.; Prabhu, R.; Purnomo, H. [et al.]. 1998. CIMAT criteria and indicators modification and adaptation tool. <http://www.cifor.cgiar.org/acm/methods/toolbox3.html>. August 5, 2002.
- Hammond, A.; Adriaanse, A.; Rodenburg, E. [et al.]. 1995. Environmental indicators: a systematic approach to measuring and reporting on environmental policy performance in the context of sustainable development. World Resources Institute, Washington, DC. 54 p.
- Lélé, S.; Norgaard, R.B. 1996. Sustainability and the scientist's burden. *Conservation Biology*. 10: 354-365.
- Prabhu, R.; Colfer, C.J.P.; Dudley, R.G. 1999a. Guidelines for developing, testing and selecting criteria and indicators for sustainable forest management. Criteria and Indicators Toolbox Series, No. 1. CIFOR, Bogor, Indonesia. 183 p.
- Prabhu, R.; Haggith, M.H.; Purnomo, A. [et al.]. 1999b. CIMAT, Criteria and Indicators Modification and Adaptation Tool. Criteria and Indicators Toolbox Series, No. 3. CIFOR, Bogor, Indonesia. CD media.
- Pradhu, R.; Ruitenbeek, H.J.; Boyle, T.J.B.; Colfer, C.J.P. 2001. Between voodoo science and adaptive management: the role and research needs for indicators of sustainable forest management. In: Raison, R.J.; Brown, A.G.; Flinn, D.W. eds. Criteria and indicators for sustainable forest management. IUFRO 7 Research Series. New York: CABI Publishing. 39-66.
- Raison, R.J.; Flinn, D.W.; Brown, A.G. 2001. Application of criteria and indicators to support sustainable forest management: some key issues. In: Raison, R.J.; Brown, A.G.; Flinn, D.W. eds. Criteria and Indicators for Sustainable Forest Management. IUFRO 7 Research Series. New York: CABI Publishing. 2-18.
- Reynolds, K.M. 1999. NetWeaver for EMDS version 2.0 user guide: a knowledge base development system. Gen. Tech. Rep. PNW-471. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. 75 p.
- Reynolds, K.M.; Johnson, K.N.; Gordon, S.N. (in review). The science/policy interface in logic-based evaluation of forest ecosystem sustainability. *Forest Policy and Economics*.
- United Nations. 1992. Forest principles: report of the United Nations Conference on Environment and Development. United Nations, New York. 111 p.
- WGCICSMTBF (Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests) 1995. Criteria and indicators for the conservation and sustainable management of temperate and boreal forests: the Montreal Process. Canadian Forest Service, Hull, Quebec. 87.
- Zadeh, L. A. 1976. The concept of a linguistic variable and its application to approximate reasoning, part III. *Information Science*. 9: 43-80.

## COMPATIBILITY OF TIMBER AND CONSERVATION: TRACING THE TRADEOFF FRONTIER

Claire A. Montgomery<sup>1</sup>

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### ABSTRACT

The production possibility approach to compatibility research can be useful to forest policymakers in two ways. It can make tradeoffs between competing forest uses explicit so that policymakers can make informed policy judgments. It can help identify situations where there appears to be substantial opportunity to improve over current management. This paper describes two studies that illustrate the methods and potential usefulness of the production possibility approach. Nalle (2001) modeled tradeoffs between two wildlife species—the common porcupine (*Erethizon dorsatum*) and the great horned owl (*Bubo virginianus*)—and the value of timber production in a study area on the west side of the central Cascade Range of Oregon. Lichtenstein and Montgomery (in press) modeled tradeoffs between biodiversity, defined as a set of 167 terrestrial vertebrate species and the value of timber production in a study area in the Coast Range of Oregon. Both studies compared current management to the solutions on the production possibility frontier by simulating the current landowner pattern and objectives. They found that opportunities for improvement may exist.

**KEY WORDS:** Joint production, production possibility frontier, economics of biodiversity, forest economics, heuristic optimization.

### THE PRODUCTION POSSIBILITY APPROACH

The word compatibility has a particular meaning to economists. It refers to the attributes of the set of all feasible combinations of outputs on a site, known as the production possibility set. That set defines the productive capacity of a site with respect to the outputs being modeled. If the set is empty, there are no feasible combinations of the modeled outputs; they are completely incompatible. Most forest uses exhibit some degree of compatibility. Modeling the production possibility set is helpful for addressing two important forest land management questions. First, is current management inefficient? That is, is it possible to produce more of all outputs or, at least, more of some without decreasing the others? Second, if current management is not inefficient, increasing one output imposes tradeoffs. What is the magnitude of the tradeoffs required? That is, what is the degree of compatibility between the outputs and how likely is it that optimal management means management for both uses?

Figure 1(a) illustrates a hypothetical production possibility set for two outputs, wildlife and timber. The combinations of outputs represented by points inside the frontier are inefficient in the sense that one output can be increased at no cost. If the frontier accurately measures the productive capacity of the site and represents the outputs that matter to society, society will benefit from increasing at least one output, while decreasing none. There are reasons managers may continue current management, even when research suggests it might be inefficient or inside the frontier. These include uncertainty about the modeled production relations, uncertainty about future events and disturbances that might occur on the site, institutional constraints, and the cost of adjusting to new management regimes. Nonetheless, one goal of compatibility research is to identify inefficient management—where the benefits of change may outweigh the cost and risk associated with change.

In contrast, the subset of points along the frontier of the production possibility set are efficient in production because there are no unambiguous opportunities for gain.

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## Compatibility

—Set of all feasible combinations of outputs on a site.

### Production possibility set

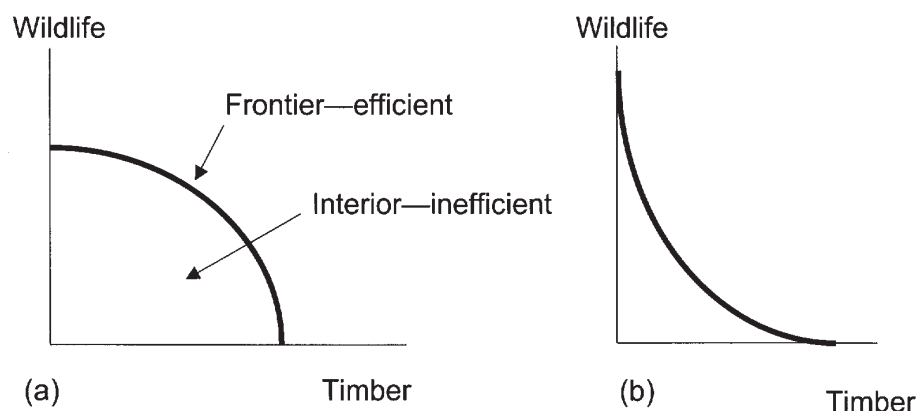


Figure 1—Two hypothetical production possibility sets illustrating efficient management on the frontier and inefficient management in the interior of the set.

Any increase in one output requires a decrease in another. The slope of the production possibility frontier (PPF) describes the amount of the other output that must be forgone and indicates the degree of compatibility between the outputs. For example, in Figure 1(a), increasing timber from zero costs little initially in terms of forgone wildlife; the slope of the PPF is flat. But as the level of timber increases, further increases require increasingly greater reductions in wildlife; the slope of the PPF becomes steep. Conversely, increasing wildlife from zero costs little initially in terms of forgone timber, but becomes more costly as the level of wildlife increases.

Whether the tradeoff incurred when moving from one combination of outputs to another is desirable or not depends on how society values the outputs. That question belongs in the realm of valuation research; compatibility research does not try to answer it. But with the production possibility set depicted in Figure 1(a), optimal management will likely produce both outputs, rather than one or the other. The more concave to the origin the PPF is, the more likely joint production of outputs will be optimal.

Figure 1(b) depicts a production possibility set for which it is optimal to manage the site exclusively for one use or the other even though there are feasible combinations of both. The cost of increasing wildlife from zero is

initially very high and, likewise, the cost of increasing timber from zero is initially very high. The two outputs are less compatible than in Figure 1(a). Again, the choice of which output is preferable depends on their value to society.

As part of the wood compatibility initiative research program, Stevens and Montgomery (2002) reviewed the forest economics literature, searching for examples of compatibility research. They found many studies that tried to model multiple forest uses, but they found few that tried to define the productive capacity of a site using the production possibility approach. Some early studies introduced the idea of applying the production possibility approach to forests (Gregory 1955; Hagenstein and Dowdle 1962; Muhlenberg 1964), and in subsequent decades, a few have carried the idea further (Connaughton and Fight 1984; Jones and Schuster 1985; Arthaud and Rose 1996).

Now there is renewed interest in the production possibility approach to compatibility research (Rohweder et al. 2000; Shunk 2000; Calkin et al., in press; Lichtenstein and Montgomery, in press; Nalle 2001), partly because of heightened interest in the policy arena in cost-effective management for nonmarket forest uses. At the same time, there have been advances in the knowledge, methods, and technology required for realistic modeling of production possibilities and biological diversity. Examples include the

development of the technology of geographic information systems (GIS) and the accumulation of spatial data about forests that support spatially explicit modeling of real landscapes; the development of simulation models that model spatial and dynamic relations between different forest uses; the development of optimization methods, such as stochastic heuristic search algorithms, that are extremely flexible; and the development of computing technology that can solve complex problems in a relevant time frame.

This paper describes two examples of recent compatibility research (Lichtenstein and Montgomery, in press; Nalle 2001) that illustrate the methods and the potential usefulness of the approach.

## GENERAL APPROACH

The two studies described in this paper took the same general approach:

- They integrated biological and economic models in an optimizing framework to address economic issues related to efficiency.
- They used the integrated model to estimate the frontier of the production possibility set for the modeled outputs on a particular site to assess its productive capacity—what can be produced?
- They simulated policy scenarios, particularly management under the current landowners, and compared the outcomes to the PPF to search for opportunities for improvement.

Both studies evaluated tradeoffs between wildlife and timber production. Nalle (2001) represents studies involving individual wildlife species. Lichtenstein and Montgomery (in press) represents studies involving multiple species of vertebrates.

## SINGLE SPECIES MODELS

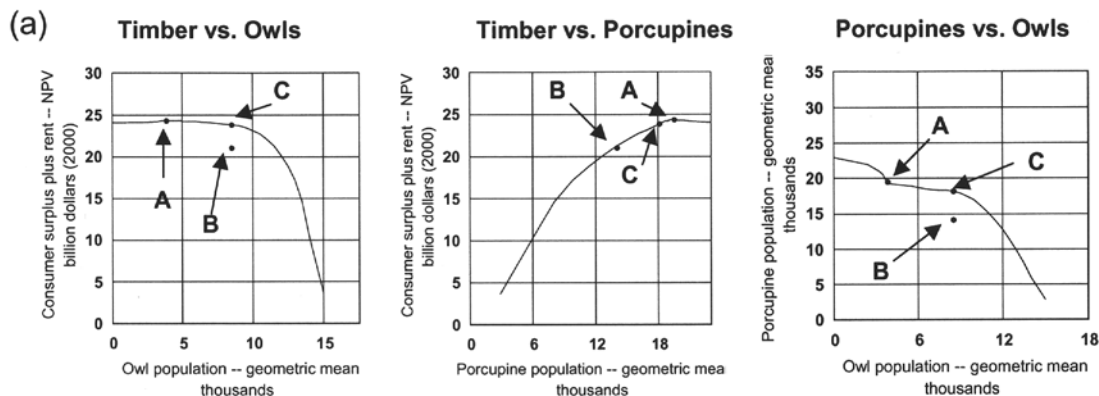
Nalle (2001) modeled the tradeoffs between two species with different habitat needs, the common porcupine (*Erethizon dorsatum*) and the great horned owl (*Bubo virginianus*), and timber production on a 1.7 million-ha landscape on the west side of the central Cascade Range of Oregon over a 100-year time horizon.

In earlier research, Montgomery et al. (1994) and Montgomery (1995) illustrated the application of marginal economic analysis to preservation of individual wildlife species by estimating the marginal cost curve for the northern spotted owl (*Strix occidentalis caurina*) in the Pacific Northwest. The cost of owl survival was measured as the value of forgone timber production on federal land in the region. The analysis required the integration of a biological model of owl population dynamics (Lamberson et al. 1992) and an economic model of wood products markets (Adams and Haynes 1980). Underlying the marginal cost curve was an estimate of the PPF between probability of owl survival and the level of federal timber harvest. The analysis was useful as an illustration, but its practical usefulness was limited for several reasons. It was not dynamic. Habitat was initialized to a particular configuration and it could not change over time. It was not optimized. It was only assumed that habitat was placed optimally for the owl and that least cost habitat was used first. It did not allow for management of habitat on the landscape. Land was either allocated as owl habitat reserve or it was managed for timber production and was unsuitable as owl habitat. Policy alternatives were assumed to fall on the PPF and, hence, to be cost-effective.

Nalle's study was an attempt to address some of those limitations. It extended an earlier study by Calkin et al. (in press) that modeled the tradeoffs between the northern flying squirrel (*Glaucomys sabrinus*) and the net present value<sup>2</sup> of timber production on a 10,000-ha landscape on the west side of the central Cascade Range of Oregon over a 100-year time horizon. Both studies used a spatial and dynamic biological model wildlife population simulation model, PATCH or Program to Assist in the Tracking of Critical Habitat (Schumaker 1998). The PATCH model tracks individual females on a landscape as they are born, move to inhabit a territory, produce offspring, and die. Dispersal and breeding success depends on the quality and configuration of habitat, which changes over time due to timber management and vegetation growth. A regression model to predict population size as a function of landscape attributes was estimated using PATCH simulations. The regression model was used in the optimization because PATCH is too slow to use directly in a procedure that requires millions of iterations.

An heuristic optimization algorithm was used to choose the timing and location of timber harvest to maximize timber value subject to meeting targets for the wildlife species.

<sup>2</sup> All of the studies described in this paper used a discount rate of 4% in conformance with U.S. Forest Service guidelines. The many sources of data are described in the individual papers.



(b) **Owl habitat maps: 5<sup>th</sup> decade. Dark is good habitat.**

**A: Maximum timber value**  
owls = 3800, timber=24.3

**B: Current Landowners**  
owls = 8500, timber=21.1

**C: Maximum potential for:**  
owls = 8500, timber=23.9

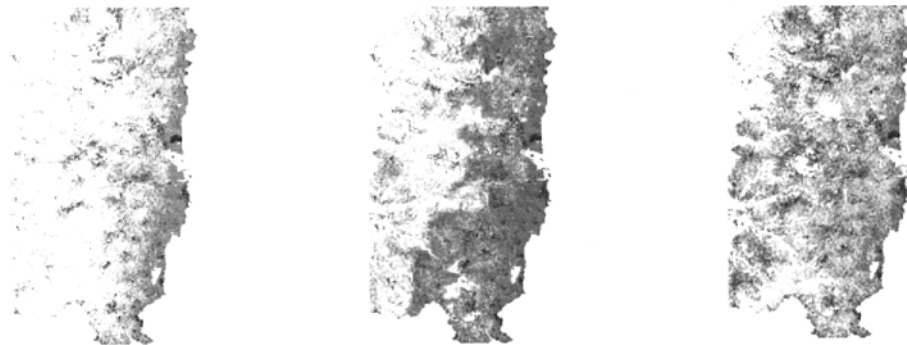


Figure 2—Pairwise production possibility frontiers between net present value of timber production, geometric mean owl population size, and geometric mean porcupine population size over 100 years in a 1.7 million-ha study area on the west side of the central Cascade Range of Oregon and owl habitat maps corresponding to three solutions: (A) maximum timber value, (B) current landowners, and (C) the PPF solution that corresponds to (B) in geometric mean owl population size (Nalle 2001).

Timber value was the present value of benefits to consumers (consumer surplus) and benefits to landowners (rent) resulting from timber production during the time horizon plus the present value of the land and timber at the end of the time horizon assuming it will be managed forever on the management regime assigned during the time horizon. Stumpage prices depended on down-sloping demand for logs and distant-dependent harvest and haul costs. The wildlife target was the geometric mean of the estimated population size in each of 10 10-year decision periods for each of the two species. The targets were varied over a grid of values for each species and the optimization was solved repeatedly to estimate the PPF without regard to landowner boundaries.

The estimated two-way PPFs for the common porcupine, the great horned owl, and the value of timber production are shown in Figure 2(a). These appear as lines in three-dimensional space because two of the outputs are complements (positively related) over the entire range—porcupines and timber up to the maximum timber value solution (Point A on all three graphs) and owls and timber as porcupine population size is increased beyond that point. Owl habitat maps in the fifth decade corresponding to three solutions are shown in Figure 2(b): (A) the maximum timber value solution, (B) the current landowner pattern simulated by maximizing the value of timber production on private land and allowing no timber harvest on public land, and (C) the PPF solution that matched the owl population of the current landowner simulation.

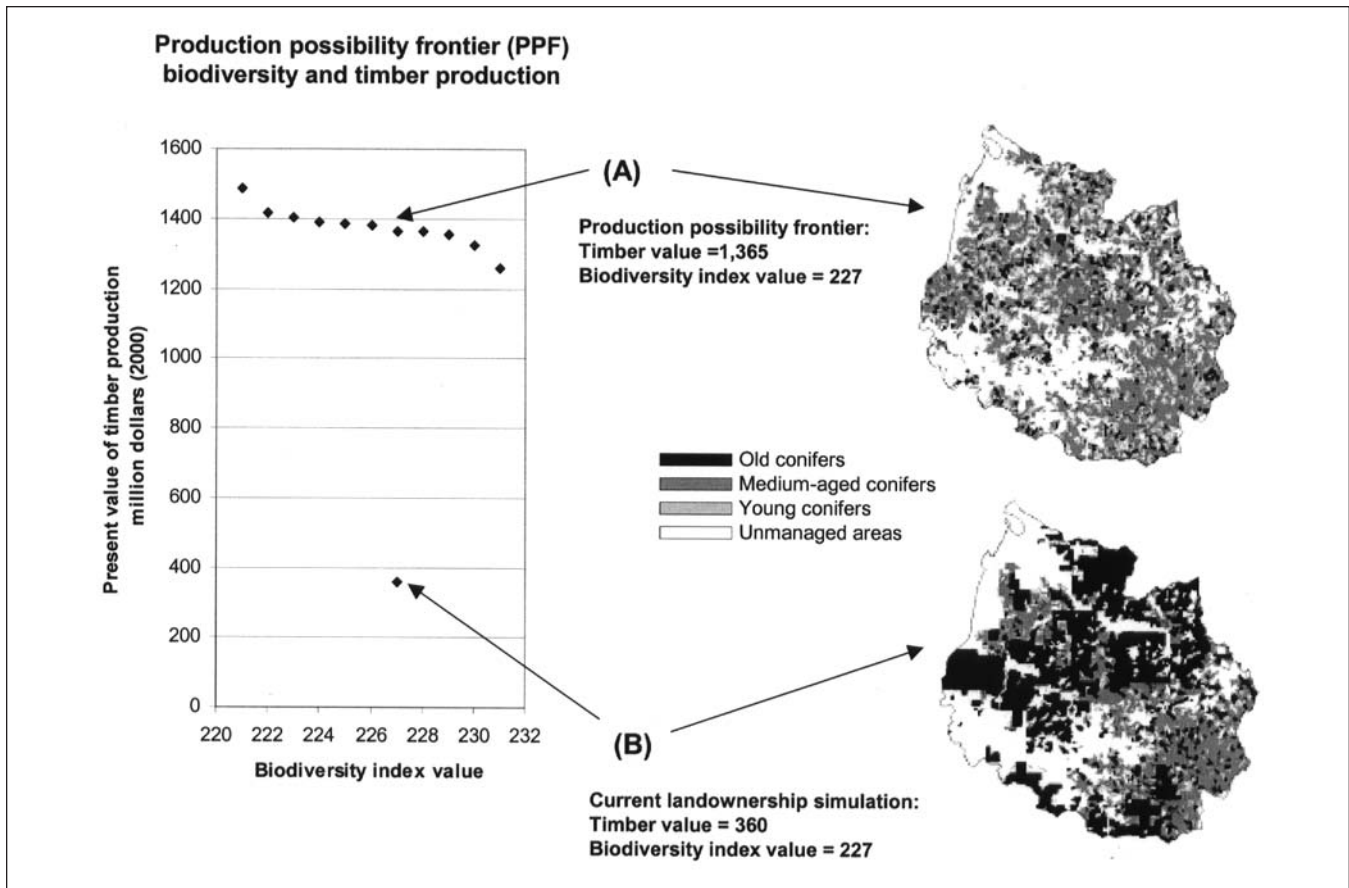


Figure 3—Production possibility frontier for an index of 167 terrestrial vertebrate species, and the present value of timber production over 100 years in a 41,200-ha study area on the west side of the Coast Range in Oregon and vegetation maps corresponding to (A) the point on the PPF with index value=227 and (B) the current landowner simulation with index value=227 (Lichtenstein and Montgomery, in press).

A comparison of the current landowner simulation, which represents potential future management, with solutions on the PPF suggests the potential for improvement. For example, it appears that the geometric mean owl population could increase by 35% without affecting timber value or porcupine population size. A comparison of owl habitat maps (B) and (C) shows that the improvement could be achieved by managing across ownerships and reducing the polarization of uses that occurs under the current landowners. However, a comparison of the habitat maps for (A), the maximum timber value solution, and (B) shows why the potential improvement is not larger. Timber processing facilities are on the western edge of the study area. Consequently, timber values are lower on federal land, which is concentrated on the eastern edge, than on private land. As a result, owl habitat is concentrated on public land even in the maximum timber value solution.

## MULTIPLE SPECIES MODELS

Lichtenstein and Montgomery (in press) modeled trade-offs between biodiversity, defined as a set of 167 native terrestrial vertebrate species, and the net present value of timber production on a 41,200-ha study area on the west side of the Coast Range in Oregon.

The challenges encountered in modeling multiple species differ from those encountered in modeling individual species. There is not sufficient information to model large numbers of species with any detail. Therefore, to be manageable, the species must be aggregated into an index. Groundwork for Lichtenstein and Montgomery's study was set in Montgomery et al. (1999). In that study, tradeoffs were assessed between market-valued land uses—open space, agriculture, and residential/commercial—and biodiversity, defined as a set of 147 native bird species, in Monroe

County, Pennsylvania. Weighted expected species richness was used as a multiple species index,  $B(y)$ , for a particular configuration of land uses,  $y$ :

$$B(y) = \sum_{s=1}^{147} w_s V(X_s(y)) \quad (1)$$

Diversity weights,  $w_s$ , were assigned to each species,  $s$ , based on the taxonomic tree as proposed by Vane-Wright et al. (1991) and modified by May (1990). Simple logistic functions,  $V(X_s)$ , were constructed to represent the probability that each species would persist on the landscape as a function of its habitat,  $X_s$ . A marginal cost curve for the index in Monroe County, showing the cost of increments in the index as the value of forgone market land values, was estimated by maximizing market land value plus biodiversity value. Since the value of biodiversity is unknown, the model was solved repeatedly for incrementally increasing “biodiversity prices.” The PPF can be derived from the marginal cost curve. Shunk (2000) extended Montgomery et al.’s (1999) study by adding timber production and allowing different rotation lengths in the Muddy Creek Basin of Oregon. Both studies were nonspatial—wildlife depended on aggregate area of habitat and land values depended on aggregate area each use. Both studies assumed that the landscape was static and the index,  $B(y)$ , was evaluated on an unchanging landscape.

Lichtenstein and Montgomery (in press) extended both studies in two ways:

1. The analysis was dynamic. It began with the current landscape and modeled the effect on the set of species as it changed over a 100-year time horizon in response to timber management. The probability of persistence was the product of short-term probabilities that depended on the vegetative cover resulting from land management activities,  $y$ , in each of 20 5-year decision periods and a 100-year probability that depended on the vegetative cover at the end of the time horizon:

$$V(y) = \left( \prod_{t=1}^{20} V_5(X_{st}(y)) \right) V_{100}(X_{s,100}(y)) \quad (2)$$

2. The biological model included a small spatial component. It required sufficient contiguous habitat to meet minimum home range requirements for each species. Although the biological model was crude, it extended earlier studies that modeled large sets of species in an optimizing framework (Ando et al. 1998, White et al. 1997; Bevers et al. 1995).

The PPF was estimated using an heuristic optimization algorithm by choosing the set of timber management activities to maximize timber value subject to targets for,  $B(y)$ . The targets were increased incrementally from zero and the model was solved repeatedly. The resulting estimate of the PPF is shown in Figure 3. As in Nalle (2001), a simulation of current landowners and their objectives—maximum timber value on private land and no timber harvest on federal land—produced an estimate of likely future management in the study area. The resulting index value was in the midrange of the PPF index values. However, the timber value was only a quarter of the PPF values. The main reason for the dramatic difference in timber value was the availability of mature timber for harvest on federal land in the first period. Vegetation maps corresponding to the end of the time horizon for the current landowner simulation and for the point on the PPF that achieved the same index value are also shown in Figure 3. The landowner pattern is clearly highlighted on the current landowner simulation map by the presence of old forest on federal land.

Before drawing conclusions about the desirability of altering current management, consider what is missing from the analysis. Federal forest policy in the Pacific Northwest is driven by concerns for preservation of mature and old-growth forest and the endangered species that rely on them for survival. In this study, endangered species were treated just as any other species. In fact, with the logistic persistence probability function, the greatest return to conservation effort is for species ranked vulnerable, where the logistic function is steepest, rather than those ranked endangered.

## FUTURE RESEARCH NEEDS

The production possibility approach is a potentially powerful policy tool. It makes tradeoffs between competing forest uses explicit so that policymakers can make informed judgements. It allows feasible management alternatives to be evaluated by comparison to unconstrained solutions on the production possibility frontier. The solutions themselves can yield general information about efficient land management for constructing feasible management alternatives.

Further work would greatly enhance the usefulness of this approach to compatibility research. Lichtenstein and Montgomery’s study highlights the importance of carefully considering the outputs that were omitted from the analysis. For example, policymakers and society would benefit from a better understanding of tradeoffs between large sets of species and particular endangered species. In fact, the

cost of one conservation program may well include lower achievement of other conservation goals. Other forest uses, besides wildlife and timber, may also be modeled (e.g., reductions in fire risk, recreation use, water yield, aquatic species). Some modeling issues yet to be resolved are the interaction between geographic scale and compatibility, uncertainty about model parameters, incorporation of disturbance regimes into the model, and the treatment of existing infrastructure and institutions.

Nonetheless, these studies do suggest some policy implications. In particular, forest land management might be improved by finding ways to induce the various land-owners to manage cooperatively across ownerships (Spies et al., in press). Current federal forest management policy is reactive. It takes market failures on private land as given and tries to compensate for those failures by managing almost exclusively for goods that are underprovided by markets. While that may be the most politically expedient policy for now, in the long-run, it may be worth the effort to search for creative policies that allow more flexible forest management on public land and better management for nonmarket forest uses on private land in the future.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Adams, D.M.; Haynes, R. 1980. The 1980 softwood timber assessment market model: structure, projections and policy simulations. *Forest Science*. 26, Monograph 22.
- Ando, A.; Camm, J.; Polasky, S.; Solow, A. 1998. Species distributions, land values, and efficient conservation. *Science* 279: 2126-2128.
- Arthaud, G.J.; Rose, D.W. 1996. A methodology for estimating production possibility frontiers for wildlife habitat and timber value at the landscape level. *Canadian Journal of Forest Research*. 26: 2191-2200.
- Beyers, M.; Hof, J.; Kent, B.; Raphael, M.G. 1995. Sustainable forest management for optimizing multi-species wildlife habitat: a coastal Douglas-fir example. *Natural Resource Modeling*. 9(1): 1-24.
- Calkin, D.; Montgomery, C.A.; Schumaker, N.H. et al. [In press]. Developing a production possibility set of wildlife species persistence and timber harvest value. *Canadian Journal of Forest Research*.
- Connaughton, K.P.; Fight, R.D. 1984. Applying tradeoff analysis to national forest planning. *Journal of Forestry*. 82(11): 680-683.
- Gregory, G.R. 1955. An economic approach to multiple use. *Forest Science*. 1(1): 6-13.
- Hagenstein, P.R.; Dowdle, B. 1962. Theoretical model for examining forest land use alternatives. *Journal of Forestry*. 60: 187-191.
- Jones, J.G.; Schuster, E.G. 1985. An application of discrete optimization for developing economically efficient multiple-use projects. Gen. Tech. Rep. INT-GTR-178. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 16 p.
- Lamberson, R.H.; McKelvey, R.; Noon, B.R.; Voss, C. 1992. A dynamic analysis of spotted owl viability in a fragmented forest. *Conservation Biology*. 6: 505-512.
- Lichtenstein, M.E.; Montgomery, C.A. [In press]. Biodiversity and timber in the Coast Range of Oregon: inside the production possibility frontier, *Land Economics*.
- May, R.M. 1990. Taxonomy as destiny. *Nature*. 347: 129-130.
- Montgomery, C. 1995. Economic analysis of the spatial dimensions of species preservation: the distribution of northern spotted owl habitat. *Forest Science*. 41(1): 67-83.
- Montgomery, C.; Brown, G.M., Jr.; Adams, D.M. 1994. The marginal cost of species preservation: the northern spotted owl. *Journal of Environmental Economics and Management*. 26: 111-128.

- Montgomery, C.A.; Pollak, R.A.; Freemark, K.; White, D. 1999. Pricing biodiversity. *Journal of Environmental Economics and Management*. 38: 1-19.
- Muhlenberg, N. 1964. A method for approximating multiple-use optima. *Forest Science*. 10(2): 209-212.
- Nalle, D.J. 2001. Optimizing spatial and temporal aspects of nature reserve design under economic and ecological objectives. Corvallis, OR: Oregon State University. 227 p. Ph.D. dissertation.
- Rohweder, M.R.; McKetta, C.W.; Riggs, R. 2000. Economic and biological compatibility of timber and wildlife production: an illustrative use of production possibilities frontier. *Wildlife Society Bulletin*. 28(2): 435-447.
- Schumaker, N.H. 1998. A users guide to the PATCH model. EPA/600/R-98/135. Corvallis, OR: U.S. Environmental Protection Agency, Environmental Research Laboratory. 120 p.
- Shunk, N.J. 2000. Choosing efficient land allocations and forest management regimes for biodiversity. Corvallis, OR: Oregon State University. 92 p. M.S. thesis.
- Spies, T. A.; Reeves, G. H.; Burnett, K. M. [et al.]. [In press]. Assessing the ecological consequences of forest policies in a multi-ownership province in Oregon. In J. Liu, J.; W. W. Taylor, W.W., eds. *Integrating landscape ecology into natural resource management*. Cambridge: Cambridge University Press.
- Stevens, J.A.; Montgomery, C.A. 2002. A synthesis of multiresource research with application to the Pacific Northwest: multiple use, tradeoffs, and joint production. Gen. Tech. Rep. PNW-GTR-539. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 44 p.
- Vane-Wright, R.K.; Humphries, C.J.; Williams, P.H. 1991. What to protect? - systematics and the agony of choice. *Biological Conservation*. 55: 235-254.
- White, D.; Minotti, P.G.; Barczak, M.J. [et al.]. 1997. Assessing risks to biodiversity from future landscape change. *Conservation Biology*. 11(2): 349-360.

## **ASSESSING TEMPORAL TRENDS IN FOREST INVENTORY AND ANALYSIS DATA: APPLICATIONS TO CRITERIA AND INDICATORS**

Joseph A. Donnegan<sup>1</sup>

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### **ABSTRACT**

The Forest Inventory and Analysis program (FIA) of the U.S. Department of Agriculture, Forest Service has conducted periodic forest inventories since the 1930s in Oregon and Washington. This work evaluates historic trends in FIA data in the context of the Montreal Process Criteria and Indicators (C&I) and in the context of examining the compatibility of timber production, while sustaining other valued forest resources. Based on 65 years of FIA data, this paper compares differences in timberland area and volume between five counties with the highest average harvest-to-growing-stock-volume (H:V) ratios and the five with the lowest H:V ratios in western Oregon. Historic Resource Planning Act data (RPA), of which FIA is a subset, along with climatic data for western Oregon, are presented to frame the results in a broader context. Timberland area and volume trends in the state are mirrored in FIA county-level data, with declines evident until the 1970s to 1980s when the downward trend leveled-off or was reversed. The trend in volume per acre for the combined group of five counties with the lowest H:V ratio and the group with the highest H:V ratio follow each other in trend until 1977 when volume per acre increases strongly for the group of low H:V counties compared with a modest decrease for the high H:V group. Climatic affects on timberland area and volume are not evident in the record, appearing to be overwhelmed by changes in land use.

**KEY WORDS:** Criteria and indicators, data warehouse, forest inventory and analysis, harvest, Oregon, wood compatibility initiative.

### **INTRODUCTION**

#### **Wood Compatibility Initiative**

The key question behind the USDA Forest Service's Wood Compatibility Initiative (WCI) is to determine whether forest managers can produce timber outputs without significantly compromising other valued forest resources including aesthetics, recreation, water quality, and wildlife habitat. In other words, can forest managers sustainably manage timber and nontimber forest resources jointly? One test, examined here, traces the influence of timber production on timberland area and timberland volume for separate counties and for aggregates of counties. Each county and aggregate exhibits different levels of timber production.

#### **Criteria and Indicators**

In terms of gauging forest sustainability, the effort to develop guidelines for sustainable management was addressed on an international level by the United Nations Conference on Environment and Development (UNCED, a.k.a. Earth Summit or Rio Summit; Rio de Janeiro, 1992) with the adoption of the Statement of Forest Principles and Chapter 11 of Agenda 21 (U.S.D.A. Forest Service 1997). Agenda 21 focuses on sustainable development with special regard to the environment, while the Statement of Forest Principles narrows the focus to forested ecosystems. As an outgrowth of these summits, a working group, now composed of 12 countries (Argentina, Australia, Canada, Chile, China, Japan, the Republic of Korea, Mexico, New Zealand, the Russian Federation, the United States of America, and Uruguay), developed and formalized the Criteria and Indicators for the Conservation and Sustainable

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Management of Boreal and Temperate Forests (C&I; Anonymous 1995) in the Montreal Process and the Santiago Declaration. A total of seven criteria and 67 specific indicators to assess those criteria were listed in these documents. The criteria include the following broad concerns:

- Criterion 1: Conservation of biological diversity,
- Criterion 2: Maintenance of productive capacity of forest ecosystems,
- Criterion 3: Maintenance of forest ecosystem health and vitality,
- Criterion 4: Conservation and maintenance of soil and water resources,
- Criterion 5: Maintenance of forest contribution to global carbon cycles,
- Criterion 6: Maintenance and enhancement of long-term multiple socioeconomic benefits to meet the needs of societies, and
- Criterion 7: Legal, institutional and economic framework for forest conservation and sustainable management.

The specific indicators addressed in this study, timberland area and volume, are indicator-components of the above Criterion 2 and 5:

- 2a: Area of forest land and net area of forest land available for timber production,
- 2b: Total growing stock of both merchantable and non-merchantable tree species on forest land available for timber production,
- 5a: Total forest ecosystem biomass and carbon pool, and if appropriate, by forest type, age class, and successional stages.

For the FIA assessments, timberland is defined as forest land that is available for, and capable of producing at least 20 cubic feet of industrial wood per acre, per year. Growing-stock volumes are the live, net bole volumes for sound (non-cull) trees with diameters five inches and greater. Growing-stock volume is used to calculate biomass with species-specific equations.

State and region-wide assessments of the C&I (Oregon Department of Forestry 1999, State of Hawaii 2000) have taken on greater importance as researchers seek to spatially apportion trends from national-level assessments (USDA Forest Service 1997). Scale questions remain about the resolution at which the C&I are discernable and applicable (Woodley et al. 1999).

## Forest Inventory and Analysis

With the international agreement on specific C&I, it is important to frame resource assessments in terms of the C&I to facilitate regional and international comparisons for policy evaluation. Inventories of forest resources have been conducted in the United States since the passage of the McSweeney-McNary Forest Research Act of 1928. These assessments began by estimating timber volumes, forest area, site productivity, and stocking levels (i.e., regeneration) based on timber company estimates and field survey by forest service crews. From this work, forest type maps were produced. Inventory assessments were historically conducted approximately every ten years. More recently the FIA inventory has grown to encompass field-plot inventory and monitoring of a variety of forest resources including timber, wildlife habitat, nontimber forest products, watershed quality, and forest health (Frayer and Furnival 1999).

As the Forest Survey has evolved into the current FIA program, changes in definitions and methods have been required to account for different needs and changing values among users of forest resources. Mapping of dominant forest types has been replaced with field-intensive inventories that seek to quantify tree, field plot, and regional changes. The inventory field-plot footprint has changed design from ten subplots per plot to five, and most recently to four subplots per plot. Additionally, the sampling design changed from collecting tree-level information on a fixed radius plot to collecting data on a variable radius plot. In the most recent design, FIA is again using a fixed-radius plot. Changes in methods and definitions complicate comparisons of results through time. Each inventory is treated as a separate estimate of resources at each point in time. Units are reported in English units to maintain the ability to compare estimates through time with historic reports.

The two estimates of forest sustainability from the C&I used in this study, area of timberland and growing-stock volume, are compared through time among the ten western Oregon counties that average the highest and lowest harvest-to-growing-stock-volume (H:V) ratios. The historic inventory data is being compiled on an ongoing basis in a data warehouse that will summarize the periodic (~10-year intervals) forest inventories at the spatial scale of county.

## RESEARCH QUESTIONS

The following questions helped to focus this phase of the research, addressing the issues in the Wood Compatibility Initiative:

# Oregon Counties

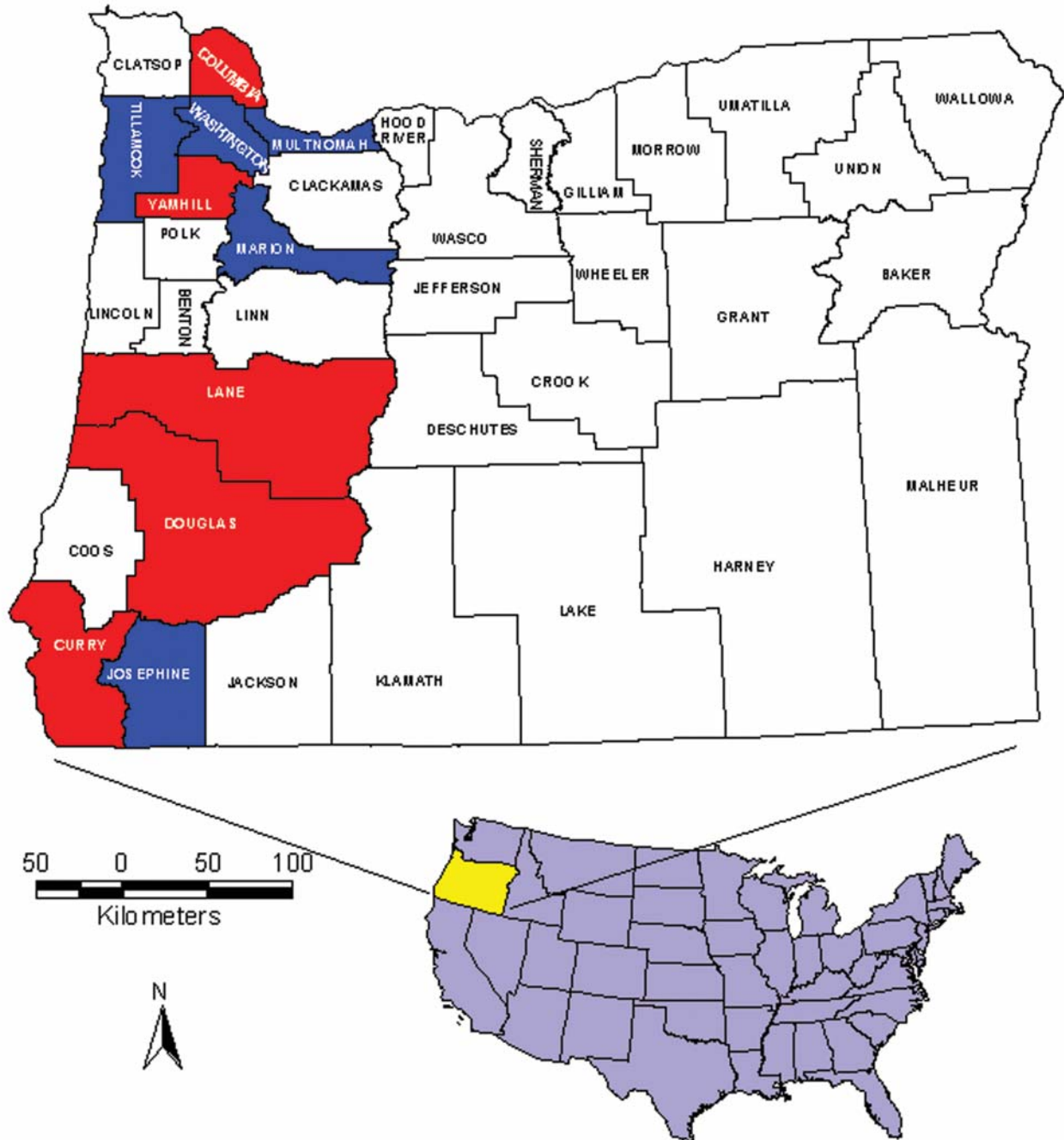


Figure 1—Oregon counties with highest (red) and lowest (blue) harvest-to-volume ratios for non-federal lands in western Oregon.

**Table 1—Counties chosen to compare forest conditions based on the average harvest to average volume (H:V) ratio**

| County     | Average Harvest <sup>a</sup> | Average Volume <sup>b</sup> | No. plots in county |      |      | H:V ratio (%) |
|------------|------------------------------|-----------------------------|---------------------|------|------|---------------|
|            |                              |                             | 1972                | 1985 | 1995 |               |
| Josephine  | 19,819                       | 1,133,900                   | 31                  | 20   | 29   | 1.75          |
| Marion     | 39,604                       | 2,033,714                   | 21                  | 20   | 26   | 1.95          |
| Washington | 53,583                       | 2,583,096                   | 30                  | 28   | 40   | 2.07          |
| Multnomah  | 9,605                        | 445,031                     | 6                   | 6    | 8    | 2.16          |
| Tillamook  | 136,232                      | 5,612,819                   | 71                  | 69   | 75   | 2.43          |
| Yamhill    | 52,593                       | 1,417,502                   | 18                  | 16   | 26   | 3.71          |
| Lane       | 509,104                      | 12,219,928                  | 114                 | 112  | 125  | 4.17          |
| Curry      | 108,876                      | 2,566,292                   | 50                  | 41   | 47   | 4.24          |
| Douglas    | 611,716                      | 14,196,386                  | 135                 | 145  | 162  | 4.31          |
| Columbia   | 153,053                      | 2,979,878                   | 43                  | 43   | 47   | 5.14          |

<sup>a</sup> Non-federal timberlands, 1962-1998; thousand board feet Scribner.

<sup>b</sup> Non-federal timberlands, 1930s-1990s; thousand board feet Scribner.

1. Can forest resource trends be tracked reliably at county resolution using FIA data?
2. Are there differences in the trends for timberland area and growing-stock volume between counties experiencing different harvest levels (harvest levels measured as H:V ratio)?
3. Do climatic trends coincide with changes in timberland area or growing-stock volume?

## METHODS

### Database Development

To address questions regarding the affects of human-induced disturbance on forest conditions, two existing data sets were combined into a summary-statistics database: statistics from printed, historic, county-level forest survey reports (1930s-1970s; earliest reports derived from forest type maps), and electronically-archived, plot-level data sets (1980s to most recent inventories). Historic county-level reports were collected for Oregon. Their summary statistics (e.g. volume by species and ownership, area by forest type and ownership, site index area by forest type and ownership,

stocking levels by forest type, ownership and age class) were entered into spreadsheets via optical character recognition and key input. The data was converted via programming code to a summary-level database. Select variables in the existing, electronically-archived, plot-level data were summarized and loaded into the summary-statistics database. The database will be continually updated as new data are processed from continuing resource inventories and as additional states and variables are evaluated. Growing-stock volume, area, site index, and stocking levels, all by ownership and forest type, have been collected from the start of the inventory program in the 1930s. Data for the late 1950s-1970s were originally reported only at the survey-unit level (combinations of counties). However, this data is archived as paper plot cards and may be summarized for the historic database in future projects. Data for the 1980s and 1990s was summarized only for non-federal lands. The trends outlined in this work apply only to non-federal lands. A related, current project in FIA will link public and private lands for the most recent inventories. Non-federal data are reported as a summary of timberland ownership, exclusive of national forest, Bureau of Land Management, and national park lands.

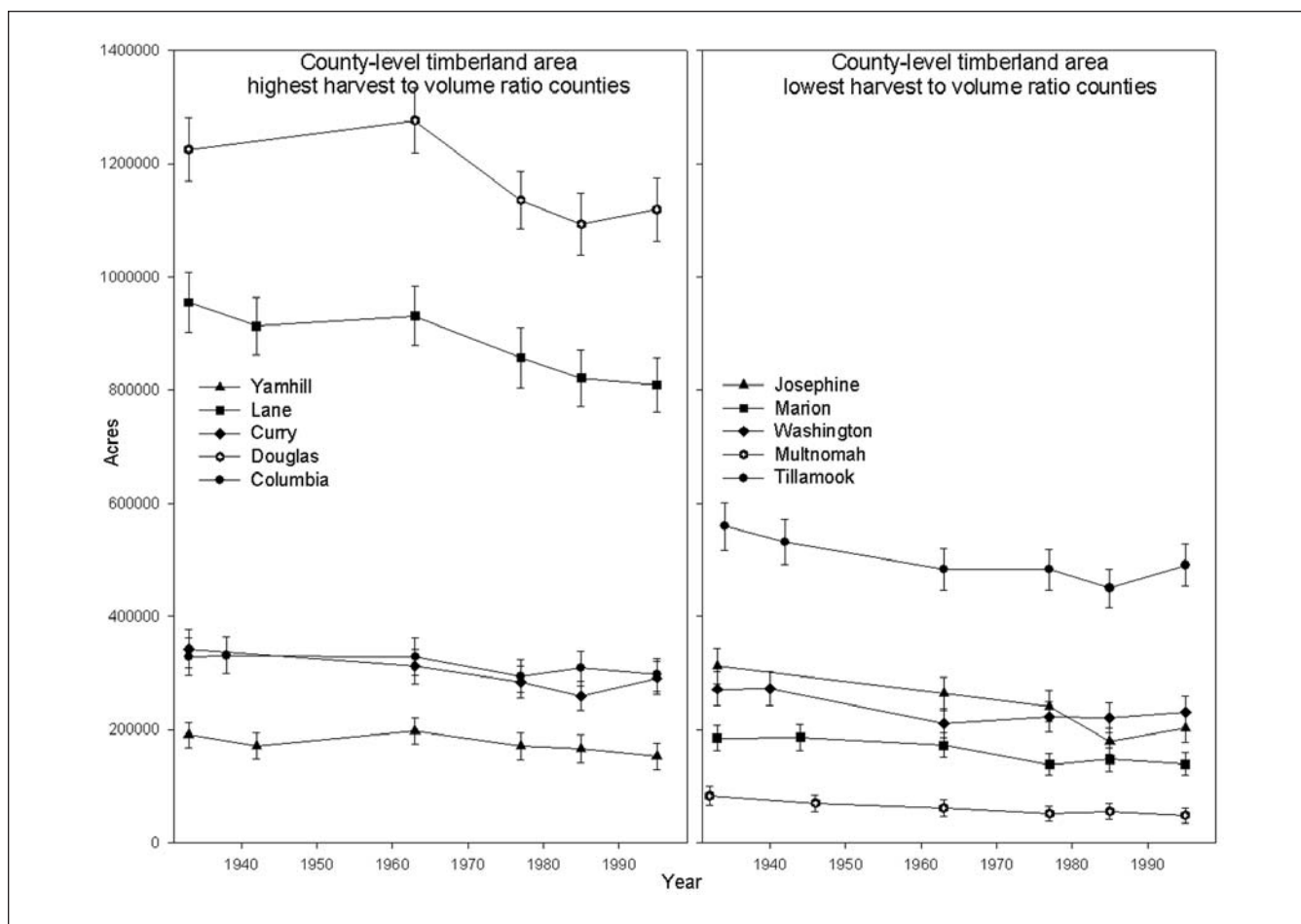


Figure 2—County-level estimates of non-federal timberland area through time. The counties in the left graphic have the highest harvest-to-volume ratios, while the counties on the right have the lowest harvest-to-volume ratios in western Oregon. Error bars for the estimates (68% confidence interval) are derived from the western Oregon 1995 inventory.

### Comparing Counties

If timber harvest has a substantial influence on timberland area and growing-stock volume, we would expect area and volume for counties with high H:V ratios to differ from counties with low H:V ratios. The western Oregon counties used for this analysis, Josephine, Marion, Washington, Multnomah, Tillamook, Yamhill, Lane, Curry, Douglas, and Columbia (Figure 1), were selected to emphasize differences in forest conditions based on the ratio of harvest to growing-stock volume summarized within each county. The average harvest for a county (1962-1998) was divided by the average volume across periodic inventories and expressed as a percentage (Table 1; ~10-year intervals) for all western Oregon counties. The H:V ratios were ordered from lowest to highest by county. The five lowest and the five highest were selected for comparison. Changes in timberland area and volume were compared between the two sets of counties. County-level harvest data (Oregon

Department of Forestry) were summarized for non-federal ownerships and smoothed with a centered, 11-year moving average spline. Data was smoothed to show the overall trend of harvest. The state-level, aggregated trend for timberland area and growing-stock volume across all private ownerships in Oregon (RPA data 2000) was evaluated against the separate county-level trends to show how individual counties diverge from larger, spatial-scale trends. Growing-stock volume and timberland area also were each summed across the group of highest H:V-ratio counties and across the group of lowest H:V-ratio counties to show the effect of increased sample size on the variability of the estimates. Growing stock volume-per-acre trends were compared between the high and low H:V groups of counties.

Trends in temperature and precipitation data were graphed to investigate possible climatic influences on trends in timberland area and volume. These data were obtained

**Table 2—Estimated county-level changes in non-federal timberland area, and growing-stock volume ranked by harvest to volume (H:V) ratio from forest survey and forest inventory and analysis data**

| County              | Change in non-federal timberland area, 1933-1995 (%) | Change in non-federal timberland volume, 1933-1995 (%) | H:V ratio (%) |
|---------------------|------------------------------------------------------|--------------------------------------------------------|---------------|
| Josephine           | -35                                                  | -32                                                    | 1.75          |
| Marion              | -24                                                  | +12                                                    | 1.95          |
| Washington          | -15                                                  | +14                                                    | 2.07          |
| Multnomah           | -41                                                  | +15                                                    | 2.16          |
| Tillamook           | -12                                                  | -23                                                    | 2.43          |
| Low 5 H:V Combined  | -21                                                  | +5                                                     | 2.19          |
| Yamhill             | -19                                                  | +8                                                     | 3.71          |
| Lane                | -15                                                  | -61                                                    | 4.17          |
| Curry               | -15                                                  | -70                                                    | 4.24          |
| Douglas             | -9                                                   | -67                                                    | 4.31          |
| Columbia            | -10                                                  | +49                                                    | 5.14          |
| High 5 H:V Combined | -12                                                  | -55                                                    | 4.30          |

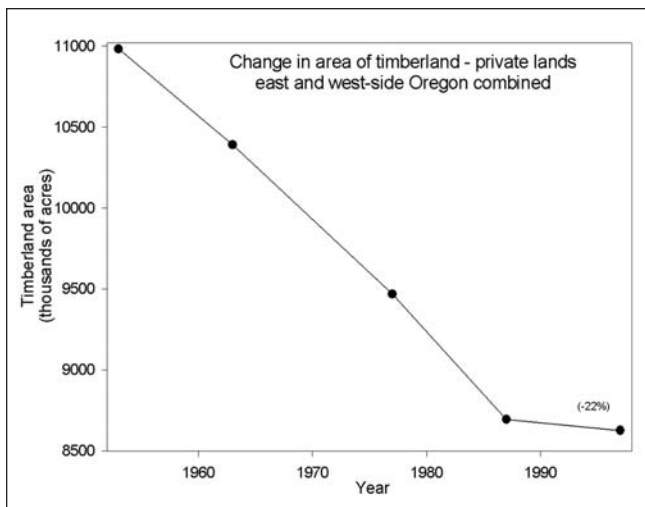


Figure 3—Change in the area of private timberland for the entire state of Oregon, 1953 to 1997. Source: Resource Planning Act data, 2000.

from the Oregon Climate Service (2001) for the zones along the Oregon Coast and within the Willamette Valley. The Oregon Climate Service has tested and corrected these data for temporal homogeneity, and missing values were estimated by examining nearby station trends. Annual values were smoothed for presentation of decadal-scale trends using a centered, 11-year moving average spline. Means for the record were computed over the period 1895-1999.

## RESULTS

Trends in county-level estimates of timberland area exhibit consistent declines over the period ~1933 to 1995 (Figure 2, Table 2). As a group, the highest average decline in area of timberland is noted for counties with the lowest H:V ratios. In comparison to the individual counties, private timberland area for the state of Oregon (from RPA for private ownerships) has declined by ~22% over the period 1953-1997 (Figure 3).

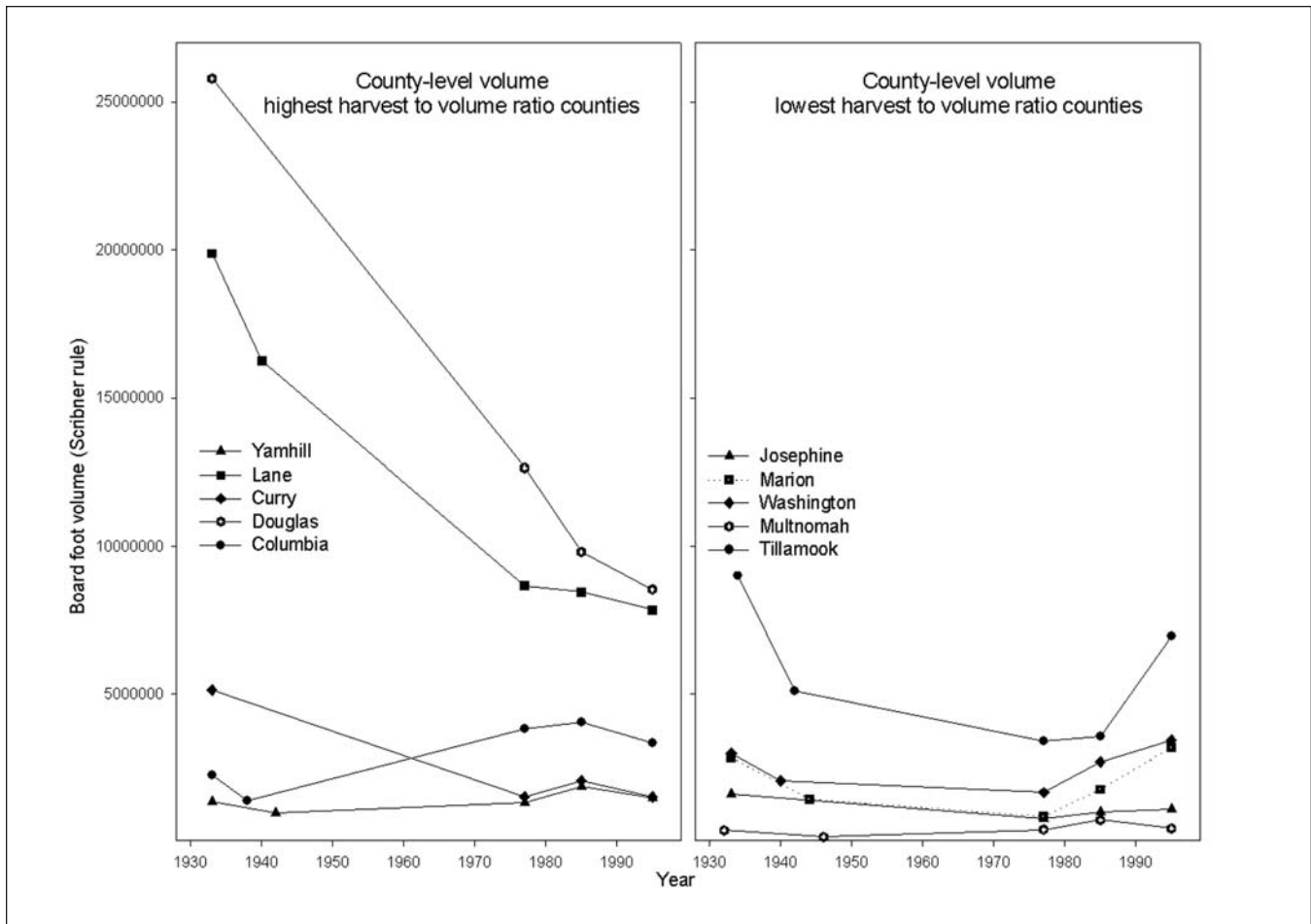


Figure 4—County-level estimates of non-federal timberland volume through time. The counties in the left graphic have the highest harvest-to-volume ratios, while the counties on the right have the lowest harvest-to-volume ratios for western Oregon.

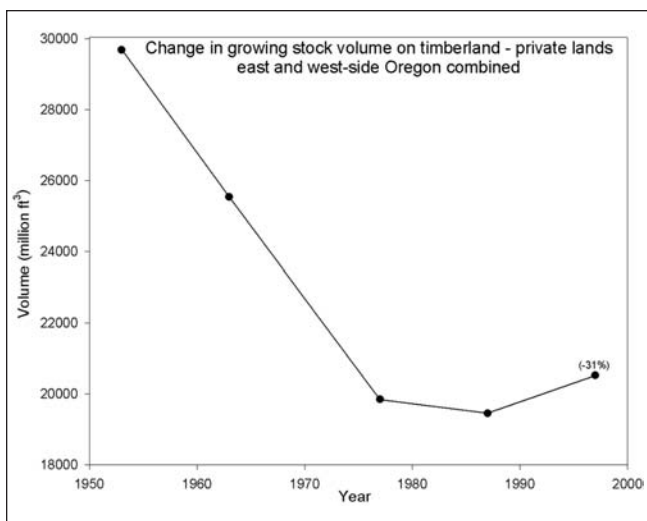


Figure 5—Change in growing stock volume on private timberland for the entire state of Oregon, 1953 to 1997. Source: Resource Planning Act data, 2000.

Estimates of county-level growing-stock volume show mixed results over the period ~1933-1995 (Figure 4, Table 2). Three out of the five low H:V counties show increases in volume, while three out of the five high H:V counties show decreases. The county with the lowest H:V ratio, Josephine, shows a decrease of 32%, while the highest H:V county, Columbia, shows an increase of 49%. The initially downward trend in volume (except Multnomah) for low H:V counties is reversed between the 1977 and 1985 inventory. Growing-stock volume on private lands for the state of Oregon (from RPA for private ownerships) has declined by ~31% over the period 1953-1997 (Figure 5). Compared with the steep downward trend in volume for the period 1953-1977, RPA data indicates a change in trend post 1977. The downward trend in volume is reversed between the 1980s and 1990s.

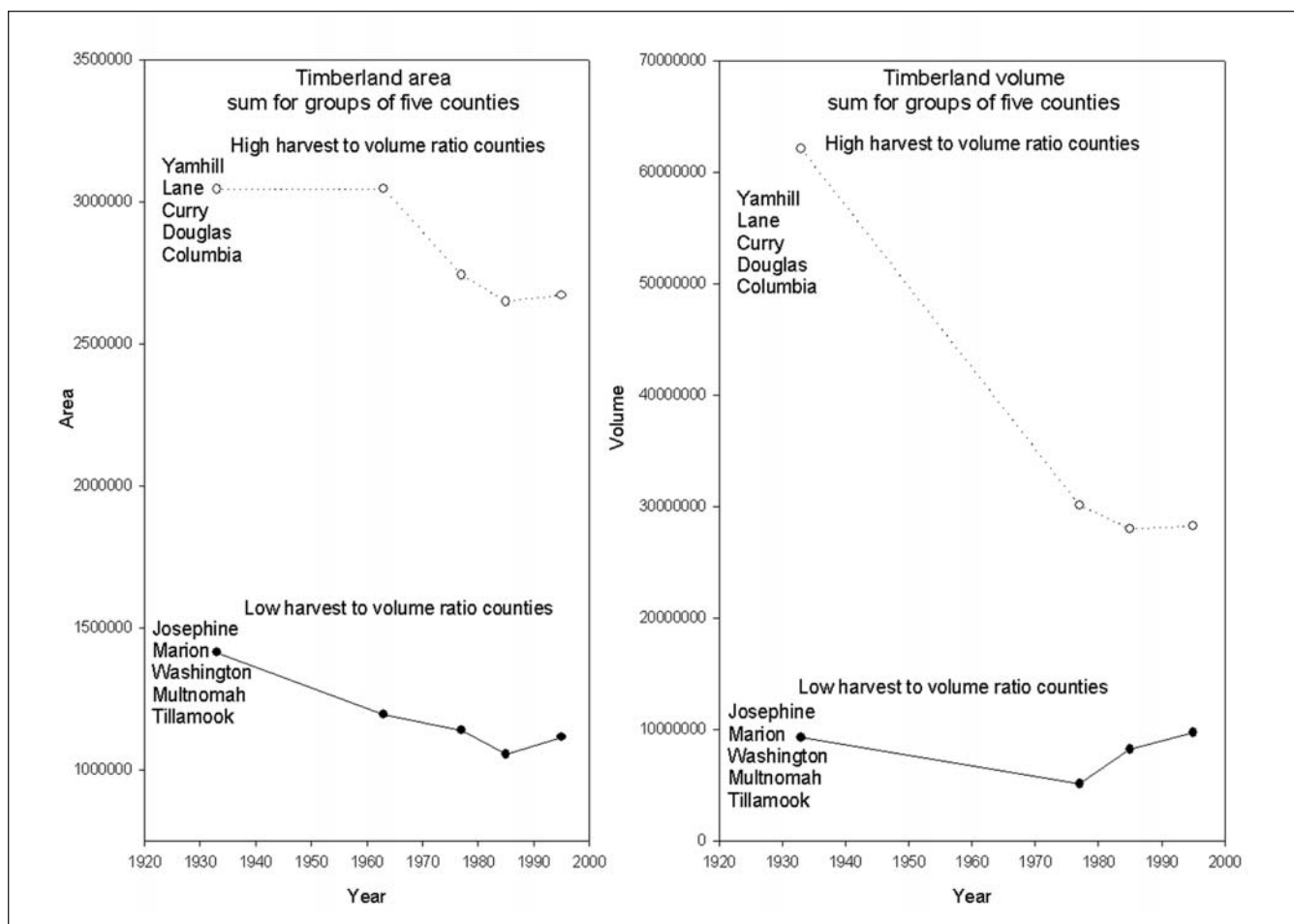


Figure 6—Non-federal timberland area (left) and growing-stock volume (right) summed across the highest H:V counties (top curves) and across the lowest H:V counties (lower curves).

When summed for the group of the five highest and the group of the five lowest H:V-ratio counties, timberland area and growing-stock volume each demonstrate differences in trends between the high and low H:V county groups (Figure 6). Timberland area shows the strongest decrease from 1963 to 1985 for the high H:V counties. For the low H:V counties, from the start of the inventory in the 1930s, area of timberland decreased gradually until 1985. Between 1985 and 1995, timberland area showed slight increases. Growing stock volume decreased from 1933 to 1977 for both high and low H:V county groups. Between 1977 and 1985, the downward trend reversed for the low H:V group, and continued upward into the 1990s. The high H:V group slowed in the loss of volume between 1977 and 1985, and increased slightly between 1985 and 1995.

Smoothed harvest data for the ten counties examined demonstrates mixed trends over the period 1962-1998 (Figure 7). Curry, Lane, and Douglas counties show an

overall trend of decreasing harvest for the high H:V group (three out of five decreased), while Tillamook shows a decreasing harvest trend for the low H:V group (one out of five decreased). Yamhill, Columbia, Josephine, Marion, Washington, and Multnomah counties show increases in harvest over the same period.

When aggregated above the county level, for groups of five counties, growing-stock volume per acre (Figure 8) shows similar trends to the growing-stock volume trends. Growing-stock volume-per-acre, aggregated among the five counties with the highest H:V ratio, differs in trend direction from the aggregate of the five counties with the lowest H:V ratio for the period 1977-1985. The high H:V group shows a decline in volume per acre, while the low H:V group shows an increase during this period. The increase from 1985-1995 is stronger for the low H:V group than for the high H:V group.

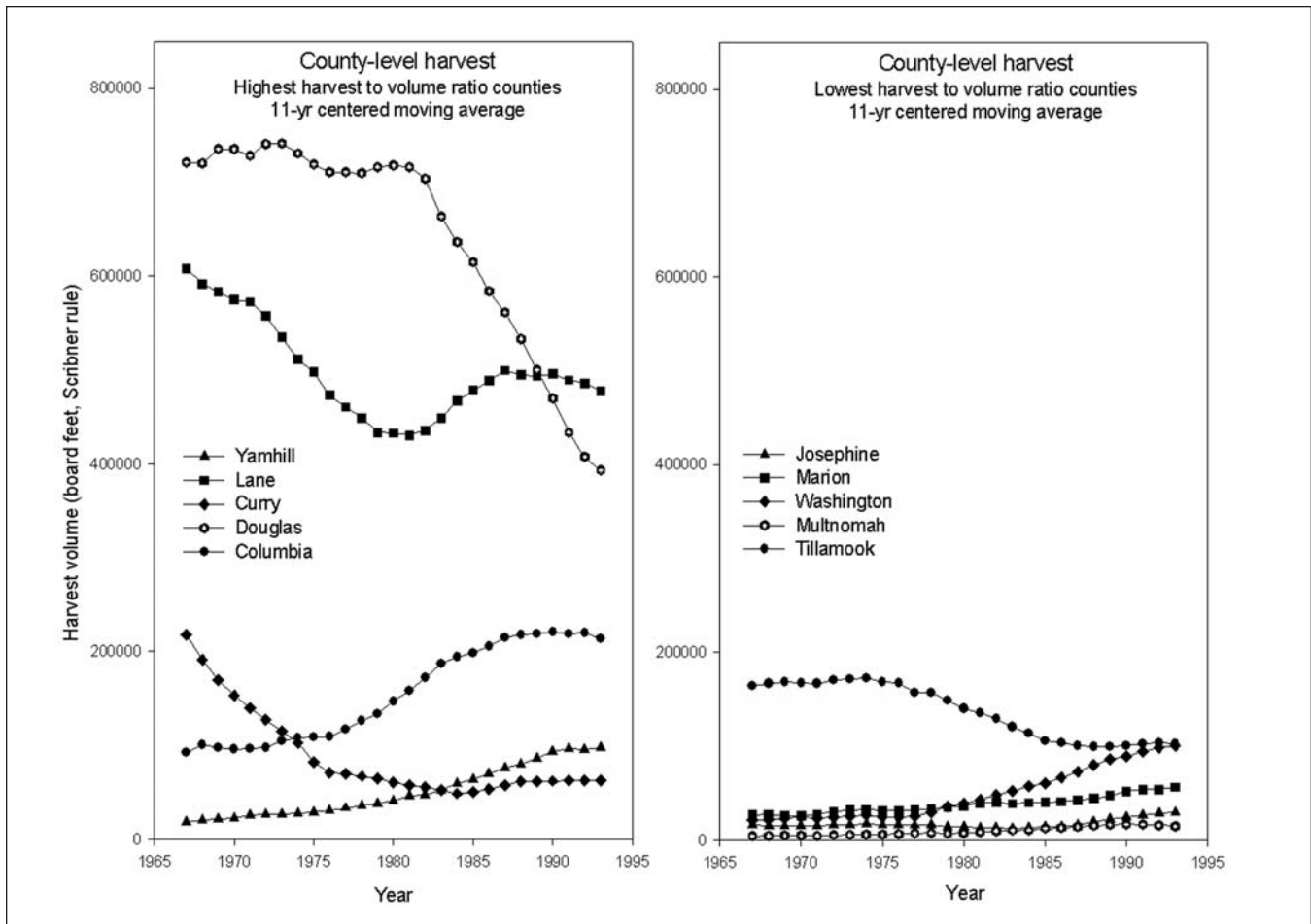


Figure 7—County-level harvest estimates for non-federal timberland smoothed with a centered, 11-year moving average spline. Base data source: Oregon Department of Forestry.

The climatic zones encompassing the Oregon Coast and Willamette Valley are closely aligned with each other, with respect to decadal-scale trends in temperature and precipitation, especially from ~1922-1993 (Figure 9). From ~1922-1945, moisture availability was lower than average, with temperatures generally higher than the mean and precipitation below the mean. From ~1945-1980, moisture availability was higher, with temperatures lower and precipitation higher than the mean. Post 1980, moisture availability was lower than average, except for high precipitation noted for 1996 and 1998. Trends in timberland area and volume did not appear to follow moisture availability trends on either an individual county basis (Figures 2 and 4) or among the summed groups of high and low H:V counties (Figure 6). Contrary to expected moisture-availability-influences on tree growth, the ~1945-1980 period of high moisture availability coincided with the period of declining timberland area, declining growing-stock volume, and declining growing stock volume per acre trends in the forest inventory record.

## DISCUSSION

### Tracking Change at the County-Level

County-level FIA data for the ten counties examined shows definite resource trends through time, with generally consistent trends between timberland area and growing-stock within a county (research question 1; Figures 2 and 4). While direction in trends for area and volume within a county generally agree, decreases in area tend to temporally lag decreases in volume. The lag may suggest that following harvest, land is being converted from timberland into other uses. Interpretation of this lag must be conservative due to fewer inventory data points for volume along the timeline, especially between 1944 and 1977 (i.e. county-level volume data for 1963 is currently unavailable).

FIA data is generally stratified and aggregated at coarse spatial scales to include more sample points and decrease the error associated with estimates. Grouping counties into

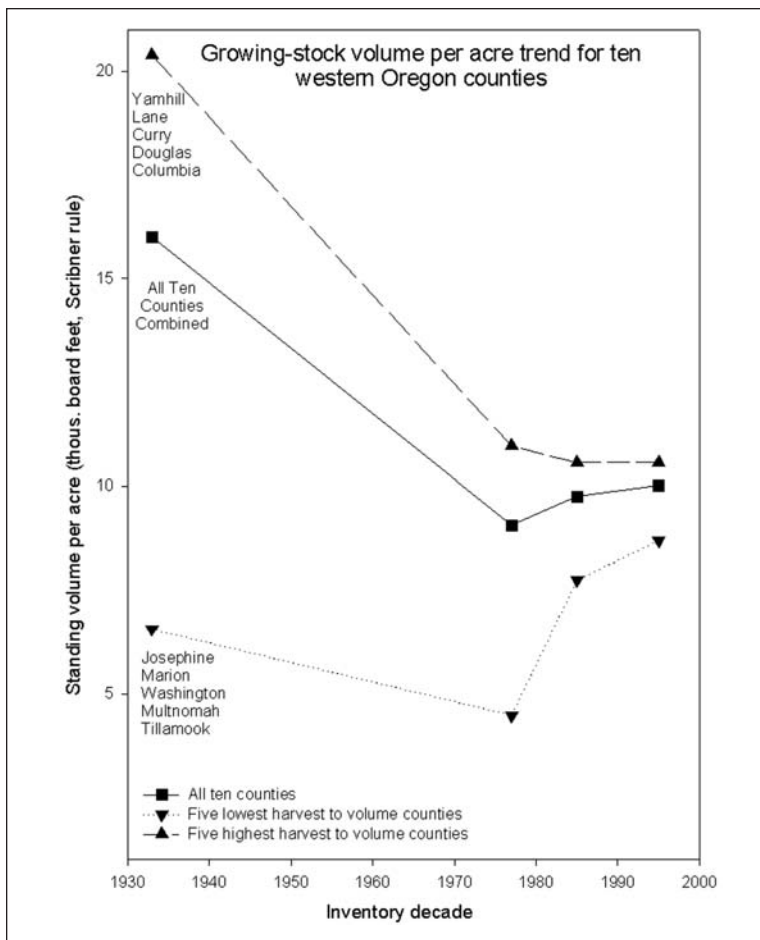


Figure 8—Growing-stock volume per acre trend for the ten western Oregon counties with the highest and the lowest harvest-to-volume ratio for non-federal timberland. The five counties aggregated for the highest harvest-to-volume ratio include: Yamhill, Lane, Curry, Douglas, and Columbia. The five with counties aggregated for the lowest harvest-to-volume ratios include: Josephine, Marion, Washington, Multnomah, and Tillamook.

survey units (e.g., northwest Oregon, west-central Oregon, southwest Oregon, etc.) increases sample size and the reliability of estimates. Aggregation is especially important when data are further subdivided among ownership groups and forest types that can result in reduced sample sizes. The observed variability for the county-scale estimates may be an artifact of fine-spatial-scale decomposition of the data. Aggregating estimates by survey unit and by approximate ecoregion (Bailey 1995) will likely help decrease variability in future trend analysis of these data.

#### Trend Differences Between High and Low H:V County Groups

There is a difference in the trend for volume on a per-acre basis between aggregates of the five counties with the highest and lowest H:V ratios (research question 2; Figure 8). Between 1933 and 1977, growing-stock volume per acre was declining more rapidly for the high H:V group than for the low H:V group of counties. Between 1977 and 1985,

the downward trend in volume per acre was slowed for the high H:V group, and reversed for low H:V group. Post 1977, the high and low H:V county groups appeared to be getting more similar to each other in terms of volume-per-acre trend, perhaps as forest managers applied similar stocking and silvicultural techniques across western Oregon. The counties with the lowest H:V ratio demonstrate an increase in volume per acre since the mid-1970s, and may contain trees that are growing to larger diameters on timberland with longer rotation times between harvests.

Growing-stock volume and harvest are expected to be influenced by the area of operable forest land. Thus, in metropolitan and rapidly developing counties, as urbanization increases, pressure to reduce harvest may influence H:V ratios. Population change (1930-1970, 1970-1990, and 1930-1990) was examined by county, but did not appear to be related to H:V ratios in the 10 counties examined.

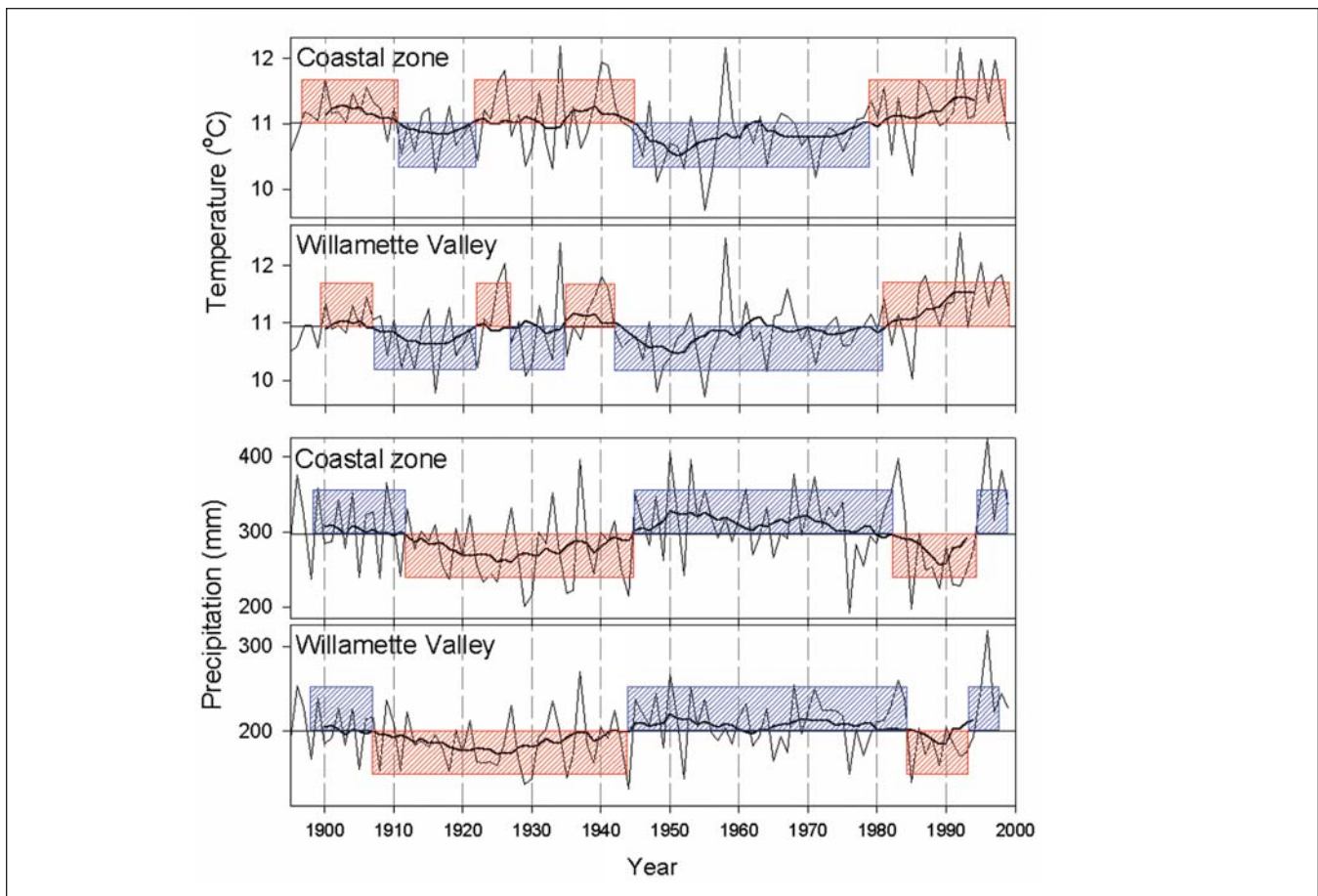


Figure 9—Temperature and precipitation trends for the Oregon Coast and Willamette Valley climatic zones. Bold line represents smoothed data using a centered, 11-year moving average spline. Red and blue boxes show trends above and below the mean for the period.

### Climatic Influences on Timberland Area and Growing-Stock Volume

FIA data for timberland area and growing-stock volume does not reflect the decadal-scale climatic trends (research question 3). The expected influence (see Swetnam and Betancourt 1998; Donnegan et al. 2001) of the moisture availability trends (Figure 9) on tree growth would be a mild acceleration of growth in the early part of the record and a mild deceleration of growth in the latter part of the record. The range of variability for the smoothed temperature and precipitation record is somewhat narrow, and inter-annual variability may play a more significant role in tree growth. Extensive tree-level data, examined via dendrochronology, would help resolve the effects of moisture availability on volume-per-acre trend.

### Reasons for Observed Trends

Land-use and planning may help explain some of the temporal trends observed in the aggregated FIA data. High and low H:V county groups differ primarily in the height

of the curves for area and volume, and not so much in temporal trend (Figure 6). The discrepancy in the height of the curves reflects the fact that timber producers initially purchased the most productive lands. In terms of land-use planning, in 1971, the Oregon legislature passed the Oregon Forest Practices Act setting “minimum standards for reforestation, road construction and maintenance, timber harvesting, chemical application and slash disposal” (Oregon Department of Forestry 2001). In 1973, the legislature passed senate bills 100 and 101 requiring comprehensive land-use planning at the county level. The implementation of these plans in the late-1970s and 1980s coincides with the change in trend seen in timberland area and volume for the county groups. Economic forces, especially decreases in log export, likely play an important role in the change in area and volume trend as well. In-depth socioeconomic analyses are planned to further explain the trends in timberland area, and volume. Work is also in progress to explore driving forces for changes in carbon stocks and sequestration rates.

As the standards for the size of merchantable timber have changed through time with the removal of the largest-diameter tree size classes, the standard for the minimum-sized tree diameter-class that is counted in the inventory has become smaller. That is, as large trees were harvested through time, the minimum diameter-size standards for inclusion in the inventory were reduced. This decrease in the size of trees counted in the inventory through time leads to an underestimation of timberland area and volume in the earliest years of the survey. Thus, the temporal trends in timberland area and growing-stock volume should be interpreted as conservative estimates of change.

This test of the historic Oregon data warehouse exemplifies the utility of county-level estimates. When trends in size class, ownership, and forest type data are evaluated, aggregation will become more important as the sample size in each category is subdivided. Analyses comparing forest condition for the most heavily harvested areas against historically similar, but less heavily harvested areas are key to assessing the degree to which we can manage for multiple resources. Historic data are important to document where forest types have changed and to investigate possible reasons for the change. The C&I offer one method for standardizing a set of indicators comparing ecosystem conditions at a variety of scales, nationally and internationally.

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## LITERATURE CITED

- Anonymous. 1995. Sustaining the world's forests: the Santiago agreement. *Journal of Forestry*. 93: 18-21.
- Bailey, R.G. 1995. Description of the ecoregions of the United States. Second edition, revised and expanded (1st ed. 1980). Misc. Publ. 1391 (rev.), Washington D.C.: USDA Forest Service. 108 p. with separate map at 1: 7,500,000.
- Donnegan, J.A.; Veblen, T.T.; Sibold, J.S. 2001. Climatic and human influences on fire history in Pike National Forest, central Colorado. *Canadian Journal of Forest Research*. 31: 1526-1539.
- Frayser, W.E.; Furnival, G.M. 1999. Forest survey sampling designs: a history. *Journal of Forestry*. 97: 4-10.
- Oregon Climate Service. 2001. Monthly precipitation and temperature for Oregon climate zones. <http://www.ocs.orst.edu/ocs.shtml>. August, 15 2001.
- Oregon Department of Forestry. 1999. Oregon's forests at the millennium: first approximation report. State of Oregon, Salem, OR, USA. 222 p.
- Oregon Department of Forestry. 2001. The Evolution of Oregon's forest practice rules. <http://www.odf.state.or.us/FP/BackgroundPg/EvolutionFPA>. September 29, 2001.
- State of Hawaii. 2000. Criteria and indicators for sustainable forest management in Hawaii: first approximation report - 2000. Department of Land and Natural Resources. Division of Forestry and Wildlife. <http://www.hawaii.gov/dlnr/dofaw/pubs/forests2000/far2000.htm>. July 14, 2001.
- Swetnam, T.W.; Betancourt, J.L. 1998. Mesoscale disturbance and ecological response to decadal variability in the American Southwest. *Journal of Climate* 11: 3128-3147.
- USDA Forest Service. 1997. Report of the United States on the criteria and indicators for the sustainable management of temperate and boreal forests. U.S. Department of Agriculture, Forest Service, Washington, DC, USA. 220 p.
- Woodley, S.; Alward, G.; Gutierrez, L. et al. 1999. North American test of criteria and indicators of sustainable forestry. United States Department of Agriculture, Forest Service, Inventory and Monitoring Institute Report No. 3. [http://fsweb.ftcol.wo.fs.fed.us/imi/cifor/cifor\\_1.html](http://fsweb.ftcol.wo.fs.fed.us/imi/cifor/cifor_1.html). June 21, 2001.

## **SOCIAL ACCEPTABILITY OF NATURAL RESOURCE DECISION-MAKING PROCESSES**

Keith M. Reynolds<sup>1</sup>

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### **ABSTRACT**

In recent decades, conflict and litigation with public constituencies who find current forest management decisions unacceptable has characterized natural resource management. To devise publicly-supportable management strategies, it is critical to understand how the public forms opinions about, and judges the acceptability of, forest management practices and the decision-making processes that create them. This report summarizes key findings of an in-depth study on use of a knowledge-based logic modeling system, for organizing and analyzing the social acceptability of natural resource management decision processes.

There are three main concerns associated with using knowledge bases to evaluate social acceptability: some potential to become a black box, problems associated with using numeric values to evaluate a concept as complex as social acceptability, and our incomplete understanding of factors that influence social acceptability judgments. These caveats do not result from limitations inherent to knowledge bases, but they may hamper our ability to use these specific types of knowledge bases effectively in planning. However, if the caveats are fully acknowledged, the knowledge base could be a valuable tool for improving forest management decision processes.

**KEY WORDS:** Social acceptability, logic, model, decision making, land management.

### **INTRODUCTION**

Natural resource agencies, such as the USDA Forest Service (USFS), manage the Nation's natural resources in the face of many different and competing interests. In recent years, this task has been stymied by the growing discrepancy between processes and decisions generated by resource agencies and those favored by public constituents. Public groups and land management agencies have become mired in costly litigation and emotional discourse over public land management decisions as a result. Since 1983, nearly 1,200 appeals of forest plans occurred that have prevented the USFS from implementing forest plans as projected (Steelman 1999). This legal gridlock suggests that the USFS could substantially improve its traditional decision-making practices by incorporating public concerns more effectively.

To devise management strategies that are publicly supported, instead of thwarted, it is critical to understand how the public forms opinions about, and judges the acceptability of, forest management practices and the decision-making processes that create them. It also is important to learn how agencies can integrate these judgments with other decision factors to generate acceptable decisions. I summarize some key findings of a very in-depth study by Kakoyannis et al. (2001) on the utility of NetWeaver<sup>2</sup>, a knowledge-based logic modeling system for organizing and analyzing the social acceptability of natural resource management processes. I also present an alternative view of the suitability of logic models in this problem area as a counterpoint to arguments in the original study.

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<sup>2</sup> 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.

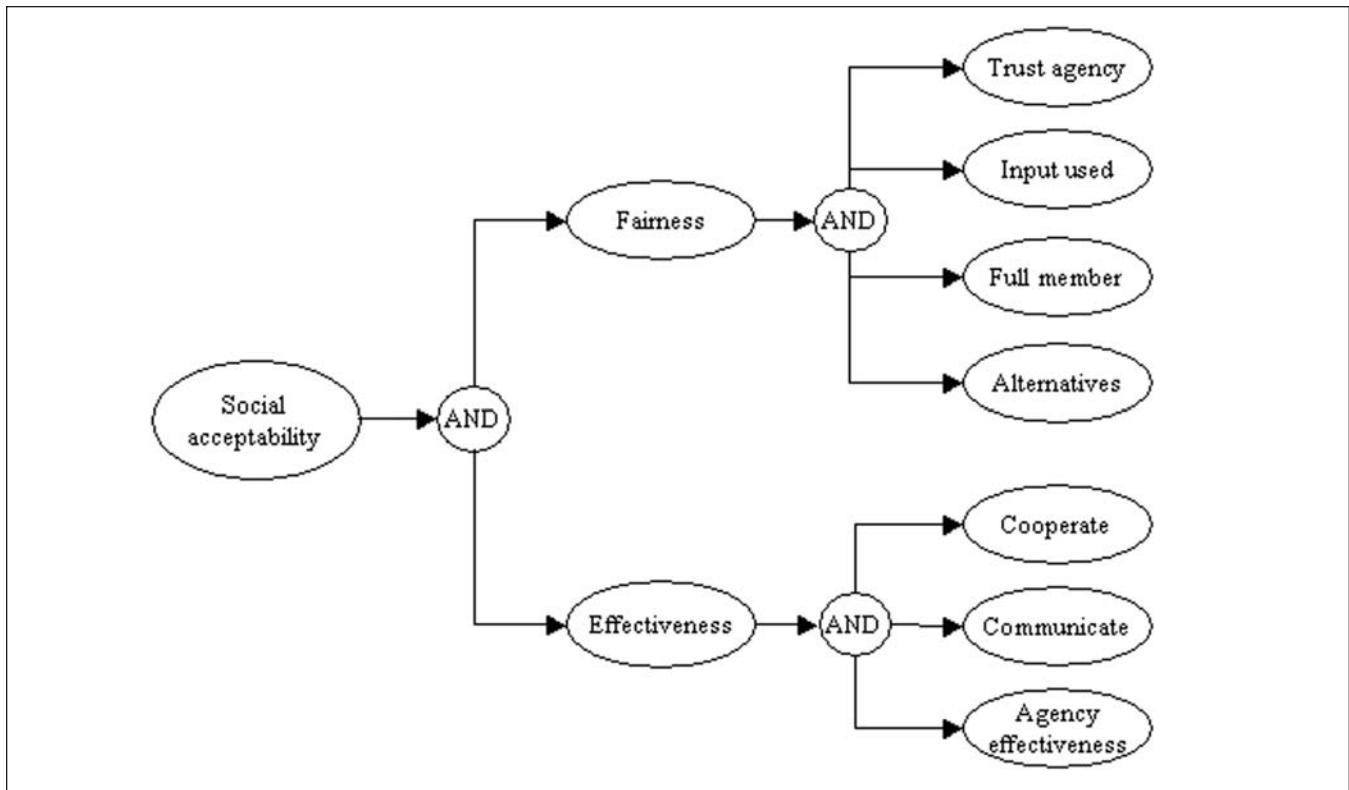


Figure 1—First three levels of propositions for knowledge-based evaluation of social acceptability of a natural resource decision-making process. The knowledge base evaluates the strength of support for a proposition based on a logical expression and strength of support for its premises. For example, Fairness and Effectiveness are premises of Social acceptability. The AND operator evaluates a set of premises as limiting factors. The strength of evidence in a set of premises is constrained by the premise with least evidence.

## SOCIALLY ACCEPTABLE DECISION PROCESSES

Kakoyannis et al. (2001) laid the foundation for the knowledge synthesis captured in the NetWeaver logic model with an in-depth analysis of currently available literature on social acceptability. As background, the authors describe the origins of differing world views of nature, how conflicts arise from such differences, and key factors influencing social acceptability, including:

- insituational, spatial, and social context (Brunson 1992; Hansis 1995; Perry and Pope 1995; Steel et al. 1994; Vining and Ebreo 1991; Williams and Carr 1993),
- institutional and individual trust (Binney et al. 1996; Brockner et al. 1997; Glaser 1997; Kasperson et al. 1992; La Porte and Metlay 1996; Moore 1996; Peters et al. 1997; Pijawka and Mushkatel 1991; Shindler and O'Brian 1998; Wondolleck 1988; Wondolleck and Yaffee 1994),
- perceptions of risk (Arrandale 1999; FEMAT 1993; Fischhoff et al. 1981; Hendershot 1996; Kasperson et al. 1992; Lober 1996; Slovic 1987, 1997; Sullivan 1998), and
- forms of knowledge.(Binney et al. 1996; Brothers et al. 1991; Cheek et al. 1997; Fortner and Lyon 1985; Kearney et al. 1996; Kloppenburg 1991; Shelby and Speaker 1990; Stankey 1976, 1996; Steel et al. 1990, 1994).

Perhaps the most important conclusion emerging from the analysis was that, too often, management agencies focus on public acceptance of agency decisions and do not adequately appreciate that attempts to achieve public acceptance of natural resource policy and management plans are inherently a question of processes rather than outcomes (Kakoyannis et al. 2001). To encourage managers to focus on process when designing decision-making processes, the knowledge base for social acceptability focuses on acceptability of decision processes. Emphasizing evaluation of decision-making processes in model design enables

resource management agencies to perhaps increase the likelihood of developing socially acceptable management plans and policies.

## NETWEAVER MODELS IN FOREST MANAGEMENT

A knowledge base is a formal logic specification for organizing and interpreting information; in a strict sense, it is a form of meta database. The NetWeaver implementation of a knowledge base represents a problem in terms of propositions about topics of interest and their logical interrelations. In a NetWeaver knowledge base design, a management- or policy-related question is translated into a testable proposition, which is a “statement in terms of a truth to be demonstrated” (Webster’s Dictionary 1998). For example, if the question concerns social acceptability of a forest management decision process, the associated proposition might be as simple as “the decision process is socially acceptable.” The statement of the proposition itself is inherently ambiguous because social acceptability is a complex and abstract concept. However, the formal specification of a proposition makes the semantic content of the proposition more clear and precise (Figure 1). In NetWeaver, strength of support for propositions is evaluated with fuzzy math (Reynolds 1999), a branch of applied mathematics that implements qualitative reasoning (Zadeh 1976).

Each iteration of discourse extends the logic structure another level deeper by logical decomposition of the level above. The pattern of discourse generally proceeds from abstract to concrete propositions, with a tendency for premises of a particular proposition to be less abstract than the proposition they support. In the sense of logical discourse, propositions required for testing the assertion of social acceptability are both premises and propositions in their own right. The current knowledge base asserts, for example, that a decision process is socially acceptable to the degree that the process is perceived as fair and effective (Figure 1). The semantics of the concepts of fairness and effectiveness are defined by their own respective underlying premises (Figure 1), and so on.

Eventually, each logic pathway terminates in a premise that can be evaluated by reference to data. Logic pathways in a knowledge base can thus be construed as a cognitive map of the problem that provides a formal data specification. The specification not only describes what data are to be evaluated, but how to interpret the data to arrive at conclusions.

## KNOWLEDGE BASE DESIGN

The knowledge base consists of networks of propositions that influence social acceptability. The framework attempts to account for available knowledge about public acceptance of natural resource decision-making processes and relationships among various factors that affect the main proposition.

The knowledge base was designed to evaluate degree of support for the proposition that a natural resource decision-making process is socially acceptable. The focus on process, rather than outcomes, allows the knowledge base to better contend with different contexts because the process is more transferable to a variety of management scenarios than is a particular decision outcome. Based on the procedural justice literature (Wondolleck 1988; Tuler and Webler 1999), the main proposition depends both on fairness and nonfairness principles that also were stated as propositions (Figure 1). A review of the research literature from various fields was used to further elaborate the structure of propositions considered to be important for public acceptability of natural resource decision-making processes.

Nearly all propositions in the knowledge base for social acceptability are based on the premise that the public believes the statement to be true. In this way, overall support for the main proposition of social acceptability is arranged to specifically reflect public opinions of statements and not what an agency member might believe to be true about that same statement. Because of this arrangement, it is essential that users entering data for lower-order propositions be members of the public or someone who can speak for public opinion on these topics.

## KEY SOCIAL ISSUES IN LOGIC DESIGN

Kakoyannis et al. (2001) identified four key social issues related to model design based on their review of the literature and the process of organizing information into a knowledge base for social acceptability.

1. Natural resource agencies focus too much on the social acceptability of their decisions as opposed to the acceptability of their decision-making processes.
2. The NetWeaver knowledge-based system allows users to adjust knowledge base design for a specific context. However, unless modifications are well documented, this flexibility can potentially reduce the transparency of the process by which the knowledge base evaluates agency decision-making.

3. Natural resource management and science programs are dominated by the technical-rational paradigm; a model of thinking and acting that rests on a rational, scientifically-based analytic process which also acts to constrain incorporation of subjective, qualitative knowledge.
4. Our understanding of the social acceptability of decision-making processes is incomplete and needs further study.

The following sections briefly discuss issues 1 to 3 (see Kakoyannis et al. 2001 for an in-depth discussion of additional research needs), and summarizes recommendations on which the two reports concur.

### **Acceptability of Decisions Versus Decision Processes**

If decision-makers focus on the decision-making process itself, Wondolleck (1985, 1988) suggests that other, more pertinent questions will arise naturally such as “What information do we need? Where can we get the information needed? Who should we involve? What problems are we likely to encounter and how might we overcome them?” A focus on process is especially critical when the decisions are “complex and value laden and when there are limits to technical expertise in reaching solutions” that are often found in natural resource controversies (Wondolleck 1985). When socially acceptable processes are achieved, socially acceptable decisions will naturally follow (Shindler et al. 1999). For this reason, the social acceptability knowledge base was designed around a question of process.

Many studies have examined procedural criteria for developing socially acceptable policies. Procedural issues that have been found to influence public satisfaction include: opportunity to participate (Tuler and Webler 1999; Smith and McDonough 2001); power to influence process and outcomes (Tuler and Webler 1999); having multiple methods of public participation (Blahna and Yonts-Shepard 1989; Smith and McDonough 2001); access to reliable information (Shindler and Neburka 1997; Smith and McDonough 2001); forming interpersonal relationships between citizens and agency members (Lauber and Knuth 1997; Webler and Tuler 2000); and so forth.

### **Recommendations**

Continue to develop awareness within all levels of the agency concerning importance of decision processes on public judgments of acceptability as opposed to decision outcomes.

Improve strategies for including broad public interests at the beginning of decision-making processes.

Continue to study the strengths and shortcomings of agency decision-making processes to refine protocols and improve agency implementation of the techniques.

### **Transparency of Model Logic**

NetWeaver allows users to modify the structure of a knowledge base to exclude specific components from an evaluation if users judge that those components are not relevant to their particular management situation. However, the ability to modify the knowledge base creates some concern. The opportunity for discretion often goes hand in hand with the potential to, perhaps inadvertently, create a hidden process. Although the capacity of NetWeaver for documenting a knowledge base ensures the opportunity to provide the rationale behind structural changes is available, it does not ensure that the documentation is actually provided. If users amend the knowledge base and do not adequately document how and why the knowledge base was altered, the knowledge base can become another black box.

The potential to modify structure of a knowledge base also raises several questions. How will managers know when modifications are needed? Who is the appropriate person to make these changes? Do they have adequate understanding of the knowledge base to make changes? Are there adequate criteria to guide such modifications? Depending on the degree of modifications made to a knowledge base, evaluations may produce very different results. Such concerns suggest that researchers and managers should use caution in comparing results of evaluations between different contexts.

### **Recommendation**

Recognize the caveats associated with modifying knowledge base design.

### **Technical-rational Approach to Decisions**

NetWeaver allows knowledge base developers to document assumptions and caveats that influence evaluation of a knowledge base. Managers can review assumptions to determine how well they apply to their own management issues and revise either the assumptions or model design accordingly. Thus, the creation of a knowledge base can be particularly valuable for forest management planning; it allows managers and scientists to obtain a better understanding of the factors considered to influence public acceptance of an agency’s decision-making process.

Kakoyannis et al. (2001) strongly urge caution against agency members entering data for evaluation based on their own perceptions of public attitudes. Various studies, describing both agency and public perspectives on the same issue,

demonstrate that perception of degree of support for any particular proposition may differ widely between, as well as within, agency members and citizens. Shindler and O'Brian (1998), for example, found that agency members tended to rate their performance in various areas more highly than members of the public did.

Even if members of the public are chosen to complete these responses in an attempt to have an evaluation reflect public opinion, several issues still need to be considered. Most importantly, who represents the public? Can citizens who are involved in public participation processes represent the wider, non-participating public? Can interest groups represent the public? Public opinion is a generic term for a wide variety of values, beliefs, and attitudes held by society. Opinions from a few users will not adequately reflect the varying responses observed in the broader public. The generation of an accurate answer to the question of social acceptability of the entire public will be largely dependent on the representativeness of the users providing data to the knowledge base. The knowledge base should not be used to evaluate social acceptability without careful attention to a robust sampling design and without consideration of the caveats associated with mapping very subjective ordinal responses into a continuous metric that expresses degree of support for propositions.

Finally, given the latter provisos, the knowledge base could be used to explore how key responses differ in central tendency and variance among demographic subgroups. Interesting contrasts include, for example, responses that are tightly clustered within, and distinctive between, subgroups versus responses that vary widely both within and among groups. Demographic analyses of this type could be used to better focus research on addressing issues of social acceptability that could lead to refinements of the logic specification of the knowledge base.

## DISCUSSION

Kakoyannis et al. (2001) offer some strong cautions concerning application of technical-rational models in general, and logic-based knowledge base models in particular, to actual evaluation of social data. Several cautions were discussed here and are well founded. Certainly, care in suitably documenting structural changes to models, and care in design of robust sampling procedures represent legitimate concerns. On the other hand, a more fundamental concern about the difficulty of adequately representing social values in a logic framework is perhaps somewhat overstated. I

agree with Kakoyannis et al. (2001) that the concepts of social acceptability are very abstract and very complex, and that this first knowledge base is therefore only a rough first approximation. However, reasoning is a fundamental human activity; we do it every day in the context of almost all actions we take, including deciding how acceptable a decision process may have been. I would argue, therefore, that, to the degree that the thought processes involved draw on normative concepts and are rational in some sense, the evidence by which people arrive at their evaluations is susceptible to modeling in a logic framework. A somewhat subtler point, perhaps, is that the logic framework by which evidence is considered represents a social science specification for how to synthesize the collection of evidence into an overall conclusion. This framework, however, should not be construed as a model of how a member of the public literally reasons about acceptability.

In developing a knowledge base for evaluating the social acceptability of land management decision processes, Kakoyannis et al. (2001) found that knowledge bases can be an effective method of synthesizing and representing information. In particular, the knowledge base approach holds considerable potential with regard to the ability to account for factors affecting social acceptability. The process by which researchers examine the literature, synthesize major ideas, and arrange those ideas into the formal logic structure of a knowledge base can be extremely useful in clarifying concepts. The development of the knowledge base into a network structure also helped to reveal research gaps associated with particular topics or fields and therefore provides insight into future research needs. This feature, in conjunction with the ability of a logic engine to evaluate the relative influence of missing data through knowledge of the data's location and frequency in the model's structure, can help researchers prioritize acquisition of new information.

The conceptual framework for each component of the USDA Forest Service Pacific Northwest Research Station's Compatibility Initiative is useful as a basis for researchers and managers to begin discussing integrated research among the different disciplines involved. In particular, being able to visualize the social acceptability construct in a formal logic framework might prove especially useful for individuals unaccustomed to working with social data. This process of attempting to integrate the social, economic, and biological knowledge bases could help provoke interesting and enlightening discussions about perceived linkages among the three different components. It is likely that some questions will be answered while new ones arise as managers,

scientists, and citizens collaborate to integrate these knowledge bases. This type of communication could be an effective way of initiating the integration necessary to achieve acceptable forest management decisions.

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## LITERATURE CITED

- Arrandale, T. 1999. The right-to-know trap. *Governing*. 12(8): 56.
- Binney, S.E.; Mason, R.; Martsolf, S.W.; Detweiler, J.H. 1996. Credibility, public trust, and the transport of radioactive waste through local communities. *Environment and Behavior*. 28(3): 283-301.
- Blahna, D.J.; Yonts-Shepard, S. 1989. Public involvement in resource planning: toward bridging the gap between policy and implementation. *Society and Natural Resources*. 2(3): 209-227.
- Brockner, J.; Siegel, P.A.; Daly, J.P. [et al.]. 1997. When trust matters: the moderating effect of outcome favorability. *Administrative Science Quarterly*. 42: 558-583.
- Brothers, C.C.; Fortner, R.W.; Mayer, V.J. 1991. The impact of television news on public environmental knowledge. *Journal of Environmental Education*. 22(4): 22-29.
- Brunson, M.W. 1992. Professional bias, public perspectives, and communication pitfalls for natural resource managers. *Rangelands*. 14(5): 292-295.
- Cheek, K.A.; Shindler, B.; McQuillan, A. 1997. The role of knowledge in public acceptance of ecosystem management: a literature review. Corvallis, OR: Department of Forest Resources, Oregon State University. 24 p.
- FEMAT [Forest Ecosystem Management Assessment Team]. 1993. Forest Ecosystem Management: An Ecological, Economic, and Social Assessment. Portland, OR: U.S. Department of Agriculture; U.S. Department of the Interior [and others]. [Irregular pagination].
- Fischhoff, B.; Lichtenstein, S.; Slovic, P. [et al.]. 1981. *Acceptable Risk*. London: Cambridge University Press. 185 p.
- Fortner, R.W.; Lyon, A.E. 1985. Effects of a Cousteau television special on viewer knowledge and attitudes. *The Journal of Environmental Education*. 16(3): 12-20.
- Glaser, R. 1997. Paving the road to TRUST. *HR Focus*. 74(1): 5(1).
- Hansis, R. 1995. The social acceptability of clearcutting in the Pacific Northwest. *Human Organization*. 54(1): 95-101.
- Hendershot, D. 1996. Risk guidelines as a risk management tool. *Process Safety Progress*. 15(4): 213-218.
- Kakoyannis, C.; Shindler, B.; Stankey, G. 2001. Understanding the social acceptability of natural resource decisionmaking processes by using a knowledge base modeling approach. Gen. Tech Rep. PNW-GTR-518. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 40 p.
- Kasperson, R.E.; Golding, D.; Tuler, S. 1992. Social distrust as a factor in siting hazardous facilities and communicating risks. *Journal of Social Issues*. 48(4): 161-187.
- Kearney, A.; Bradley, G.; Kaplan, R.; Kaplan, S. 1996. Stakeholder perspectives of appropriate forest management in the Pacific Northwest. Seattle, WA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 17 p.
- Kloppenborg, J. 1991. Social theory and the de/reconstruction of agricultural science: local knowledge for an alternative agriculture. *Rural Sociology*. 56(4): 519-548.
- La Porte, T.R.; Metlay, D.S. 1996. Hazards and institutional trustworthiness: facing a deficit of trust. *Public Administration Review*. 56: 341-347.
- Lauber, B.T.; Knuth, B.A. 1997. Fairness in moose management decision-making: the citizens' perspective. *Wildlife Society Bulletin*. 25(4): 776-787.

- Lober, D.J. 1996. Why not here?: the importance of context, process, and outcome on public attitudes toward siting of waste facilities. *Society and Natural Resources*. 9(4): 375-394.
- Moore, S.A. 1996. The role of trust in social networks: Formation, function, and fragility." In: Saunders, D.A.; Craig, J.; Mattiske, E.M., eds. *Nature Conservation 4: The Role of Networks*. Chipping Norton, New South Wales, Australia: Surrey Beatty and Sons: 148-154.
- Perry, G.M.; Pope, C.A. 1995. Environmental polarization and the use of old-growth forests in the Pacific Northwest. *Journal of Environmental Management*. 44: 385-397.
- Peters, R.G.; Covello, V.T.; McCallum, D.B. 1997. The determinants of trust and credibility in environmental risk communication: an empirical study." *Risk Analysis*. 17(1): 43-54.
- Pijawka, K.D.; Mushkatel, A.H. 1991. Public opposition to the siting of the high-level nuclear waste repository: the importance of trust. *Policy Studies Review*. 10(4): 180-194.
- Reynolds, K.M. 1999. EMDS users guide (version 2.0): knowledge-based decision support for ecological assessment. Gen. Tech. Rep. PNW-GTR-470. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 63 p.
- Shelby, B.; Speaker, R.W. 1990. Public attitudes and perceptions about prescribed burning. In Walstad, J.D.; Radosevich, S.R.; Sandberg, D.V., eds. *Natural and Prescribed Fire in Pacific Northwest Forests*. Corvallis, OR: Oregon State University Press: 253-260.
- Shindler, B.; Cheek, K.A.; Stankey, G.H. 1999. Monitoring and evaluating citizen-agency interactions: a framework developed for adaptive management. Gen. Tech. Rep. PNW-GTR-452. Portland, Oregon: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 28 p.
- Shindler, B.; Neburka, J. 1997. Public participation in forest planning. *Journal of Forestry* 95(1): 17-19.
- Shindler, B.; O'Brian, K. 1998. Draft summary: citizen survey of public involvement in federal forest management. Unpublished Pacific Northwest Research Station Report, Department of Forest Resources, Oregon State University.
- Slovic, P. 1987. Perception of risk. *Science*. 236: 280-285.
- Slovic, P. 1997. Public perception of risk. *Environmental Health*. 59(9): 22(3).
- Smith, P.D.; McDonough, M.H. 2001. Beyond public participation: fairness in natural resource decision making. *Society and Natural Resources*. 14(3): 239-249.
- Stankey, G.H. 1976. Wilderness fire policy: an investigation of visitor knowledge and beliefs. Res. Pap. INT-180. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 17 p.
- Stankey, G.H. 1996. Defining the social acceptability of forest management practices and conditions: integrating science and social choice. In: Brunson, M.W.; Kruger, L.E.; Tyler, C.B.; Schroeder, S.A., eds. *Defining Social Acceptability in Ecosystem Management: A Workshop Proceedings*. Gen. Tech. Rep. PNW-GTR-369. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 99-111.
- Steel, B.S.; Soden, D.L.; Warner, R.L. 1990. The impact of knowledge and values on perceptions of environmental risk to the Great Lakes. *Society and Natural Resources*. 3: 331-348.
- Steel, B.S.; List, P.; Shindler, B. 1994. Conflicting values about federal forests: a comparison of national and Oregon publics. *Society and Natural Resources*. 7: 137-153.
- Steelman, T.A. 1999. The public comment process. *Journal of Forestry*. 97(1): 22-26.
- Sullivan, R. 1998. Assessing the acceptability of environmental risk: a public policy perspective. *Australian Journal of Environmental Management*. 5: 72-80.
- Tuler, S.; Webler, T. 1999. Voices from the forest: what participants expect of a public participation process. *Society and Natural Resources*. 12: 437-453.

- Vining, J.; Ebreo, A. 1991. Are you thinking what I think you are? A study of actual and estimated goal priorities and decision preferences of resource managers, environmentalists, and the public. *Society and Natural Resources*. 4(2): 177-196.
- Webler, T.; Tuler, S. 2000. Fairness and competence in citizen participation: theoretical reflections from a case study. *Administration and Society*. 32(5): 566.
- Webster's Revised Unabridged Dictionary. 1998. Springfield, MA: C&G Merriam Co.
- Williams, D.R.; Carr, D.S. 1993. The sociocultural meanings of outdoor recreation places. In: Ewert, A.; Chavez, D.; Magill, A., eds. *Culture, Conflict, and Communication in the Wildland-Urban Interface*. Boulder, CO: Westview Press. 209-219.
- Wondolleck, J. 1985. The importance of process in resolving environmental disputes. *Environmental Impact Assessment Review*. 5: 341-356.
- Wondolleck, J.M. 1988. *Public Lands Conflict and Resolution: Managing National Forest Disputes*. New York: Plenum Press. 263 p.
- Wondolleck, J.M.; Yaffee, S.L. 1994. *Building bridges across agency boundaries: in search of excellence in the United States Forest Service*. Seattle, WA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 90 p.
- Zadeh, L.A. 1976. The concept of a linguistic variable and its application to approximate reasoning, part III. *Information Science*. 9: 43-80.

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