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Compatibility Between Wood Production and Other Values and Uses on Forested Lands: A Problem Analysis

Charles E. Peterson and Robert A. Monserud

Authors

Charles E. Peterson is supervisory biological scientist and **Robert A. Monserud** is chief biometrician, Forestry Sciences Laboratory, 620 SW Main Street, Suite 400, Portland, OR 97205.

Abstract

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We provide background documentation for the Pacific Northwest Research Station's Wood Compatibility Initiative, a 5-year multidisciplinary research effort that began in response to 1997 Congressional direction. This problem analysis was the initial effort to examine the state of knowledge regarding compatibility between wood production and other values and to develop a framework for directing a research initiative (Wood Compatibility Initiative) that examines the central question: **Can we as a society produce wood commodities and other forest values in an environmentally acceptable and sustainable manner?** Forest policy issues are often framed as two-dimensional debates such as "jobs versus the environment." That framework assumes that forest management is a zero-sum enterprise, in which actions such as timber harvest inevitably mean substantial tradeoffs for other forest values such as wildlife habitat, clean water, and recreation. The debate ignores the possibility that instead of direct tradeoffs, opportunities exist for compatible changes that can provide more of both. The research challenge is to determine if, and at what level, timber harvest and other forest services and products can complement one another. Compatibility is seen as the degree to which we can manage for wood production without impairing other values.

Keywords: Compatible wood production, alternative silviculture, joint production, social acceptance, forest management, management options, biodiversity, aquatics, wildlife, economics.

Preface

Our objective is to provide background documentation for the Pacific Northwest Research Station's Wood Compatibility Initiative, a 5-year multidisciplinary research effort that began in 1998. This problem analysis was the initial effort to examine the state of compatibility between wood production and other values and uses on forested lands and develop a framework for directing a focused research effort. This was the first major document to build on a concept paper written by the senior author in 1997, which provided initial justification for the initiative. In late 1997 (fiscal year 1998), that was followed with Congressional appropriation and direction to the Pacific Northwest Research Station:

> 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.

This document then, is the problem analysis essentially as presented on September 30, 1998, with minor changes. For information on the progress of the initiative and funded research studies, see Haynes and Monserud (2002) and Johnson et al. (2002).

Contents

Clarification of the Problem

Competing Values and Uses

The temperate rain forests of the Douglas-fir region and southeast Alaska contain the highest quality wood-producing lands in the Nation, and they are among the most productive forests in the world (Franklin 1988, Franklin and Dyrness 1973, Walter 1985). These forests also have extremely high value for scenery and recreation, watershed protection, and fish and wildlife habitat (Everest et al. 1997). During the past decade, conflicts among demands for these values have intensified. Some sectors of our growing population have become highly polarized on forest management issues and distrustful of private and governmental institutions. Associated concerns about forest health, legal challenges, and uncertainty about future constraints on managed forest lands create additional complexity. A quest for solutions has become more difficult because society's resource problems and our agreements or disagreements on how best to manage those resources is a process that has become increasingly value laden. Consequently, finding compatibility among commodities and social and cultural values and articulating that compatibility in precise language are very demanding and necessary challenges.

Range of Management Options

Alternative solutions to the contentious issue of land management for competing uses and values are (1) zoning into different dominant uses or (2) emphasizing a range of management options that address joint production across all lands. The former (zoning) leads to a system of reserves where management is focused on only one dominant use. It is questionable, however, whether a "dominant use" allocation (either-or approach to commodities) can provide a sustainable flow of goods and services, much less a sustainable set of values such as fish and wildlife habitat. And under laws like the Endangered Species Act that do not exempt "commodity lands," a strongly differentiated land allocation is not likely to be realized.

The range of possible management options might be characterized as single-species plantation management for timber production on the one hand, and reserves or a system of connected reserves with little or no harvesting on the other. In reality, of course, reserves are not static and are subject to growth and natural disturbances that affect their ability to provide fish and wildlife resources. The most widely recognized reserves are the national parks and designated national wilderness, managed to provide a variety of nontimber values. The Northwest Forest Plan (USDA and USDI 1994a, 1994b) established well-delineated late-successional reserves on federal lands in Washington and Oregon, as well as a system of variable buffer widths for riparian areas, yet another example of a zoning or land allocation attempt at providing society with different resource values from different lands.

Although the idea of multiple use is a desirable goal, there is little awareness of instances where it has been effectively implemented (e.g., joint production of wood, fishing, recreation, hunting). In addition, there has been little concerted effort to determine the compatibility between commodities and other values and the tradeoffs, whether managing for both or managing for one at the expense of the other. In the case of riparian habitat, a key question is whether aquatic conservation objectives can be met under active management within riparian zones (the aquatic-terrestrial interface). Additional science is needed to develop ways to get beyond the current zero-sum game of tradeoffs; this is a major focus of the compatibility initiative.

Most of the previous management practices on federal lands attempted to increase wood production to meet increasing wood demands in the United States, relying on the economic efficiencies of plantation management (Curtis and Carey 1996). With the widely acknowledged importance of old-growth characteristics, current efforts in management planning attempt to provide for conservation and restoration of wildlife and fish populations. These planning efforts include the Northwest Forest Plan, the Tongass land management plan (USDA Forest Service 1997a, 1997b, 1997c), and the habitat conservation programs of Washington state (HCPs) and industry (e.g., Simpson, Plum Creek, and Weyerhaeuser), tending more to a passive spectrum of management practices.

General Research Problem

The Pacific Northwest (PNW) Research Station is undertaking a major research initiative in Alaska, Washington, and Oregon, in response to a national resource problem of increasing complexity. The research problem is that little if any scientific information is available on the compatibilities and tradeoffs between commodity production and other values (e.g., wildlife, water, aesthetics, recreation) that the public desires from our forests. A well-focused research initiative that integrates key scientific disciplines should provide sound research results that can enhance good stewardship of our forest lands, both public and private. **Therefore, the PNW Station will focus its research efforts for this initiative on options that can increase the compatibility between commodity production and other important societal values from forest lands.** 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.

Although this societal issue is relevant in any area that includes public lands, we have limited our **geographic scope** to contrasting the Douglas-fir region (west side) of Washington and Oregon with southeast Alaska, using the smallest scale that is practical for measuring the effects of interest. We anticipate that the research information will be useful across all ownerships and that the key parties interested in finding some resolution will be those interested in forest land management in the area.

Additional considerations include **temporal and spatial scales**, important for compatibility as well as for ecological resolution. Acceptability of management actions is based on the scale at which people perceive values (e.g., risk or ecological integrity) and their time scale of interest. There are also different management trajectories of planned actions and risks at each scale.

Finally, there are questions relating to compatibility: where, when, of what, and for whom, and is it even possible? We can adopt the position that compatibility exists and test how to achieve it, bearing in mind that it is a social rather than scientific construct. It is also scale dependent. Many argue that compatibility increases with scale and is approachable only at very large scales. For this initiative, however, the question is not “What happens to wood production when we manage for something else?” but rather “To what degree can we manage for wood production without impairing other values?” The set of values we choose greatly affects the outcome, which should offer tradeoffs rather than an “either/or” set of choices.

Evaluation of Current Information

Social Context

Perhaps what sets this initiative apart from previous efforts to deal with biophysical outcomes is the social context. In the previous section we introduced the issues of competing values and uses of our forest resources, and the need to seek compatibility. The challenge then is how to frame our discussion in a way that more clearly defines what the research role might be. More specifically, what are the priority values that could be derived from various management actions and where can research contribute? The management of forest land is ultimately determined by societal values, which are interpreted by various institutions and then implemented as policies and goals. These policies and goals largely condition and limit the set of management actions that are technically feasible, resulting in a limited subset that are acceptable and allowable. Although the general public might have little knowledge of land management, they have strong expectations for values and uses of forest land, especially public land. Furthermore, their social attitudes and beliefs and values do provide direction for managers, albeit indirectly.

Overarching Research Questions

The Pacific Northwest Research Station has ongoing programs that have been historically strong in research areas of silviculture (including wood production), social and economic values, wildlife, and aquatics. Although much of the ongoing core research in these disciplines is important to this issue, the questions of compatibility and sustainability are integrative resource problems, and they demand an integrated research framework that provides a set of alternatives for management and society with clearly defined tradeoffs.

1. Can we as a society produce wood commodities and still maintain other desired attributes (functions and processes) of a forest ecosystem? That is, to what degree is compatibility of wood production with other values even possible?

2. On forested lands where wood commodities are not the primary value, will we need some manipulation of the forest in order to sustain the noncommodity high-priority values? And if so, will the management actions be economically feasible (important for all ownerships), socially acceptable, and simultaneously provide some wood as a byproduct?

3. How can we evaluate a shifting balance (in time and space) between what society wants and what the biological system is capable of sustaining?

To implement the initiative, we will need to reduce these questions to manageable research problems, examples of which might be:

- What do we need to know to determine the consequences of a change in the current mix of forest management values across the region?

- What are the relations of socioeconomic components to biophysical and management policies and practices as we move across different scales, from local (stand/watershed) to intermediate (province) to regional?

- What types of silviculture and conditions allow for the maintenance or improvement of the integrity of the riparian system while simultaneously managing for wood production?

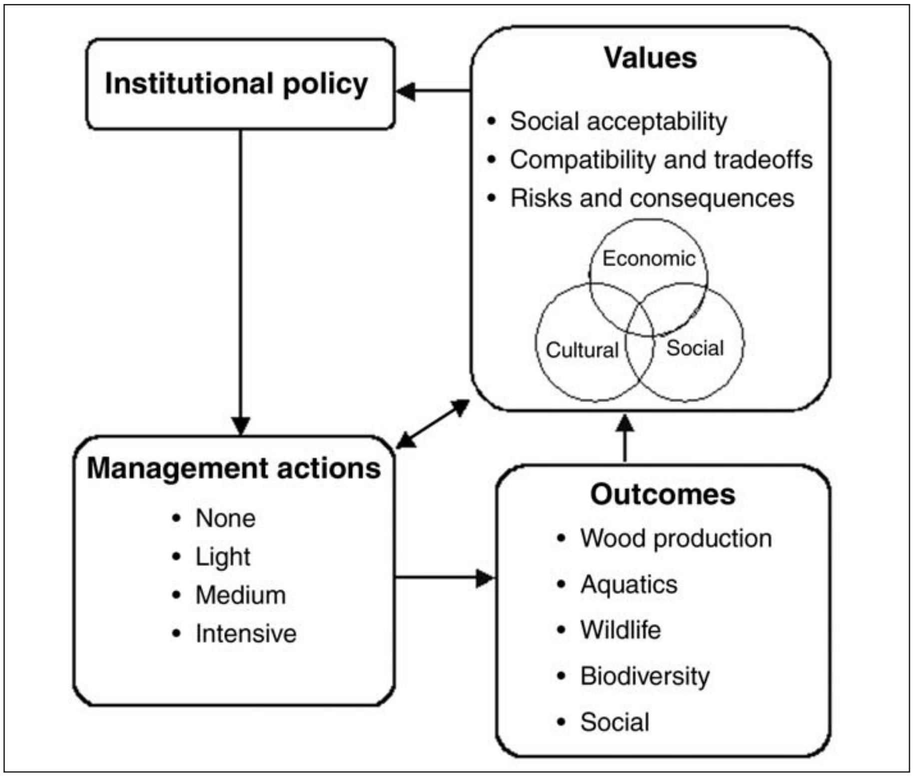

Figure 1—Basic framework showing interactions among societal values, institutions, management, and outcomes.

Conceptual Model Needed to Identify Research Component

Another major area of input was the need for a conceptual framework that allows us to develop the research problems and components while facilitating communication among people interested in specific disciplines. Figure 1 illustrates the basic interactions that help define the research context: social values influence institutional policy, which in turn affects managerial decisions and actions, resulting in a 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 are also prominent in evaluating management actions that affect water quality, biodiversity, economic dimensions, and so forth. Once management takes action, the success of that action will depend to a large extent on whether the desired mix of outcomes is acceptable. The process is complicated by the fact that many of the values are realized in different areas and over varying lengths of time after the management action. This also complicates the task of gathering research information amenable to socioeconomic evaluation of risks and consequences.

Iterative Approach

We cannot hope to build a complete detailed model up front for this initiative. Instead we intend to (1) begin with this framework of representative pieces, (2) work within each box (component) to refine needs of scale and resolution, and (3) feed results back through this framework to improve and build the framework in an iterative fashion that clarifies the most useful research hypotheses that can be tested.

Importance of Scale

Our challenges include choosing the most relevant scale for the research in both space and time, as well as identifying the necessary interactions or linkages between scales. The choice of scale should be driven by the questions being asked. Although the idea of compatibility is primarily a regional concept, both midscale (provinces) and fine-scale (stand and local watershed) detail are necessary to provide a reliable evaluation. Thus, when focusing at one scale, it is important to look to the next higher level for context and to the next lower level for understanding (i.e., a hierarchical approach). Although we would like to provide statements of compatibility on a regional level, our challenge will be to integrate across scales. For example:

Ecoregion = sum of provinces (e.g., ecophysiographic),
Province = sum of fourth-code watersheds,
Fourth code = sum of sixth-code watersheds, and
Sixth code = sum of stands, and so forth.

As most of our biophysical research is necessarily conducted at a stand or small watershed scale, the challenge is how to aggregate or scale up from an area of context such as a sixth-code watershed (which is already one level above our level of understanding of process) to a province or ecoregion level. Our discussions with scientists in the Station suggest we need to consider a number of scales in evaluating our current research efforts.

Evaluating Information Based on Outcomes

The scale-based approach illustrated above could be very useful for assessing scenarios for risks beyond the stand level. However, we need an additional framework to array the stand-level information from passive to active management expressed by the range of silvicultural treatments (as measured by basal area or green-tree retention levels) and outcomes that might be achieved, including socioeconomic evaluations of risk or consequences, and leaving scale as a third dimension. We have used this latter framework to begin evaluating how well existing information addresses our stand-level needs and what areas might represent priority gaps in our knowledge base for these outcomes.

Although forestry outputs have largely focused on wood production, a broad spectrum of additional products and values are available from the forest. However, given the limited resources, we have chosen to focus this initiative on a mix of four interactions that, taken together, include most of the major driving forces setting the public agenda on the future of forest management in the region:

- Wood production and **wildlife** needs
- Wood production and **aquatics** needs
- Wood production and **biodiversity** needs
- Wood production and **social** acceptance

We also need to assess the technical feasibility, economic viability, and social acceptability of these outcomes, keeping in mind that efficient operations and adequate markets are necessary for the use of wood as a commodity and that managers rely on forest industry for forest management operations. Likewise, compatibility of forest values under active management can only be achieved if the public understands the tradeoffs among joint benefits.

Table 1—Indication of experimental information from stand-level studies addressing joint production outcomes where wood production is either a major objective or byproduct of manipulation necessary to achieve other values

	Green-tree retention levels					
Outcomes	All	High	Medium	Low	None	Economic information
Wood and wildlife	+++	+	+++	+		
Wood and aquatics	++	++	++	+	+	
Wood and biodiversity	+++++	++	++++	++	+	
Wood and social	+++	+++	++	++	++	+
Wood	*			*	*	*

Each + represents one interdisciplinary study.
The "all" level yields no wood production but is a necessary experimental contrast. The * in the final row indicates that much of the past research addressed wood production (e.g., plantation forestry) without explicit experimental testing of impacts on other values.

A significant portion of the Station's past resources addressed intensive wood production applicable to plantation forestry, without linkages to needs of wildlife, aquatics, or biodiversity. Likewise, virtually none of the research efforts on wildlife, aquatics, or biodiversity have addressed wood production as a joint objective. Therefore, although we have a lot of research information in all these areas, there exist some gaps as to what we can say about joint outcomes. As a first approximation we offer our appraisal in table 1 of available information to address those outcomes.

Because outcomes are rarely achieved without some effect on the resource, the public is interested in monitoring those effects. For instance, as we alter structure or composition of a forest landscape, are we maintaining the integrity and resilience of important processes? Those components of the ecosystem and the attending research problems (social, economic, and biophysical) are discussed in the next section, as well as more of the detailed evaluation of the current stand-level studies incorporating new interdisciplinary approaches.

Research and Development Problem and Components

Adding research components to the conceptual model of figure 1 gives rise to a comprehensive series of research questions. A summary of existing multidisciplinary stand treatment experiments is then followed by a summary of the state of knowledge (with associated knowledge gaps) by major disciplines.

Conceptual Model with Research

We chose an outcome-based approach to the forest management problem of **wood** production jointly with other values: **wildlife** habitat and populations; **aquatic** resources; **biodiversity** measures as indicators of ecosystem health; **social** acceptance; and **economic** viability, including risks and consequences. To be successful, research is, of necessity, directed at understanding processes or describing the current state of the forest system.

In figure 1, we presented a thumbnail sketch of the key determinants of the forest management process: institutional policy leads to a suite of management actions, which result in measurable outcomes that provide society with forest values. The

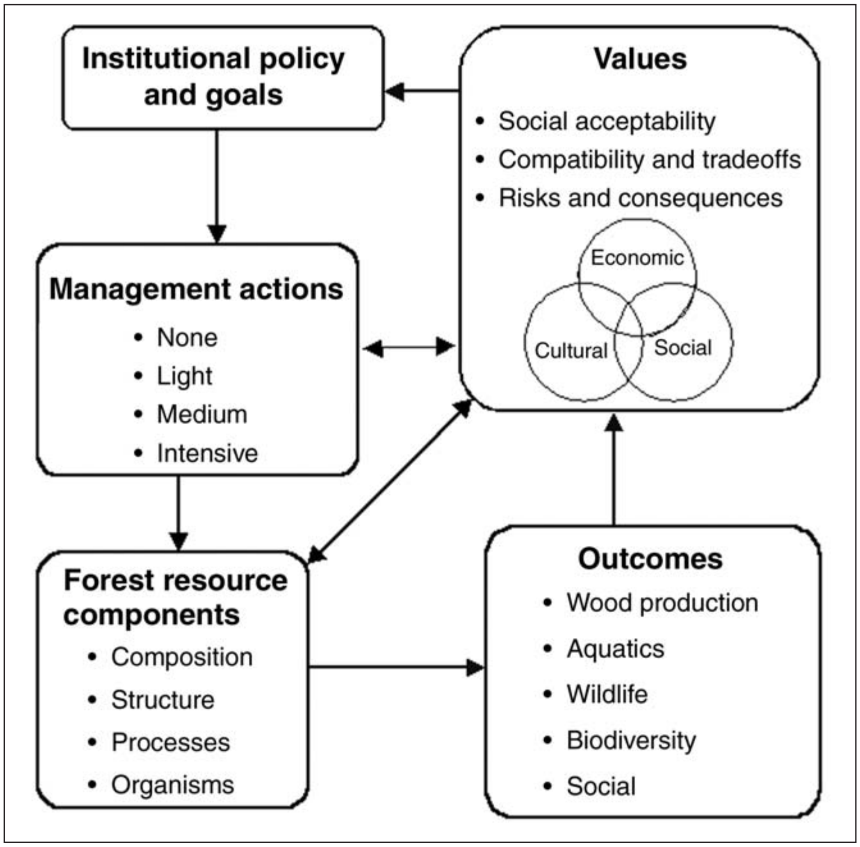

Figure 2—Conceptual model including forest resource components with interactions among social values, institutions, management, and outcomes.

mix of values feeds back into shaping institutional policy, and the process continues. This is a continuous feedback system that can adjust to changing needs and beliefs in an adaptive and iterative fashion. In order to produce desired outcomes as a result of management actions, we needed to identify the biophysical functional components of the forest resource (see fig. 2) in terms that scientists can study: structure, composition, organisms, and processes, including natural disturbances. They contain the necessary information to describe just how management actions influence the forest resource (vegetation, fish and wildlife, streams and hydrology, natural disturbances, and soil) to produce a desired mix of outcomes for society. Although socioeconomic research also could be viewed in this resource impacts box by including humans in the forest, it is found in the values and outcomes boxes (fig. 2).

Most values and outcomes derived from the forest are dependent on the structure, composition, and biophysical processes of the forest. Management actions and natural disturbances can affect all of these fundamental components. As a society, we usually try to minimize disturbances (fire, wind, landslides, and insect and disease outbreaks), or use them to advantage. Structure and function of the forest resource can be altered and moved toward a future condition through management actions varied by level and pattern of removals or plantings associated with harvest systems and transportation systems.

Resource components

- Vegetation:
  - Overstory
  - Growth, regeneration
  - Understory
  - Mortality
  - Snags
  - Coarse woody debris
- Fish and wildlife populations:
  - Habitat
  - Reproduction
  - Survival
- Streams:
  - Classes 3 and 4
- Hydrology:
  - Temperature
  - Sediment movement
  - Slope stability
- Natural disturbances
- Soils
- Organisms

Figure 3—Composition, structure, process, and organism components of forest resources.

For plant and animal systems, important processes include regeneration, growth, mortality, and factors determining productivity (see fig. 3 for more detail). Furthermore, the difficulty of working directly with mobile and elusive animals requires a sound description of the habitat and the important factors affecting it. For fish and other riparian animals, nonbiological processes affecting hydrology are crucial to habitat determination. All of these processes can be interpreted in light of their effect (positive, neutral, negative) on a variety of important organisms that constitute the forest system. Tree mortality might be a loss of wood production, but it is also the birth process of snags and woody debris that provide important habitat as well as maintain long-term soil productivity with nutrient recycling. Large-tree mortality or removal also opens canopy gaps allowing light for regeneration and a possible change in composition.

In this initiative we choose to focus on key components that are necessary to determining the outcomes associated with a given policy and set of management actions. In the interim, we must operate within the bounds set on management by the current political reality. For example, we focus on the riparian management problems of class 3 and 4 streams rather than larger stream and river systems. Similarly, we concentrate on forest management of the upland stands associated with these headwater areas. Such areas offer the greatest opportunity for demonstrating or testing the compatible production of wood and other key resources. The net effect is to sharpen the focus of the Compatibility Initiative somewhat, on young-growth rather than old-growth stands, on class 3 and 4 streams rather than class 1 and 2, and on upland rather than lowland stands.

Research Questions

In the "Evaluation of Current Information" section, we asked very broad questions that define the Compatibility Initiative in the most general terms. Rarely is a complex problem amenable to a direct general solution, however, without first attacking a series of related specific problems. To avoid the frustration of trying to solve all possible problems, we focus on two things: the organizing principle of the research framework to see which questions are the most critical (figs. 1 to 3) and the current state of knowledge in the relevant disciplines. Research questions point to knowledge gaps and to research problems. Thus, we pose several sets of interrelated questions that should help focus the research needed for resolving the compatibility issue. This is especially useful as an aid to screening research proposals. These questions point directly to knowledge gaps about specific processes or components, and at one or more scales of resolution. We collated the list from several sources: study proposals, personal communication with subject matter specialists, and a series of small technical meetings conducted to flesh out the important components of compatibility. In this section, we array the questions hierarchically, based on scale: from regional to province/midscale/landscape, and finally, down to local stand/watershed questions at the individual study level.

Regional questions—Can we produce wood in a manner that is ecologically sustainable and socially acceptable on the broad scale?

- What level of compatibility between wood production and other values do we currently have in the region, and how can we increase it?
- What do we need to know to determine the consequences of a change in values for the current mix of forest management across the region?
- What are the problems associated with evaluating forest policies and landowner behavior in multiownership landscapes?
- What are the current and potential roles of federal lands in timber production?
- Is it necessary to harvest trees on federal lands to meet biophysical goals associated with system integrity (scale: watershed to regional)?

Scale issues (watershed to province)—What conceptual and technical problems must be solved to evaluate linkages and compatibility among different uses of forest land?

- What are the overarching research questions and hypotheses for large-scale issues and studies?
- How do we link databases and ecological and socioeconomic models at different spatial and temporal scales to examine relations among forest values and uses?
- What are the scaling questions that need to be addressed to evaluate alternate forest management strategies and provinces?

- How do we generalize from the subject watershed to other watersheds, and to the region? How do tradeoffs (including risks) change as the proportion of the watershed under management changes? How do we develop robust management regimes for the entire watershed?
- What are the institutional challenges to evaluating compatibility at the province scale?
- Spatial pattern and landscape context: How do we develop models that relate pattern of forest habitat at landscape scale to quality of habitat and population performance for most species?
- Landscape- and regional-scale variation in habitat relations: How do habitat relations vary across environmental gradients?
- Habitat: How does aquatic and wildlife habitat quality vary in relation to forest structure and composition, and to watershed features (scale: local stand/watershed to midscale province)?
- Variation in forest dynamics across landscapes: How do we model the structure, composition, and changes in forest vegetation across environmental gradients, including from riparian to upland areas?
- How do we model the diversity of forest management practices by different owners across the landscape?
- How do we develop the linkages between terrestrial and aquatic ecosystems? Understanding and modeling the linkage among upslope, riparian, and aquatic ecosystems are among the most critical problems of the forest compatibility issue in the Northwest.
- Spatial modeling and accuracy: How do we evaluate and minimize the spatial errors in geographic information system (GIS) models, especially regarding map-based models of forest conditions across landscapes?
- Scaling and aggregation problems: How much fine-grained information do we need to project the effects and outputs of forest management at landscape and regional scales? If we aggregate spatial information to larger units, how much essential information is lost? How do we nest fine-scale models (project level) within coarse-scale planning/policy models (province/regional scale)?
- Effect of scale on value of alternative management strategies: Where can changes in forest management practices provide the greatest improvements in measures of compatibility? Does rearranging the management allocations on the landscape provide greater compatibility than changing stand-level prescriptions? What are the relative economics and total benefits of forest management strategies based on a combination of reserves and intensive forest management vs. strategies with no reserves but with modified silviculture?

Socioeconomic—What can socioeconomics contribute to the debate regarding public choice among conflicting goals? What kind of research would contribute to an understanding of this public policy debate?

- How do we define and measure compatibility at various spatial and temporal scales of interest?
- What are the problems and challenges associated with measuring ecological and socioeconomic values?

- What are the relations of socioeconomic components to biophysical components and management policies and practices across scales, from local (stand/watershed) to intermediate (province) to regional?
- Integration: How do we integrate across different disciplines, especially from ecological to socioeconomic? For example, how do we, from the ecological, social, and economic viewpoints, determine compatibilities and assess tradeoffs of producing biodiversity?
- What biophysical outputs are needed, over what temporal and spatial scales, to evaluate both risks and acceptance of policies by the public? What variables do socioeconomists need to make such evaluations?
- What are the appropriate units for developing economic indicators across systems? Can such units be used to cross province-level boundaries to reach the regional level?
- What is researchable regarding social acceptability of forest management?
- Can public acceptability of riparian management be achieved?
- On the assumption that aquatic and other riparian values can be safeguarded, are the returns from long-term riparian silviculture cost effective? What factors are limiting the economic viability of the management plan?
- How do we measure the risk to ecological integrity of various management alternatives and policies?
- What is the relation between risk and public acceptance? How does this differ across spatial and temporal scales? What are the implications for socioeconomic research on compatible wood production?
- What are the compatibilities and tradeoffs between wood and nonwood commodities?
- What is the role of wood quality in determining economic viability (midscale to regional)?

Riparian—Ecosystem management questions arising from the aquatic conservation strategy (ACS) and buffer-related questions: What types of silviculture and conditions allow for the maintenance of the integrity of the riparian and upland systems while simultaneously managing for wood production?

- Which watershed attributes are the most important for meeting ACS requirements? Which forest management practices are compatible with ACS?
- Is there experimental evidence that ACS is a significant improvement over previous standards and guides?
- Can timber be harvested and still meet the objectives of the ACS within and adjacent to riparian zones?
- How might landscape considerations be applied at the watershed scale to modify default standards, to allow for biological conservation, wood production, and other human uses?
- Riparian buffer design: How does buffer width affect key environmental attributes along streams of different size and the ability to withstand windthrow and flooding?

- Active management to enhance desired future conditions: Is there a class of thinnings and conditions minimizing long-term ecological impacts in the riparian zone? How are environmental responses affected by the amount and pattern of removal of trees (e.g., thinning) in relation to distance from stream?
- How does the design of the silvicultural treatment affect ecological processes and the ability of the buffer zone to minimize or capitalize upon impacts resulting from windthrow, flooding, and other major disturbances? Can we achieve outcomes that enhance riparian function through a disturbance- or management-based approach?
- Watershed considerations:
  - ♦ What proportions of a watershed should be early-, mid-, and late-successional riparian zones?
  - ♦ What are the criteria for selecting intermittent/ephemeral streams for buffer placement?
  - ♦ What are the tradeoffs among standard fixed-width buffers, buffers based on patterns of natural disturbance, and buffers based on extended rotations?
  - ♦ What are the relations between forest management and hydrology, particularly basin soils and stream channel/streambed changes during rain-on-snow events?
- Riparian restoration: What are appropriate composition and density targets for restoration, and how can they be achieved?
- Susceptibility to windthrow and disturbances: How do the rates of disturbance of riparian areas in managed landscapes compare to rates in comparable unmanaged landscapes?
  - ♦ Can sites with high windthrow probability be identified? What are the important variables?
  - ♦ Can buffer design be altered to minimize windthrow?

Stand dynamics and silviculture—What silvicultural techniques are most effective for restoring or enhancing current systems to some future condition?

- What information is needed to develop reliable models of stand dynamics for both riparian and upland forests? What model architecture is best suited to the task?
- How do successional pathways differ throughout the region by site landform, and with susceptibility to disturbance?
- How are successional pathways altered by forest management within a riparian area or on the adjacent upslope area?
  - ♦ How does silvicultural method affect the growth, regeneration, and mortality of trees in the riparian area? What are the key factors affecting such dynamics?
- What overstory tree growth rates and stand yields can be expected from implementation of a variable thinning? Will within-stand variation in growth rates increase with variable thinning?
- How do stand conditions and environmental variables influence flowering of woody plants (for the benefit of wildlife)?
- How do understory composition, size, and vigor relate to overstory conditions? How will variable thinning affect understory development?

- What growth rates can be expected from shade-tolerant tree species in overstory, midstory, and understory positions? Can these growth rates be predicted by the usual stand density measures and growth models, or are additional variables such as light needed?
- What are desirable species compositions and structure (including down woody debris), and what silvicultural treatments can regenerate and maintain such a composition without damage?
- How can shade-intolerant species like Douglas-fir be managed in partial cutting systems?
- How will timber production and quality compare with those in conventional even-aged management?
- To what degree and how often should the overstory canopy be opened to regenerate and promote the understory?
- Which components of the original even-aged stands can be functional components in a new multilayered stand?

Multidisciplinary Stand Treatment Experiments

Before providing a detailed examination of the state of knowledge for each research component, we examined existing field trials. Several large operational experiments established since 1990 by PNW Research Station scientists and cooperators (see fig. 4) provide important links between wood production and nonwood resources. Looking for a common denominator, we categorized these studies according to the residual density of trees left after harvest (green-tree retention levels). We then analyzed study designs for research that addressed the interaction of wood production with wildlife, aquatics, biodiversity, and social values (see table 2). Finally, we looked for an economic analysis, as well as an analysis of tradeoffs among the components. Detailed tables summarizing several individual studies are provided in appendix 1.

The summaries in table 2 across all studies are encouraging (see appendix 1, tables 3 through 9 for individual studies). First, all seven studies do have well-designed experiments in place evaluating a variety of intermediate thinning levels. In time, these and other related studies will help to fill the knowledge gap on nontraditional forest management. Such studies are uncommon, owing to the overwhelming prevalence of wood production objectives, especially plantation management, in the region for over half a century. Second, there are from two to five studies (differing by residual density level and functional component) testing for the joint production of wood in each of our key outcome categories (wildlife, aquatic, biodiversity, social values). These provide a good basis for expanding to additional values. Third, the column summarizing economic consequences of joint production is essentially empty. Only one study (Capitol Forest study) was designed to collect economic information to evaluate the wood production component of the study, and that was not a joint production economic analysis. Fourth, no studies are examining the tradeoffs among wood and any other resource.

State of Knowledge, Knowledge Gaps

Silviculture of wood production—Our understanding of the structure and composition of the forest can be greatly improved by examining what is (and is not) known about the silviculture of wood production.

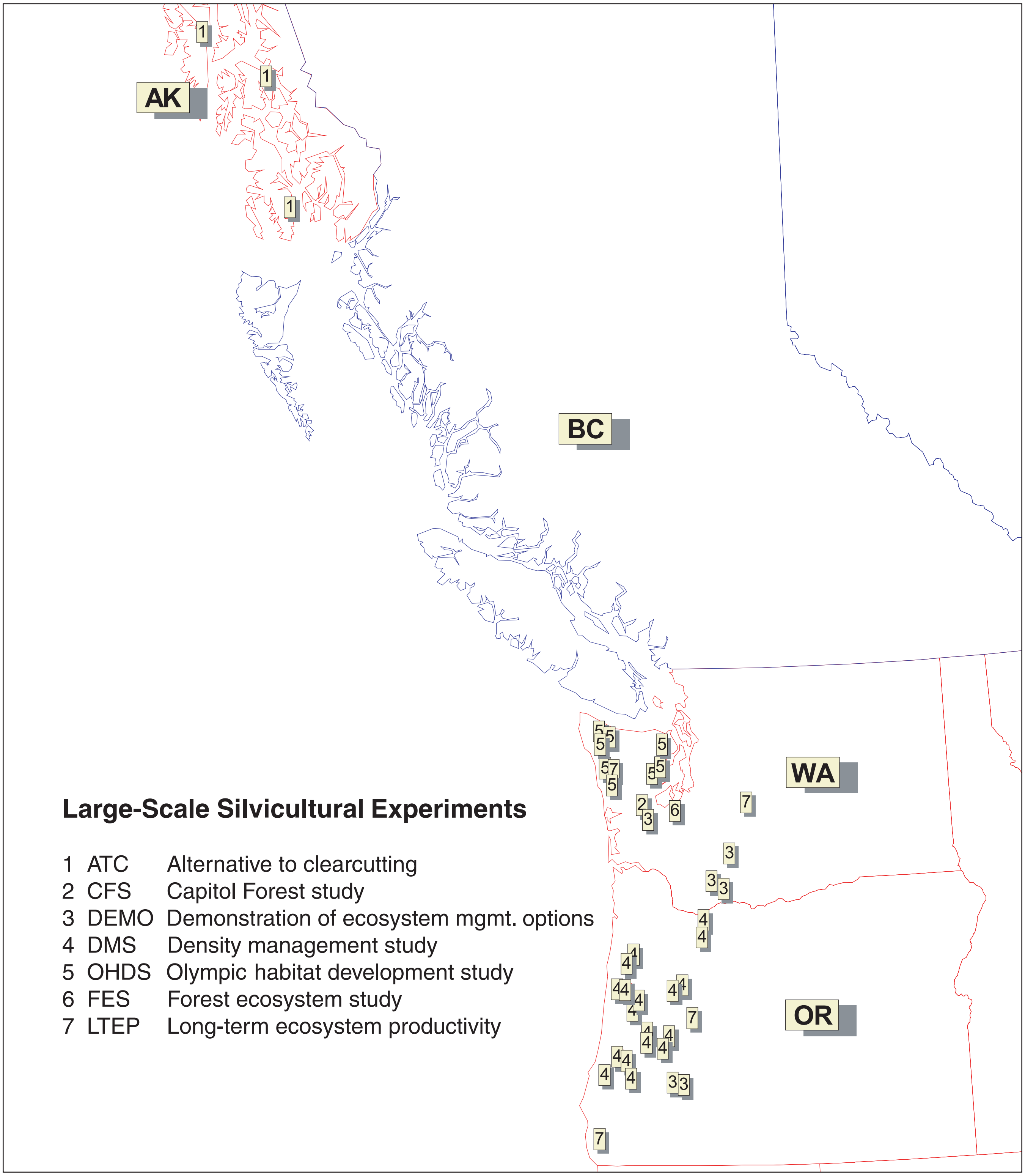

Figure 4—Distribution of large-scale operational silviculture experiments across southeast Alaska and western Washington and Oregon conducted by the Pacific Northwest Research Station.

Table 2–Ongoing stand-level experiments of the Pacific Northwest Research Station linking wood production with at least one additional resource outcome (wildlife, aquatics, biodiversity, or social values)

	Residual density levels						
Outcomes	All	High	Medium	Low	None	Economic analysis	Tradeoffs
Wood and wildlife	atc[a]	atc	atc	atc	atc		
	DEMO	DEMO	DEMO	DEMO			
	cfs	cfs		cfs	cfs		
	FES		FES				
	OHDS		OHDS				
	ltep			ltep	ltep		
Wood and aquatics	ATC	ATC	ATC	ATC	ATC		
	DMS	DMS	DMS	DMS			
Wood and biodiversity	DMS	DMS	DMS	DMS			
	DEMO	DEMO	DEMO	DEMO			
	cfs	cfs		cfs	cfs		
	FES		FES				
	OHDS		OHDS				
	LTEP			LTEP	LTEP		
Wood and social	ATC	ATC	ATC	ATC			
	dms	dms	dms	dms			
	DEMO	DEMO	DEMO				
	CFS	CFS		CFS	CFS	CFS	
	ltep			ltep	ltep		

The “all” level yields no wood production but is a necessary experimental contrast, and “none” indicates a clearcut.
[a] We use upper case to indicate studies with a given outcome as a major factor, and lower case if the factor is minor or merely a survey (e.g., ATC vs. atc).
ATC = alternatives to clearcutting (AK)
DMS = density management study (OR)
DEMO = demonstration of ecosystem management options (WA, OR)
CFS = Washington Department of Natural Resources Capitol Forest study (WA)
FES = forest ecosystem study (Fort Lewis, WA)
OHDS = Olympic habitat development study, WA
LTEP = Long-term ecosystem productivity program (WA, OR)

Western Washington and Oregon—The Douglas-fir region of western Washington and Oregon and coastal British Columbia contains the most productive forest lands in North America (Curtis and Carey 1996). Forest management in this region has been evolving for over a century, with vast experience on even-aged silviculture and plantation management accumulated in the past half-century. Methods for regenerating vigorous young stands of primary timber species following clearcut logging have been thoroughly researched and tested throughout the western Pacific Northwest (Loucks et al. 1996, Smith et al. 1997). Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), the major timber species in the Pacific Northwest, can be grown under a wide range of stockings. It rapidly responds to thinning at a wide range of stand ages, with increased diameter growth as well as branch and crown development (Reukema 1972, 1975); stocking control of densities is important to promote vigorous growth (Barbour et al. 1997). Two important shade-tolerant species, western redcedar (*Thuja plicata* Donn ex D. Don) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), respond similarly (Dilworth 1980, Nystrom et al. 1984).

Silviculturists have studied the key steps in stand management with fruitful results. Nursery methods for efficiently raising healthy, superior planting stock are now common, including techniques for inoculating roots with mycorrhizal fungi to promote quick establishment and sustained growth (Castellano and Molina 1989). Effective methods have been developed for controlling competing shrub and nontimber vegetation, thus promoting rapid growth of established individuals (Walstad and Kuch 1987). A range of harvesting systems have been developed to reduce problems such as soil compaction (Warila and Boyle 1995).

As a result of dependable stand establishment through the widespread sequence of clearcutting, burning, and planting, the length of commercial rotations on high-productivity lands decreased to as little as 40 to 50 years. Freed by nursery stock from reliance on seed sources from adjacent stands, clearcuts increased in size. Often, commercial thinning was eschewed in favor of earlier harvests (Curtis and Carey 1996). After nearly 50 years 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.

The National Forest Management Act of 1976 mandates that national forest lands cannot be harvested before the culmination of mean annual increment (MAI), the point of maximum volume production. Thus, this federal law sets a policy on rotation length. Curtis (1992, 1996, 1998) tackled the problem of rotation length and found surprising results. It is well known that the increase in mean annual increment is rather flat near the maximum (the point where periodic annual increment (PAI) crosses MAI). Curtis demonstrated that commercial thinnings can delay the sharp decline in PAI expected from classical yield tables such as McArdle et al. (1961). Using results from the levels-of-growing-stock studies, Curtis et al. (1997) found that PAI could be kept relatively constant and well above MAI in the 50- to 80-year range where a final harvest had become standard practice. The MAI curve continued to increase, albeit slowly, indicating that culmination had not yet been reached. The data indicate that the culmination may be delayed to age 120 years with thinning on some sites. European forestry practices have used a strategy of repeated light thinnings from below for well over a century; in fact, the thinnings are built into their yield tables (Assmann 1970). The overall result is that stand volume growth can be maintained at a vigorous level with thinning, forestalling the decision to clearcut and begin again. This gives the manager considerable flexibility without appreciable loss of productivity. Curtis and Carey (1996) point out numerous advantages to such extended rotations: reduced area in the regeneration phase, with associated reduction in upfront regeneration costs; larger trees with higher quality products; opportunity to improve unbalanced regional age distributions; improved habitat for some wildlife; hydrological and long-term site productivity benefits; increased carbon storage; continued flow of products from commercial thinning; and opportunity to increase stand health and vigor through thinning.

The current decade has seen a major shift in forest management practices in the Pacific Northwest, culminating in both the Northwest Forest Plan and the Tongass land management plan. Instead of the traditional goal of efficient wood production with even-aged plantations, the focus has shifted toward old-growth management, with related goals of protecting endangered species and fish habitat and promoting biodiversity (FEMAT 1993). The classic paradigm holds that the complex, multistory structure of typical old-growth stands derives from a stand development sequence that includes a dense closed-canopy stem-exclusion phase (Smith et al. 1997). Self-thinning following the stem-exclusion phase then reduces stand density and allows understory regeneration of shade-tolerant tree species to form intermediate canopy layers (Oliver and Larson 1990). Although there is some evidence that this sequence is proceeding in parts of the 1930s Tillamook burn area, recent research by Tappeiner et al. (1997) uncovered a much different successional approach. Apparently, regeneration on 10 old-growth sites in the Oregon Coast Range occurred over a prolonged period, with trees growing at low density with little self-thinning (Tappeiner et al. 1997). Thus, these open stands bypassed the dense stem-exclusion phase. Their results strongly suggest that thinning may be needed in dense young stands where the management objective is to speed development of old-growth characteristics.

Recently, Curtis (1998) reexamined a nearly forgotten experiment with what was called “selective cutting” in the Douglas-fir region in the 1930s. By the 1950s the experiment was pronounced a failure, and the individual tree selection system itself was effectively removed as a possible tool in the silviculturist’s repertoire. In fact, the original system was not at all individual tree selection, for it called for regeneration in small clearcut patches and resembled some current proposals. Flexible application might well have been successful, but as it was practiced, removals were limited to large Douglas-fir, very old stands deteriorated after disturbance, and openings were too small to allow Douglas-fir regeneration (Curtis 1998). Curtis found that the application amounted to little more than high-grading, and was a silviculture driven by short-term economics and not biology. It differed considerably from the original proposal of Kirkland and Brandstrom (1936), which instead called not for individual tree selection but rather preliminary, light salvage cuts intended to lead into a system of regeneration on small clearcuts of 2 to 10 ac, combined with thinning in younger stands; it is ironic that this is almost exactly one of the alternative-to-clearcutting regeneration systems that Curtis and Carey (1996) proposed 70 years later. As a result of harsh criticism by forestry experts of the day, partial cutting trails came to an abrupt end, and the consequent lack of research into alternatives to clearcutting severely handicaps current efforts to meet changing objectives and public concerns (Curtis 1998). The episode illustrates the dangers of adopting (or abandoning) plausible practices in the absence of supporting research.

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 are lacking for Douglas-fir (Curtis 1996). Currently, several experiments with various types of partial cuts are in the early stages. These involve a variety of thinnings, from patch cuts to variable density regimes, designed to increase within-stand heterogeneity (e.g., Olympic habitat development study, Capitol Forest study). The relevant literature on reproductive requirements for Douglas-fir establishment and survival indicates that openings of 1 ac or more are needed, or that overstory densities should be <50 percent (Isaac 1943). Worthington (1953) found regeneration success with patch cuts of 2 to 4 ac. Curtis (1996) cites unpublished current work on the Oregon State University McDonald Forest that found satisfactory initial establishment on small patch cuts of 0.25 ac and under residual overstories of 10 to 12 trees per acre. Clearly, satisfactory establishment of Douglas-fir requires that any retained overstory be very open.

Examining the state of uneven-age management in the west side of the Pacific Northwest, Emmingham (1998) concluded that regional silviculturists will need many decades to develop and maintain productive uneven-aged stands. Emmingham (1998) found that both good natural models and reliable experience with uneven-aged stands are lacking. The lack of information about how to create and manage productive uneven-aged forests is a major impediment. He also issues a warning regarding the future of stands that cannot be managed past age 80 in the late-successional reserves according to the Record of Decision in the Northwest Forest Plan (see USDA and USDI 1994a,1994b): without further management, those that have attained multilayer condition may return to single-canopy mature forests before they reach old-growth condition.

Southeast Alaska—The coastal forests of southeast Alaska comprise the temperate rain forest northernmost in the world, at latitudes (54.5 to 60.5° N) that would normally support only boreal vegetation. The majority of this forest land is dominated by uneven-aged natural stands of western hemlock-Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in various late-successional stages (USDA Forest Service 1994). The forest itself is vast, mountainous, and mostly unroaded, with the Tongass National Forest alone covering more than 17 million ac.

Specific features of the maritime climate have important effects on resource uses and management (Harris et al. 1974). Cool air temperatures and general cloudiness reduce the effect of timber harvesting on summer stream temperatures; moisture is not a limiting factor in tree regeneration; wildfire is not a major problem; a high percentage of land is occupied by muskegs; and high winds cause heavy losses to the shallow-rooted timber species by windthrow (Harris et al. 1974).

The dominant forest management system in use in southeast Alaska for the past half-century has been even-age management with clearcutting. This system was basically a transplant from the Douglas-fir region (Harris and Farr 1974). From the timber-production perspective, it was considered undesirable to manage the existing uneven-aged, defective, old-growth stands (Harris and Farr 1974). The defect averaged 30 percent of volume, and could be considerably higher in decadent stands. Furthermore, infection by dwarf mistletoe (*Arceuthobium* Bieb.) on western hemlock was often high. Foresters relied on clearcutting to economically convert this old growth to rapidly growing even-aged stands. The abundance of natural regeneration made this clearcutting system especially efficient; the clearcut opening also allowed the less shade-tolerant (but more valuable) Sitka spruce to compete with the ubiquitous western hemlock regeneration.

Figure 5—Experiments on alternatives to clearcutting in southeast Alaska old-growth forests.

Foresters have been reluctant to try partial cutting in southeast Alaska for several reasons: potential damage from wind, lack of suitable logging systems (e.g., to avoid logging damage and subsequent infection to the thin-barked hemlock and spruce residual trees), and excessive costs for these late-successional stands (USDA Forest Service 1994). Accessibility is a unique management problem, for the rugged terrain and general lack of roads necessitate air- and water-based transportation systems. Thus, some of the few experiences with selective logging are for high-quality spruce along the shoreline.

A quarter of a century ago, Harris and Farr (1974) listed an additional reason for a reliance on clearcutting: the lack of experience and trials with alternative silvicultural systems. The PNW Research Station's alternatives to clearcutting study (McClellan et al. 2000, USDA Forest Service 1994) (fig. 5) is currently filling this knowledge gap by using scientifically replicated silvicultural trials; the common harvest system in these long-term trials is helicopter logging. Additional goals are to retain more biological legacies, to retain some of the structural variety found in natural stands, and to find regeneration methods that work under adverse conditions. A key feature of the research is to determine hydrologic effects (e.g., slope stability, snowmelt, and water quality) associated with the silvicultural alternatives.

Knowledge gaps—Little is known about multispecies, uneven-age management. Silvicultural trials and experience are limited for silvicultural systems other than plantation management. Long-term data and models on stand response to variable retention, variable thinning, and green-tree retention are lacking. Knowledge on managing species other than Douglas-fir in western Washington and Oregon is quite limited, especially for hardwoods. Silvicultural information is severely lacking on achieving a desired structure and composition for riparian management and aquatic conservation. Little is known about the relation between the silvicultural manipulation of overstory structure and resources such as wildlife habitat and aquatic condition. Silvicultural systems are lacking for dealing with recent outbreaks of the Swiss needle cast (*Phaeocryptopus gaeumannii* (Rohde) Petrak) disease. Little is known about understory/overstory relations. Few documented experiments or trials in promoting desired understory species compositions and structures exist, although some research is being conducted under the rubric of nontimber forest products (Alexander et al. 2001). Understory/overstory stand modeling experience is limited to the forest vegetation simulator (FVS) (Teck et al. 1997) cover extension for the northern Idaho variant, and understory production functions are being developed by Janet Ohmann in the coastal landscape analysis and modeling study (CLAMS) (see table 10, app.).

Riparian areas—Riparian zones are recognized as fundamentally important interfaces between aquatic and upland terrestrial ecosystems. Functionally speaking, riparian areas are three-dimensional zones of interaction between terrestrial and aquatic ecosystems that extend outward from the channel to the limit of flooding and upward into the canopy of streamside vegetation (Swanson et al. 1982). Riparian vegetation provides wildlife habitat, promotes bank stability, assimilates nutrients from groundwater and streamwater, influences the climate in streams and riparian areas, and filters sediment and debris transported by surface runoff (Smith et al. 1997, Swanson et al. 1982). 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. Within a specific watershed, habitat organization can be viewed as a nested and branched spatial hierarchy. The dynamic nature of riparian areas results in substantial habitat heterogeneity and microsite complexity, resulting in a greater diversity and abundance of wildlife and vascular plants than in adjacent upslope habitats (Naiman et al. 1993).

Timber harvest can affect stream ecosystems by altering hydrological patterns, stream temperature and solar insolation, habitat complexity, organic debris delivery and accumulation, sedimentation, and channel morphology (Smith et al. 1997). 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 (Bisson et al. 1992). It is often difficult, however, to predict how a particular aquatic-riparian ecosystem will change following a management activity. Intensive timber harvesting and associated road construction are among anthropogenic factors linked to declines in diversity and abundance of salmonid species throughout the Pacific Northwest (Reeves et al. 1993).

The ACS, developed as part of the Northwest Forest Plan (USDA and USDI 1994b), established riparian reserves totaling 3.2 million ac (13 percent) of the federal lands within the range of the northern spotted owl (*Strix occidentalis*). Under this strategy, riparian reserves are used to maintain and restore riparian structures and functions of intermittent streams, confer benefits to riparian-dependent and associated nonfish species, enhance habitat conservation for organisms that are dependent on the transition zone between upslope and riparian areas, improve travel and dispersal corridors for many terrestrial animals and plants, and provide for greater connectivity of the watershed (Christensen 1997, Gregory 1997). A tall order. The width of the riparian buffers are approximately 150 to 170 ft (dominant height at 50 years) on each side of the stream. However, the scientific basis for determining the proper buffer width is weak (NCASI 1999). Estimates of buffer width necessary to protect various riparian functions generally remain uncertain, but definitely differ according to individual function (e.g., root strength, large woody debris delivery, input of organic nutrients, shade, microclimate, water quality, and wildlife habitat) (Smith et al. 1997). Therefore, delineation and management of riparian buffers need to be tied to specific objectives because individual species needs differ widely. Seemingly academic considerations such as buffer width can have a profound impact on the management of forest resources, for the majority of the productive land base can be in riparian reserves (e.g., 85 percent of the Siuslaw National Forest). The point of this discussion is not to advocate for studies on the best choice of buffer width but rather to emphasize the value and importance of finding compatible solutions that increase the societal values produced within riparian systems. Through silvicultural manipulation, it may be possible to put some riparian vegetation on a trajectory that will meet ACS objectives sooner than if not treated, while allowing for some wood production.

Biological diversity and water quality concerns are not limited to anadromous fish-bearing streams. Headwaters account for the largest percentage of streams in mountain drainage systems, and water quality begins upslope (Jones and Raphael 1997). Although mountain channels provide important aquatic habitat, supply sediment to downslope systems, and transmit land use disturbances from headwater areas down through drainage networks, they have received relatively little study compared to lowland rivers (Montgomery and Buffington 1997). Because these upland areas are also where active forest management is likely to be permitted, research is needed on the interaction of silvicultural manipulation of upland forests and the adjacent riparian zones. Furthermore, research with digital elevation models (DEMs) indicates that the accuracy of many underlying maps (see Reutebuch and Carson 1997) often is not sufficient to allow for precise location of headwater streams of class 3 and 4.[1] In fact, few studies of DEM accuracies (i.e., projections measured against independent ground measurements) have even been reported in the literature. A spatially sensitive watershed analysis would be severely handicapped by an inability to locate the upper reaches of stream systems.

Christensen (1997) lists 21 studies currently in place addressing various research problems associated with riparian areas. Good work is clearly underway. Few of the studies, however, are interdisciplinary to the point that the joint production of both wood and some additional key riparian value are examined. Christensen (1997) goes on to list seven riparian research gaps:

- Information on the structure and dynamics of riparian stands and their role in larger landscapes.
- The design and function of riparian reserves.

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[1] Reutebuch, S. 1998. Personal communication. Research forester, U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory, 4043 Roosevelt Way NE, Seattle, WA 98105-6497.

- The interaction of riparian and upslope vegetation and wildlife communities.
- The role of large-scale disturbance in the management of aquatic and riparian resources.
- The appropriate mix of stand ages, structures, and riparian forest conditions at watershed and subdrainage scales.
- A decision process that determines appropriate riparian silvicultural treatments and prioritizes riparian areas receiving management action.
- A riparian classification system and cost-effective, statistically sound monitoring methods.

Wildlife and aquatic habitat—The health and conservation of threatened wildlife species, such as the northern spotted owl and marbled murrelet (*Brachyramphus marmoratum*) have emerged in the past decade as major drivers of forest land management policy (e.g., USDA and USDI 1994a). Because the spatial requirement (home range) of wildlife increases greatly with animal size and mobility, it is difficult to design and implement sound experiments on the effects of silviculture on medium and large vertebrates by using stand-level designs. We can study songbird use of forest stands, but their populations are dependent on many factors other than stand condition, especially for the many Neotropical migrants.

Similarly, we can study raptor use of snags or other habitat components, but we cannot conclude that increasing snags will increase populations.[2] To study animal density and reproductive success, it is necessary to have experimental units greater in area than the home range. Accordingly, experiments with a wildlife component usually concentrate on smaller animals. In some cases, the size of these animals' home ranges determined the minimum size of the treatment units in a silvicultural experiment (e.g., 40 ac in DEMO (demonstration of ecosystem management options); see Aubry et al. 1999). Often, there are either key species in the food chain (e.g., northern flying squirrel (*Glaucomys sabrinus*)—an important species in the diet of the northern spotted owl) or indicators of ecosystem health and biodiversity.

Wildlife habitat and aquatic conservation have received strong emphasis in both the Northwest Forest Plan (USDA and USDI 1994b) and the Tongass land management plan (USDA Forest Service 1997a, 1997b, 1997c). The focus is often on the habitat of key species (e.g., salmon (*Oncorhynchus*), northern spotted owl in west side, deer (*Odocoileus*) in southeast Alaska) because of the difficulty of determining their population dynamics (e.g., abundance, reproduction, survival) (fig. 6). Recently, the importance of major disturbances such as floods and landslides for long-term health of aquatic systems has been emphasized by Reeves et al. (1995). Increasing attention is being paid to monitoring and studying woody debris from an ecological rather than purely fuel-loading point of view (e.g., density management study, Olympic habitat development study).

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[2] Harrington, C. 1998. Personal communication. Research forester, U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory, 3625 93rd Avenue, Olympia, WA 98512-9193.

Figure 6—Sitka deer and associated habitat are major subsistence issues in southeast Alaska.

Knowledge gaps—Needed information includes relations between overstory manipulation and silvicultural trials on the riparian system and wildlife habitat, and modeling the complex linkages between forest stands and streams composing a given watershed. Little is known about secondary species that are not listed as endangered or crucial for subsistence hunting and fishing. Little is known about the relation between silviculture and nontimber resources such as the key linkage between wildlife habitat and aquatic condition. A preliminary report[3] on the density management study (fig. 7) indicates that sampling methods for the two main constituents (riparian vertebrates and microhabitat conditions) of the study were conducted nearly independently, resulting in weak linkages both in time and space, which will greatly increase the uncertainty of conclusions.

Biodiversity—The past decade has seen the ascendance of biodiversity as an indicator of forest health in Northwest forests. The Northwest Forest Plan puts strong emphasis on promoting biodiversity in the process of managing for the protection of endangered species and old growth (FEMAT 1993). Reid and Miller (1989) define the conservation of biodiversity as the management of human interactions with the variety of life forms and ecosystems so as to maximize the benefits they provide today and maintain their potential to meet future generations' needs and aspirations. Carey (1994) contends that artificial conflicts between conserving biodiversity and maintaining wood production disappear if it is recognized that the conservation of biodiversity is the foundation for sustainable forestry.

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[3] Cunningham, P. 1998. Personal communication. Biometrician, U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331.

Figure 7—Fisheye image for measuring amount of shade over streams in the density management study of riparian areas (photo by Sam Chan).

Focusing on the goal of increasing and maintaining biodiversity, Carey (1994) proposed a biodiversity pathway for forest management based on comparisons of biotic communities in old growth, young natural stands, and managed forests. This proposal is based on (1) conserving biological legacies during harvest and regeneration, (2) minimizing time in the stem exclusion stage of stand development, (3) ensuring diversity and niche diversification in later stages through thinnings and coarse woody debris management (logs and cavity trees), and (4) using extended rotations of 90 to 130+ years on a significant portion of the land base (Curtis and Carey 1996). Basically, these practices are designed to speed the development of old-growth characteristics while maintaining a flow of wood products through thinnings. Based on an examination of the literature, Carey et al. (1996) concluded that forests actively managed for biodiversity could support virtually all wildlife species occurring in western Washington, and was better than traditional timber management for species as diverse as elk (*Cervus elaphus*), pileated woodpecker (*Dryocopus pileatus*), and the northern spotted owl. In addition to producing nontimber values and maintaining biodiversity, the approach is capable of jointly producing substantial timber outputs.

Biodiversity is a rather old ecological concept. A 20-year old review by Dennis et al. (1979) found over 1,000 publications. A rich literature notwithstanding, there is little agreement on how to reliably measure this abstraction (see Grassle et al. 1979). Basically, a diversity index is a measure of qualitative dispersion of a population of individuals belonging to several qualitatively different categories (Pielou 1982); in ecology, these categories are usually species. In the same way that the standard deviation or the range measure quantitative variability of a population, diversity indices measure qualitative variability (Pielou 1982). Three classical measures of biodiversity have been widely used in the ecological literature: species counts (a.k.a. species richness), the Shannon index, and the Simpson index (Patil and Taillie 1979). The first, species richness, is elegantly simple and captures the most fundamental aspect of an ecological community's diversity (Pielou 1982).The latter two indices are based on different functions of the relative abundance of each species.

Recently, the meaning of biodiversity has expanded in the Pacific Northwest to include abiotic elements such as snags and woody debris, and structural elements such as multiple canopy layers, legacy trees from the previous stand, and a heterogeneous stand structure (e.g., Carey et al. 1996, Parminter et al. 1995). Process-based definitions such as IUCN (1991) and Reid and Miller (1989) are appealing in their generality but difficult to measure and index (but see Carey 1994). Zeide (1998) contends that the concept of biodiversity may be indefinable in principle and therefore meaningless because it encompasses the total abundance of organisms, species, populations, communities, and their environments, together with all their complex interrelations. The DEMO study (Halpern and Raphael 1999) is one systematic research effort at an operational scale that has as a primary objective the effects of green-tree-retention harvests on biodiversity (fig. 8). As a result of the external scientific review of the DEMO study plan, biodiversity components addressing canopy invertebrates (see Progar et al. 1999) and ectomycorrhizal fungi (Cázares et al. 1999) were incorporated to strengthen the study.

Knowledge gaps—Smith et al. (1997) list the following tasks to fill gaps in our knowledge of management for biodiversity in young stands: quantify the functional significance of old-growth legacy components for maintaining native biodiversity in young forests; quantify the functional significance of hardwoods for wildlife, and determine appropriate mixes and spatial arrangements of hardwoods and conifers; document the spatial and temporal effects of management on a broad range of plant and animal species; accelerate development of old-growth characteristics in young stands; determine the effect of habitat patches and corridors on the long-term population dynamics of both plant and animal species; develop simulation models that project the effects of young-stand management on the development of stand and landscape structure as well as the status of animal populations over long timeframes and spatial scales; and determine important species-habitat associations for maintaining biodiversity and ecosystem integrity.

Economic analysis—Wood production and quality. Analyses have been primarily on Douglas-fir management in western Washington and Oregon, with a focus on traditional wood products and mill recovery. Regional economic analyses are strong on the supply side. There is a long history of forest management in the region by industry and governmental agencies.

Knowledge gaps—Little is known about managing secondary species, especially western hemlock and red alder (*Alnus rubra* Bong.). An important gap is emerging regarding young-growth wood quality relations to silviculture and market requirements, especially for the limited markets in southeast Alaska. Economic analyses are often site specific, with little insight on how to generalize. Landscape distribution

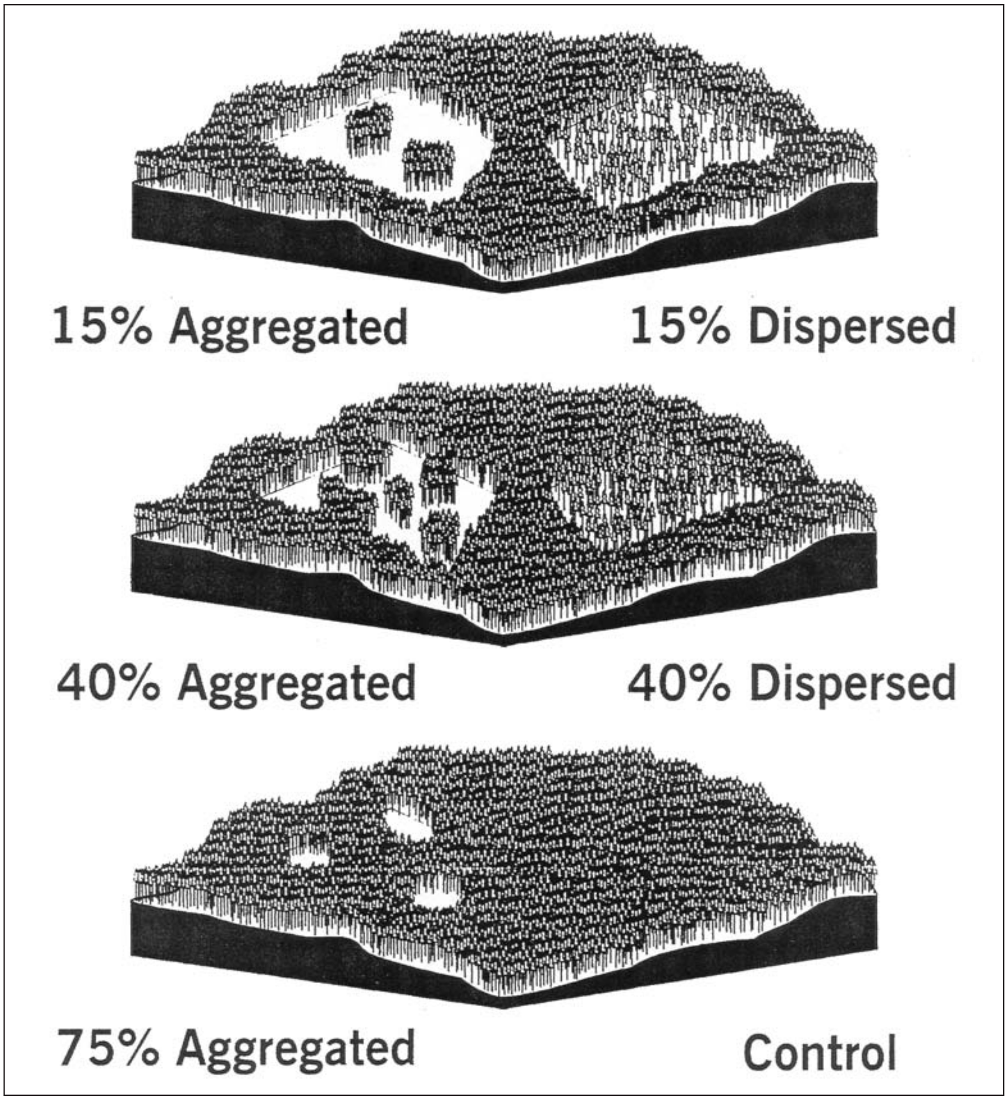

Figure 8—Green-tree retention harvest treatments used in demonstration of ecosystem management options study (Aubry et al. 1999; figure by Ken Bible).

and regional variation in wood quality are poorly understood. Regional analysis of the implications of changing timber quality and quantity on local and regional economies is lacking.

In the FEMAT process, the assumption was made that the timber economy would adjust to reduced harvest volumes from federal land by switching to manufacture of value-added products (Barbour 1998). This assumption failed to consider the question of quality of raw materials. Much of the volume to be removed from federal land will come from thinnings in young plantations, and a large proportion of timber cut from private land will come from the youngest merchantable age classes. Neither of these resources lends itself well to secondary products such as composite structural members (Barbour 1998).

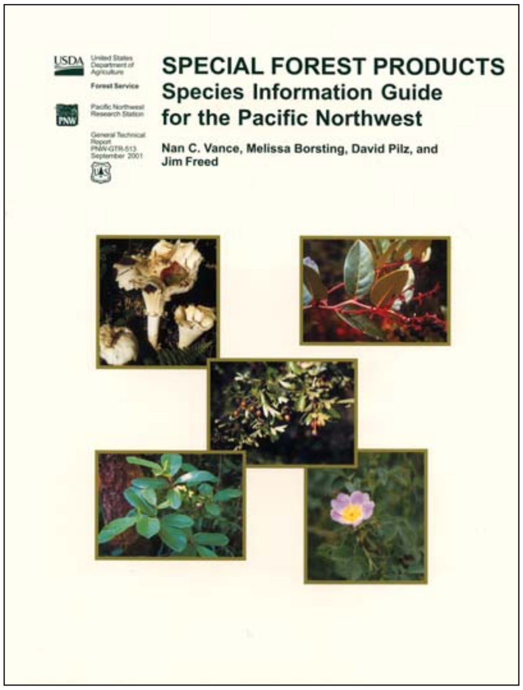

Figure 9—Special forest products are highlighted in a species information guide.

Nontimber forest products (NTFPs)—These are items gathered from the forest that have spiritual, subsistence, or market value (Molina et al. 1997). Many NTFPs have been harvested for as long as people have lived in and near forests. In the Pacific Northwest, commercial exploitation of NTFPs began early this century and includes mushrooms, medicines, floral greens and boughs, berries, nuts, and Christmas trees (Everett 2001, Vance et al. 2001) (fig. 9). In the last two decades, interest and market demand increased in some market sectors (Freed 1997); the market for medicinal herbs has increased for a number of herbal species as people seek alternatives to conventional Western health care (Brevoort 1998, Everett 2001). Land managers and landowners often perceive NTFPs as more easily renewable than timber, failing to recognize potentially destructive harvest activities (Vance et al. 2001). In the Pacific Northwest, a run on Pacific yew (*Taxus brevifolia* Nutt.) bark for cancer treatment in the early 1990s required passage of the Pacific Yew Act of 1992 to limit the felling of this slow-growing late-successional conifer (Molina et al. 1997, Vance 1995).

Knowledge gaps—Vance (2002) describes the effort at addressing knowledge gaps by scientists in the Pacific Northwest at the PNW Research Station, listing among the outputs 49 publications between 1992 and 1997. The complex biology and lack of information on harvesting of special forest product species present a significant challenge for integrative ecosystem management (Molina et al. 1997). Numerous federal and state laws exist to protect forest resources. Under strong environmental regulations and in a litigious climate, resource managers require substantial data to support management decisions. Unfortunately, baseline data on the effects of harvest, on markets, and on the biology, ecology, and productivity for many special forest product species are short term, incomplete, or nonexistent (Molina et al. 1997, Vance et al. 2001). Although legislation in 2000 via the Department of the Interior appropriations bill and the national strategy for special forest products in 2001 have acknowledged that regulated access to NTFP resources should be encouraged, the USDA Forest Service lacks needed information on what constitutes sustainable harvest of these resources to conduct significant permitting and monitoring in any consistent way. These species have important ecosystem functions, such as providing food and cover for wildlife and beneficial insects, and capturing and cycling nutrients. Yet, we poorly understand these complex dependencies, and the effects of harvesting special forest products on ecosystem function and integrity are largely unknown (Molina et al. 1997, Vance 2002). Understory plant reproductive biology, quality, and abundance are key because of the linkages to wildlife habitat, aquatic conservation, and maintenance of forest complexity.

Social values and compatibility—The social acceptability of forest management is complex, with a critical dimension being how timber harvests are visually perceived (Gobster 1994, Ribe 1999). Visual perceptions of acceptability often tend to derive from aesthetic reactions (Nassauer 1992). These perceptions are generally understood to be a primary cause of public reactions to forest management (Ulrich 1986). Some progress in understanding social acceptability is being made, however. Recent advances in stand visualization systems (SVS) by McGaughey (1997) provide a new tool for allowing social scientists to experimentally examine the relation between people's visual preferences and simulated forest management scenarios.

The tradeoff between negative public perceptions and silvicultural benefits of clearcuts is a long-standing dilemma in forest management (Horwitz 1974). Working with the DEMO experiment, Ribe (1999) examined whether vista views of the 15-percent minimum retention standard now prescribed by the Northwest Forest Plan might offer some resolution. The results are not very encouraging. It appears unlikely that any pattern of 15-percent retention will be seen by viewers as any more acceptable than clearcuts. Scenic beauty perceptions may instead be improved if the aggregated clumps of retained trees are designed to minimize the visual magnitude of openings in the forest canopy (Iverson 1985). Ribe (1999) notes that information about forest harvests can influence perceptions of scenes including such harvests. He suggests that managers should pay attention to not only appearance but the "appropriateness" of landscapes, as proposed by Gobster (1996). Ribe (1999) concludes that such an integrated approach might produce more socially acceptable forest landscapes than the fragmented landscapes that arise from traditional, reductionist planning where each resource, including visual quality, is separately understood and competitively suboptimized (Hirt 1994, Kimmins 1992).

Sociologists view compatibility as inherently a human judgment.[4] Judgments are based on many factors, including world view, knowledge, and belief system. A variety of social values and uses can be considered in order to evaluate compatibility:

- Commodity values: timber, range, minerals, water.
- Amenity values: wildlife, scenery, lifestyle.
- Environmental quality values: air and water quality.

[4] Clark, R. 1998. Personal communication. Research social scientist, U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory, 4043 Roosevelt Way NE, Seattle, WA 98105-6497.

- Ecological values: biodiversity, habitat conservation, threatened and endangered species.
- Public use values: recreation, tourism, subsistence, gathering.
- Spiritual values: sacred places.
- Health values: medicines.
- Security values: sense of social continuity and heritage.

These myriad values lie at the center of the forest management debates across the region and Nation.

People's judgments of what constitutes acceptable and compatible forest management practices are influenced by many things:

- What they know and believe about forests and their uses.
- Whether they trust professionals and agencies, and the information they provide.
- Whether they understand the intent of the proposed action (e.g., Can they visualize it?).
- What they value about the area under consideration.
- How they believe proposed changes will affect forests and special places.
- What expectations they have for how forests should or should not be managed.
- What role they have in the decision process.

Because **recreation** is probably the most studied social value, R. Clark (see footnote 4) used it as a case example suggesting propositions that might be considered along with biophysical questions in developing an integrated research program:

> Whether intended or not, almost all forest management activities affect recreational opportunities and uses. The effects are not necessarily negative, and depend largely on the preferences and expectations of recreationists. The overriding question is: Under what condition can diverse recreation values and uses be integrated with various resource uses, such as wood production? How can research and management be designed up front to account for such interrelations?
>
> There are several research questions to consider when attempting to improve understanding of interactions between recreation and timber harvesting (e.g., where and how recreation options might be created, maintained, or enhanced). The range of compatible options in any given area might include (1) silviculture for recreation without timber as a consideration, (2) silviculture for recreation with timber as a byproduct, (3) silviculture for both recreation and timber, (4) silviculture for timber with recreation as a byproduct, and (5) silviculture for timber without recreation as a consideration. Each of these options requires information about existing and potential site attributes and uses, as well as recreationists' patterns, demands, preferences, and needs. Understanding of when and how recreation can be integrated with other resources requires identification of potential determinants of conflict and compatibility early in the process. Forest conditions (from stand to landscape) change through time and may provide different benefits for different people at different times. Some existing and

potential users may be inadvertently disenfranchised unless we understand what the forest is providing, when, and for whom, and how other forest uses may affect these relations.

Knowledge gaps—We need improved understanding of dynamic relations linking values and beliefs to the determination of institutional objectives, policies, and goals, as affected by forest management. Because compatibility between wood and other values is primarily a problem of social acceptability, this gap is fundamental.

Synthesis and Integration Plan for the Initiative

Rules for determining the compatible production of wood and several major forest resources have not been demonstrated. Macroeconomists have developed forest sector models that attempt to quantify the tradeoffs between resources (Kallio et al. 1987, Nabuurs et al. 1998). Such exercises often focus on two-dimensional joint production functions, and usually only for market-driven outputs. Our problem is more complex (the interaction of wood production with wildlife, aquatics, biodiversity, and social values). Furthermore, forest sector modelers have traditionally abstracted the output from all forest ecosystem processes into simple averages. Ideally we would incorporate process details while retaining the ability to aggregate to higher scales of analysis. Such a problem is clearly researchable, albeit difficult. Even limited success should provide important and useful results for the future management of forest resources in the Pacific Northwest and southeast Alaska.

We are not without help. The CLAMS team (Spies et al., in press) (app. table 10) in Corvallis, Oregon, has mounted a coordinated multidimensional analysis of major factors affecting current forest policy at the province scale (the Oregon Coast Range). Their experience should save us valuable time, especially in the synthesis and integration of knowledge relating to scale issues. Internationally, Fedra's International Institute for Applied Systems Analysis (IIASA) team has considerable experience in multidimensional regional analysis (Fedra et al. 1991), but they have not attempted to bridge the joint compatibility of ecological and social systems.

Effective synthesis and integration in large research programs is frequently an elusive goal. The multidisciplinary nature of the research might increase the difficulty of system integration, but it alone is not the problem; the problem is the failure to organize and integrate from the beginning. System integration is especially difficult in biological, social, and economic sciences, where strong theories are lacking and science has often been reductionist. Scientists can still concentrate on testing hypotheses in their field while collecting the minimal data needed to link their results to those in other disciplines. Successful completion of the Wood Compatibility Initiative requires a general framework (figs. 1 to 3) unifying the broad suite of values spanning aquatic conservation, water quality, wildlife habitat, social acceptability, and the production of both wood and nonwood commodities and values. It is crucial that (1) the relations between management actions and the resulting mix of outputs and values be determined, as well as (2) the associated tradeoffs relating these numerous values. This requires a state-of-the-art organization system for tracking and categorizing information relevant to the compatibility issue. It also requires that functional relations among processes and outcomes be explicitly stated, and that some measure of reliability be placed on each functional relation. For all of these tasks, we will examine the utility of a knowledge-based decision support system as a critical synthesis and integration tool (Reynolds et al. 1997).

Knowledge-Based System

A knowledge base can (1) efficiently organize and store all relevant information within and among the main disciplines, (2) evaluate the truth of a given hypothesis or proposition, and (3) provide a trace of all logical connections, assumptions, and data used to test the proposition. The ecosystem management decision support (EMDS) system used by Reynolds et al. (1997) has several advantages: it combines the Netweaver[5] paradigm (knowledge base plus fuzzy logic) with the ArcView geographic information system, operating in a Windows environment. The resultant product allows for evaluating alternate management plans (propositions) with the geographic realism needed for both watershed and regional analysis. The advantage of fuzzy logic is that missing data can be tolerated, and the degree of "truth" can be determined continuously. This allows for an objective comparison of tradeoffs among the available suite of values produced under a given management regime.

The Netweaver component of EMDS could be used to develop a prototype knowledge base that will synthesize and integrate key information and relations linking all of the main disciplines and values. Three scales need to be examined: fine (watershed/stand), intermediate (landscape/province), and regional (western Washington and Oregon).

Systems Approach: Local to Regional

The research challenge is to develop a regional model that is sufficiently sensitive to local conditions and management while reflecting midscale context and broad-scale policy goals. This requires both stand and watershed modeling, as well as regional systems modeling. Developing proper linkages across different resources and spatial scales is crucial. The resulting set of commodities and outcomes will be evaluated for compatibility between wood production and other important values (e.g., fish, wildlife, recreation, biodiversity). The determination of key variables linking disciplines such as silviculture, wildlife biology, and hydrology should be apparent from the research framework (e.g., fig. 1) that will eventually be developed into a full systems synthesis model as long-term studies are established and short-term studies are completed. An integrating framework should facilitate the development of a multidisciplinary research program that not only addresses these numerous values but ensures that associated tradeoffs linking them will be examined as well.

Stand Modeling

Stand modeling will be an important tool. We need traditional projections of the yield from silvicultural alternatives. We also need predictions of the physical structure and composition of the vegetation for estimates of wildlife habitat, aquatic condition, scenic quality, and recreation potential, to name a few. Understory structure and composition will be needed for several of these. Such stand model projections will be tools for aggregating to larger scales (e.g., watersheds).

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[5] 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 10—Monitoring stream quality as part of riparian characteristics in the density management study. (photo by Sam Chan)

Because many of the alternatives we will be examining are not plantation management, we must consider models that can handle more than the common pure even-aged stand condition. This has led us to consider the variants of FVS that cover western Oregon and Washington and southeast Alaska. To begin, we would like to examine the utility and accuracy of these FVS variants, especially regarding overstory development, understory structure and composition, response to stand treatment, and compatibility with stand visualization. A considerable advantage of FVS is that it is the corporate model for stand projection in the USDA Forest Service.

The CLAMS program (Spies et al., in press) has had success with an ecological gap model, Zelig. Comparison of the accuracy and utility of Zelig and FVS would be fruitful, although conceptual differences between these disparate classes of models have been well documented in the literature (Shugart 1984).

Watershed Modeling

Watershed modeling will be necessary to evaluate midscale spatial effects. It has become increasingly apparent that stands cannot be managed wisely and efficiently in isolation (Sachs et al. 1998). For example, it is not useful to try to determine the overall effects of silvicultural manipulation in a watershed by considering stands independently. We are especially interested in the linkage between stands and the streams that share a given watershed, as well as habitat assessment (fig. 10). Watershed analysis is a potentially powerful tool that could allow for a comparison of management alternatives at the watershed scale. The Augusta Creek disturbance scenarios are a powerful example of novel insight that can be gained from watershed-level modeling (Cissel et al. 1998).

Because of the multiple ownerships common in western Oregon and Washington forests, one of the most promising classes of land for study at the watershed level is the adaptive management area (AMA). The AMAs are large enough for replication of smaller watersheds. With standard randomization and replication of treatments, good science could be done within the otherwise restrictive record of decision guidelines. Because of its concordant drainages, the Cispus AMA would be an excellent candidate for experimentation. An additional advantage is that the stand data and management unit structure on the Cispus are already formatted for projection by FVS, and for visualization by SVS and a companion tool called UTOOLS (Ager and McGaughey 1997, McGaughey 1997). The advantage of a modeling unit the size of an AMA is that it is large enough to reflect midscale spatial effects, yet small enough to incorporate considerable inventory detail at the fine scale.

Ecoregional Modeling

Ultimately, we need to examine scenarios comparing management alternatives at the regional scale. Forest harvesting can fundamentally alter landscape patterns, with potential impacts on biodiversity, regional hydrology, and certain wildlife populations. Compatibility itself is inherently a large-scale concept that cannot be properly evaluated by looking at a series of stands or even watersheds in isolation. This requires proper linkages not only across key disciplines but among at least three scales: stand (fine scale), watershed (midscale), and regional (large scale). The complexity of this latter task is enormous. Some of the world experts in regional ecological analyses make up the IIASA team (e.g., Fedra et al. 1991). Their strength lies in a strong graphics interface based on a functional representation of key processes. Displays are simultaneously regional and local, with rich detail on state variables.

The proper management of large areas requires data that must be consistent and complete (Sachs et al. 1998). Data acquisition is obviously a major problem in regional analyses, and can severely limit the choice of hypotheses that can be examined. Satellite remote sensing provides some relief, provided that the resource of interest can be detected by the sensors. Recently, nearest-neighbor methods are being developed in an attempt to bridge the gap between complete census data and more common sample-based data. If a map of key resources cannot be drawn, then regional analyses will not be successful. As the number of holes (missing data) in the map increases, the credibility of the regional analysis decreases.

Two broad paradigms are available for large-scale regional analysis: bottom-up (aggregation of fine-scale data), and top-down (disaggregation). Because of the near impossibility of obtaining a complete regional data set of key processes and resources by aggregating fine-scale data, the bottom-up modeling approach is problematic for regional analyses. Most environmental scientists prefer fine-scale studies (reductionist) that attempt to isolate the sources of variability on one or a few important processes. This produces highly detailed information on very few locations that cannot be extrapolated to the landscape. Top-down methods such as forest sector models suffer from the disaggregation problem that arises from ignoring variability. They force strong and restrictive assumptions to ensure regional coverage of key resources. The lack of information on fine-scale processes, however, will limit the flexibility and depth of hypotheses that can be examined regionally.

Regional analyses then require complete data on key resources. This data must be organized in a coherent manner for analysis (GIS), and the data must correspond to the important hypotheses and policies being examined. If no data on a key process are available (e.g., response to a climate change scenario), then no statement can be made about the effect of alternative management plans or policies on that aspect of the resource.

Visualization

We need to be able to communicate visually the integrated predictions of a series of alternate management actions. The focus is on developing software that can display relevant detail at the stand and watershed level. The SVS and UTOOLS products of McGaughey (1997) should provide needed topographic realism to evaluate alternate management strategies. Visualization is also needed for evaluating the effects of management on recreation and visual quality, especially from a variety of vantage points and perspectives.

Publication of a Synthesis from the Problem Analysis

Products of the problem analysis will be a conceptual model of the research necessary to begin addressing the policy and research questions, a summary of the research available to date, and tentative conclusions of what can be learned from the already available research information about the research hypotheses. Information will be synthesized into a report examining the issues of compatible production of wood and other key resources. The initial report will focus on the state of knowledge and associated knowledge gaps.

Metric Equivalents

When you know:	Multiply by:	To find:
Acres (ac)	0.405	Hectares (ha)
Feet (ft)	.304	Meters (m)
Square feet per acre (ft^2/ac)	.229	Square meters per hectare (m^2/ha)

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Appendix 1: Ongoing Operational Stand-Level Silvicultural Experiments

These stand-level silvicultural experiments have a primary or secondary focus in addition to wood production.

Table 3—Alternatives to clearcutting stand management experiment in Alaska

	Residual density levels (basal area percentage)				
Outcomes	**All (100)**	**High (75)**	**Medium (50)**	**Low (25)**	**None (0-5)**
Wood[a] and wildlife[b]	x	x	x	x	
Wood and aquatics[c]	X	X	X	X	
Wood and biodiversity[d]					
Wood and social[e]					
Wood and economic[f]	x	x	x	x	

X = major focus, x = minor focus.
[a] Wood production is the primary focus. Design is 9 treatments x 3 blocks: clearcutting with and without reserved trees (0 and 5 percent residual basal area); single-tree selection (25 and 75 percent), clump and gap group selection (25 and 75 percent), uncut control (100 percent). Three spatial patterns of retained trees will be tested at 25 and 75 percent retention levels: uniform dispersal, clumps within a uniform matrix, and gaps within a uniform matrix.
[b] Wildlife studied: songbirds.
[c] Aquatic variables: hydrology; slope stability; water quality; snow accumulation and melt; head-water stream ecology.
[d] Biodiversity measure: biological legacies retained.
[e] Social variables: visual quality and social acceptance component to be added later.
[f] Economic measures: helicopter logging; hemlock dwarf mistletoe; harvest-related wounding and windthrow.
Source: McClellan et al. 2000, USDA Forest Service 1994.

Intent of the study: Test alternate silvicultural systems that lead to forest structures similar to old-growth forests. Only helicopter logging is used on all treatments. The major emphasis is on silviculture, hydrology (especially slope stability), and stream ecology. It is a stand-level study with a completely randomized design with replicated blocks. Treatment areas are large, approximately 45 ac, to reflect operational sizes. Three residual stand factors will be tested: stand density, tree spatial pattern, and patch size.

Table 4—Capitol Forest study: Washington Department of Natural Resources stand management experiment

	Residual density levels (basal area percentage)				
Outcomes	All (100)	High (75)	Medium (50)	Low (25)	None (0)
Wood[a] and wildlife[b]	x	x		x	x
Wood and aquatics[c]					
Wood and biodiversity[d]	x	x		x	x
Wood and social[e]	X	X		X	X
Wood and economic[f]	X	X		X	X

X = major focus, x = minor focus.
[a] Wood production is primary. The regeneration system design includes a clearcut, small patch cutting, retained overstory (shelterwood without subsequent removal), group selection, and extended rotation with commercial thinning. Thinning in young production stands is intended to enhance development of late-seral attributes and wildlife benefits on the extended rotation trial area.
[b] Wildlife studied: leave-tree selection for wildlife, small mammals, diurnal birds, seed production for wildlife, use of canopy gaps by bats, amphibians in coarse woody debris and riparian areas.
[c] Aquatic variables: amphibians.
[d] Biodiversity measures: ground layer/soil processes including vascular plants, mycorrhizal fungi, soil food web, special forest products (plants and mushrooms).
[e] Social variables: public response to visual appearance. The study emphasizes developing rules for visual management to guide managers in selecting silvicultural options for visually sensitive landscapes.
[f] Economic measures: economics of thinning operations and all treatments and management including detailed breakdown of costs.
Source: Curtis 1996, Thysell et al. 1997.

Intent of the study: Focus is on the development of late-seral attributes in young production-forest stands through thinning and silvicultural systems. The emphasis is on the interaction between thinning and (1) wildlife, (2) ground layer/soil processes, and (3) visual appearance. Economic assessments are integral and focus on an evaluation of tradeoffs leading to the most efficient silviculture for wood production while providing acceptable levels of other public values. Stand-level components will be projected to the landscape level, especially for visual acceptance. Harvest units are operational sizes—15 to 80 ac—each replicated three times in a randomized block design. Use of McGaughey’s stand visualization system is a key tool.

Table 5—Demonstration of ecosystem management options (DEMO) study—stand management experiment

	Residual density levels (basal area percentage)				
Outcomes	All (100)	High (75)	Medium (50)	Low (25)	None (0)
Wood[a] and wildlife[b]	X	X	X	X	
Wood and aquatics[c]					
Wood and biodiversity[d]	X	X	X	X	
Wood and social[e]	X	X	X	X	
Wood and economic[f]					

X = major focus, x = minor focus.
[a] Wood production is the primary objective. The focus is on different amounts and patterns of green-tree retention. The specific thinning design includes three levels of patch cuts, two levels of dispersed thinnings, and an uncut control. There was only one entry, so the long-term silviculture value has not been determined.
[b] Wildlife measures: patterns of species richness and abundance of vertebrates (birds, arboreal rodents, small terrestrial mammals, bats, and amphibians) in response to the amount and pattern of overstory removal.
[c] Aquatic/hydrology measures: snow-melt and rain-on-snow dynamics with respect to partial canopy densities—one block only.
[d] Biodiversity measures: community structure and dynamics of ectomycorrhizal fungi; canopy invertebrates; understory vegetation, including herbs, shrubs, and tree regeneration; snags and coarse woody debris. Biodiversity is a strong focus in this study.
[e] Social measures: forest harvest intensities most acceptable to the public (including why, for whom, and under what circumstances).
[f] Economic measures: dropped because of lack of funding.
Source: Halpern and Raphael 1999.

Intent of the study: Response to congressional direction to establish a “New Perspectives” demonstration in western Washington and Oregon of the effects and economics of alternative harvesting experiments on wildlife, vegetation, and hydrology. Little is known on the short- and long-term effects of varying disturbance levels on forest ecosystem structure and function. Goals are similar to those of the alternatives to clearcutting study but with different green-tree retention patterns. An information database system is being developed to support research needs.

Table 6—Density management study stand management experiment

Outcomes	Residual density levels (trees per acre)				
	All	High (120)	Medium (80)	Low (40)	None
Wood[a] and wildlife[b]	x	x	x	x	
Wood and aquatics[c]	X	X	X	X	
Wood and biodiversity[d]	X	X	X	X	
Wood and social[e]	x	x	x	x	
Wood and economic[f]	x	x	x	x	

X = major focus, x = minor focus.
[a] Wood production is primary. Control plus three density management treatments were assigned randomly to 50-acre parcels in management blocks. Treatments are high density (120 trees per acre [tpa]), moderate density (80 tpa), variable density (light to heavy, from 40 to 120 tpa). Different riparian buffer widths and streamside tree retention levels will be examined. Both outplanting and natural regeneration will be encouraged.
[b] Wildlife studied: Neotropical birds.
[c] Aquatic/hydrologic measures: aquatic habitats, fauna (fish and amphibians), and stream vertebrate assemblages in headwater systems, including dry channels to second-order streams (on 12 blocks). Four riparian buffer zone designs are examined: streamside retention (approximately 7 meters), variable width with 15 meters minimum, 1 potential-tree height, 2 potential-tree heights.
[d] Biodiversity measures: lichens and bryophytes, down and woody debris, microclimate gradient from stream to uplands (this is the only study examining microclimate gradient), understory vegetation (including natural regeneration).
[e] Social measures: public comment, tours, and involvement.
[f] Economic measures: none
Source: Olson et al. 1999.

Intent of the study: Evaluate alternate silvicultural systems that will accelerate old-growth characteristics (e.g., large trees, multiple vertical layers) and achieve biodiversity goals. The interaction of riparian stand composition and structure with associated upland thinning regimes will be examined, with specific emphasis on microclimate, microhabitat, woody debris, understory vegetation, natural regeneration, lichen and bryophyte development, amphibian response, aquatic habitats, and stream vertebrate assemblages in headwater systems. The focus is on 30- to 70-year-old stands.

Table 7—Olympic habitat development study stand management experiment in Washington

	Residual density levels (basal area percentage)				
Outcomes	All (100)	High (75)	Medium (50)	Low (25)	None (0)
Wood[a] and wildlife[b]	X	X			
Wood and aquatics[c]					
Wood and biodiversity[d]	X	X			
Wood and social[e]					

X = major focus, x = minor focus.

[a] Wood production is a secondary objective. Variable-density thinning was done in young production stands (30 to 70 years old) to enhance wildlife habitat: 10 percent of area is in uncut patches, 15 percent of area is in openings (small patch cuts), and 25 to 30 percent of basal area is removed. No regeneration harvests were included.

[b] Wildlife variables: forest-floor small mammals, amphibians, and vegetation communities, including an emphasis on seed and nut production for wildlife, and a pretreatment bat survey.

[c] Aquatic components: terrestrial amphibians.

[d] Biodiversity measures: coarse woody debris manipulation; accelerating development of a range of understory and midstory plants; legacies (snags left standing, uncut patches); lichens; light levels versus flowering of woody shrubs.

[e] Social variables: social and economic benefits to wood-dependent communities.

Source: Harrington and Carey 1997.

Intent of the study: Tests how management practices (e.g., variable-density thinning) can influence small-mammal populations over a wide range of stand and site conditions in 30- to 70-year-old stands. This is the only study that will examine possible benefits from manipulating woody debris and accelerating development of a range of understory and midstory plants in stands not receiving a regeneration harvest cut.

Table 8—Forest ecosystem study (Fort Lewis, Washington) stand management experiment

	Residual density levels (basal area percentage)				
Outcomes	All (100)	High (75)	Medium (50)	Low (25)	None (0)
Wood[a] and wildlife[b]	X		X		
Wood and aquatics[c]					
Wood and biodiversity[d]	X		X		
Wood and social[e]					
Wood and economic[f]					

X = major focus, x = minor focus.

[a] Wood production is primary. Treatments are based on residual relative density (RD), which is $RD = G/\sqrt{Dg}$, where G = stand basal area and Dg = quadratic mean stand diameter (Curtis 1982). Treatments include a control (residual relative density RD > 7, one experimental variable-density thinning (mix of 15 percent RD2, 35 percent RD4, 35 percent RD6, and 15 percent RD8), two traditional commercial thinnings (now RD7), and two commercial thinnings followed by one variable-density thinning. Treatments of control and variable density thinning were randomly assigned. Experimental blocks had different prior management: legacies with no thinning, and legacy removal with two commercial thinnings. No regeneration harvests. Treatments included underplanting with root-rot resistant and shade-tolerant species.

[b] Wildlife studied: forest-floor small mammals, arboreal rodents, winter birds, cavity creation and management (providing nest boxes, creating cavities in trees, and inoculating trees with top rot to produce cavities), and supplemental feeding to test hypotheses about cavities and food abundance. Special emphasis on northern flying squirrel includes study of population structure and density, den use, space use, and predation by weasels and owls in relation to silvicultural treatments.

[c] Aquatic measures: none.

[d] Biodiversity measures: truffles, mushrooms, soil food webs (ratio of fungal to bacterial biomass, composition of nematode communities), plant communities, and litter invertebrates. Half the stands had residual coarse woody debris components (large live trees, large dead trees, large decaying logs from the preceding stands), half had coarse woody debris removed.

[e] Social measures: none.

[f] Economic measures: none

Source: Carey et al. 1999.

Intent of the study: Test how management practices (e.g., variable-density thinning) can influence small-mammal populations (especially the flying squirrel) in 45- to 55-year-old stands. This is the only study that will examine possible biodiversity benefits from manipulating woody debris and accelerating development of a range of understory and midstory plants in stands not receiving a regeneration harvest cut.

Table 9—Long-term ecosystem productivity stand management experiment in Oregon and Washington

Outcomes	Residual relative stocking levels (proportion of the maximum density)				
	All (0.8-1)	High (0.8)	Medium (0.5)	Low (0.25-0.3)	None (0)
Wood[a] and wildlife[b]	x			x	x
Wood and aquatics[c]					
Wood and biodiversity[d]	X			X	X
Wood and social[e]	x			x	x
Wood and economic[f]					

X = major focus, x = minor focus.
[a] Wood production: This is a long-term site productivity study rather than a silviculture experiment. Four vegetation treatments are (1) clearcut followed by Douglas-fir planting, (2) clearcut followed by early seral natural regeneration and planting, (3) thinning to a relative stocking of 0.25-0.3 of the maximum density, and (4) control. Two organic matter (OM) treatments split evenly across the clearcut units: low OM treatment removed whole trees (with helicopter logging), all residual pieces >4 inches small-end diameter, and all pieces >10 feet long; high OM treatment removed all trees (whole tree helicopter logging) except for 15 to 20 percent, which were then felled and left on the ground.
[b] Wildlife studied: For large mammals, their preharvest use of the site is determined by estimating browsing activity. Presence in the stand is determined by making pellet counts. For small mammals, trapping surveys determine the species composition and distribution on the site. Bird populations are censused before and after treatment.
[c] Aquatic measures: none.
[d] Biodiversity measures: Detailed vegetation surveys before and after treatment, including percentage of cover by species and vegetation map by strata (overstory, shrubs, understory); insect species composition, with main focus on belowground processes.
[e] Social measures: social acceptance research by R. Ribe, University of Oregon.
[f] Economic measures: none
Source: Little et al. 2000.

Intent of the study: The question that drives long-term ecosystem productivity studies is: What factors, influenced directly or indirectly by management, most affect the long-term productivity of the land? This experiment seeks to evaluate 200-year effects of plant-assemblage and woody-debris changes on soil properties linked to productivity, and on actual net primary productivity and diversity of these assemblages. The hypothesis is that early-successional, pioneer plants build mineral soil organic matter and available nutrient pools, and improve soil structure that might sustain growth of Douglas-fir at older ages. Late-successional species are hypothesized to build litter layers and hold more nutrients in organic substrates. Fast-growing Douglas-fir monocultures are hypothesized to reduce mineral soil organic matter.

Appendix 2: Prototype of Large-Scale Integration and Analysis

Table 10—Coastal landscape analysis and modeling study (CLAMS) policy analysis of the coastal province (Oregon)

	Residual density levels (basal area percentage)				
Outcomes	**All**	**High**	**Medium[a] 110 to 150 ft^2/ac**	**Low**	**None**
Wood[b] and wildlife[c]	X		X		X
Wood and aquatics[d]	x		x		x
Wood and biodiversity[e]	X		X		X
Wood and social[f]	x		x		x
Wood and economic[g]	X		X		X

X = major focus, x = minor focus.
[a] Thinning differs by landowner: private nonindustrial owners are assumed to thin from above to 150 square feet per acre; all other landowners are assumed to thin from below to 110 square feet per acre. Thinning is characterized as an absolute target, not a percentage, so degree of intensity differs by initial density.
[b] Wood production is primary: The study consists of large-scale simulation and optimization analyses (no thinning trials, experiments, or installations). The intent is to mimic landowner behavior. Regeneration harvest differs by landowner: private industry lands end with a regeneration clearcut (50- to 60-year rotation); USDA Forest Service (esp. Siuslaw NF): no final regeneration cut; state lands (ODF): no decision yet, but rotation lengths will increase.
[c] Wildlife studied: predicted changes in abundance and distribution of terrestrial vertebrates over time and across scales; birds, including northern spotted owl, predicted as function of stand structure; anadromous fish as function of landform and habitat.
[d] Aquatic measures: The decision was made not to model water quantity and quality; however, watersheds are identified and mapped, and a model for the probability of landslide and debris flow is being developed.
[e] Biodiversity measures: biological diversity links to landscape/watershed condition, natural processes, and management policy. An attempt is made to link to social acceptance.
[f] Social measures: emphasis on accurately reflecting landowner behavior; recreation is addressed.
[g] Economic measures: constrained optimization (harvest scheduling) to determine net worth of current policy; a focus on log quality and valuation, and stand valuation; log flows and timbersheds.
Source: Spies et al., in press, and numerous workshop handouts.

Intent of the study: Develop and evaluate concepts and tools to understand patterns and dynamics of provincial ecosystems (specifically, the Coast Range of Oregon), and to analyze the aggregate ecological, economic, and social consequences of forest policies for different owners. Synthesis and integration of all major issues affecting policy is the major thrust of CLAMS. Spies: “The system is more important than any one component.” Strong emphasis is on incorporating economic and social factors into the analyses. Hierarchical scale issues (e.g., difficulty of identifying small watersheds) are crucial for generalizing from a stand/watershed up to the Coast Range province level.

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Web site	http://www.fs.fed.us/pnw
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Publication requests	(503) 808-2138
FAX	(503) 808-2130
E-mail	pnw_pnwpubs@fs.fed.us
Mailing address	Publications Distribution Pacific Northwest Research Station P.O. Box 3890 Portland, OR 97208-3890

U.S. Department of Agriculture
Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, OR 97208-3890