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A Basis for Understanding Compatibility Among Wood Production and Other Forest Values

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Abstract

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In the public debate over forest management, many issues are portrayed as tradeoffs between biophysical and socioeconomic components of ecosystems. This simplistic portrayal ignores potential opportunities for compatible changes in outputs (either goods or services) among alternative management strategies. In response, a research effort called the Wood Compatibility Initiative (WCI) builds on an extensive body of existing work to examine biophysical and socioeconomic compatibility of managed forests. In this paper, we introduce the conceptual model for the WCI, the scale of analysis, and the overall research strategy. After a short discussion on joint production, we provide examples of compatible wood production at each of four scales: stand, watershed-landscape, ecological province, and region level. These examples highlight the progress of WCI during the first three years (1998-2000). We then discuss our progress toward understanding compatibility. Four key research questions address the extent to which we may judge compatibility between wood production and other forest values. Finally, we present our strategy for synthesizing this broad collection of research information on compatible wood production.

Keywords: Joint production, compatible production, forest management research.

Contents

Overview

This paper summarizes the progress, during its first three years (1998-2000), of the effort at the Pacific Northwest Research Station to organize a wood compatibility initiative. It is divided into four major sections. First, we discuss the problem and approaches addressed by the Wood Compatibility Initiative (WCI) including plans for future synthesis work. Second, we briefly summarize joint production research in forestry. Third, we summarize examples of research that address compatible wood production at four spatial scales. Fourth, we synthesize existing work to answer several questions about compatibility.

The Wood Compatibility Initiative

The need for sustainable approaches to meet increasing demands on the forest has focused attention on an important question: “Can we as a society produce wood commodities and other forest values in an environmentally acceptable and sustainable manner?” Little scientific information is available, however, on the compatibilities, tradeoffs, and joint production possibilities between commodity production and forest values such as wildlife, water, aesthetics, and recreation that the public desires from our forests. Basically, this is a question about reaching and maintaining a desirable structure and function of a forest ecosystem under management. The question is not limited to wood production: On forested lands where wood commodities are not the primary value, will we need some silvicultural manipulation of the forest to sustain the noncommodity high-priority values (e.g., species conversion in riparian areas to improve aquatic conservation)? If so, will the management actions be economically feasible and socially acceptable? Fundamentally, we need scientific knowledge to evaluate the shifting balance between what society wants (values and associated tradeoffs) and what the biological system is capable of sustaining. Science contributes by quantifying the expected outcomes of relevant management alternatives, among different periods and at different spatial scales, along with their associated levels of uncertainty.

In the public debate over forest management, many issues are portrayed as tradeoffs between biophysical and socioeconomic components of ecosystems. This portrayal often leads people to focus on direct tradeoffs rather than on the possible opportunities for compatible changes in outputs (either goods or services) that exist among alternative management strategies. This debate process has become increasingly value-laden as people attempt to describe the links between management practices and sustainable forest production. It has led to an effort at the Pacific Northwest Research Station (PNW) to develop a greater understanding of potential compatibility among commodities, ecological, social, and cultural values.

The resulting research effort, the WCI, structures a research program from an extensive body of existing work. The WCI addresses two aspects of the compatibility issue. First, how do various forest management practices relate to an array of associated goods and services? Second, how do different approaches to forest management affect relatively large and complex ecosystems?

The purpose of the WCI is to explore options that may increase the compatibility between wood production and other societal values derived from forest lands. It has four key research questions:

- To what degree can wood production take place without impairing other forest values?

- How can the links between management actions and stand-level outputs of goods and services be developed?

- What are the methodological problems in developing broad-scale measures of ecosystem condition and performance?

- How can broad-scale measures be used to illustrate compatibility (or tradeoffs) between biophysical and socioeconomic systems at national and ecoregion levels?

The Conceptual Model

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

Some scientists see figure 1 as too simple to provide a “good” representation of the system under consideration. They might argue that, for example, ecological integrity should have two or three axes given the complexity and sometimes competing or contradictory dimensions to the problem. Though this would add more dimensions to figure 1, the essential policy and science issues illustrated would be much the same.

Figure 2 illustrates the basic interactions among these multiple values, ideas, actions, and outcomes/outputs, providing the context for research. Social values influence institutional policy that in turn affects managerial decisions and actions, resulting in both a change in forest resource components and the associated mix of outcomes. Decisions and proposed actions are evaluated—often challenged—by society before being implemented, as a normal part of the planning process. Note that social concerns are not just at the top of this cycle in constructing policy and goals, but that social actions are woven through water, biodiversity, economic dimensions, and so forth. Thus we need to distinguish social activity and public use from the outcome of social acceptability. Once management takes action, the final evaluation will be based on the extent to which the desired mix of measurable outcomes was achieved. A complication is that many values are realized in different areas and over varying

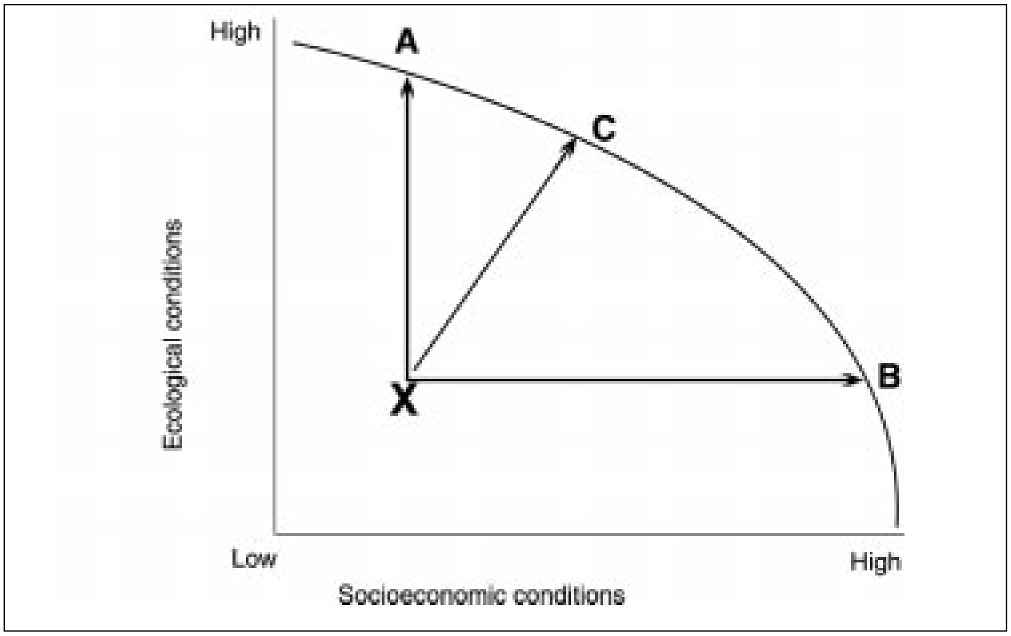

Figure 1—Hypothetical joint production function between ecological and socioeconomic conditions showing opportunities for compatible changes of both.

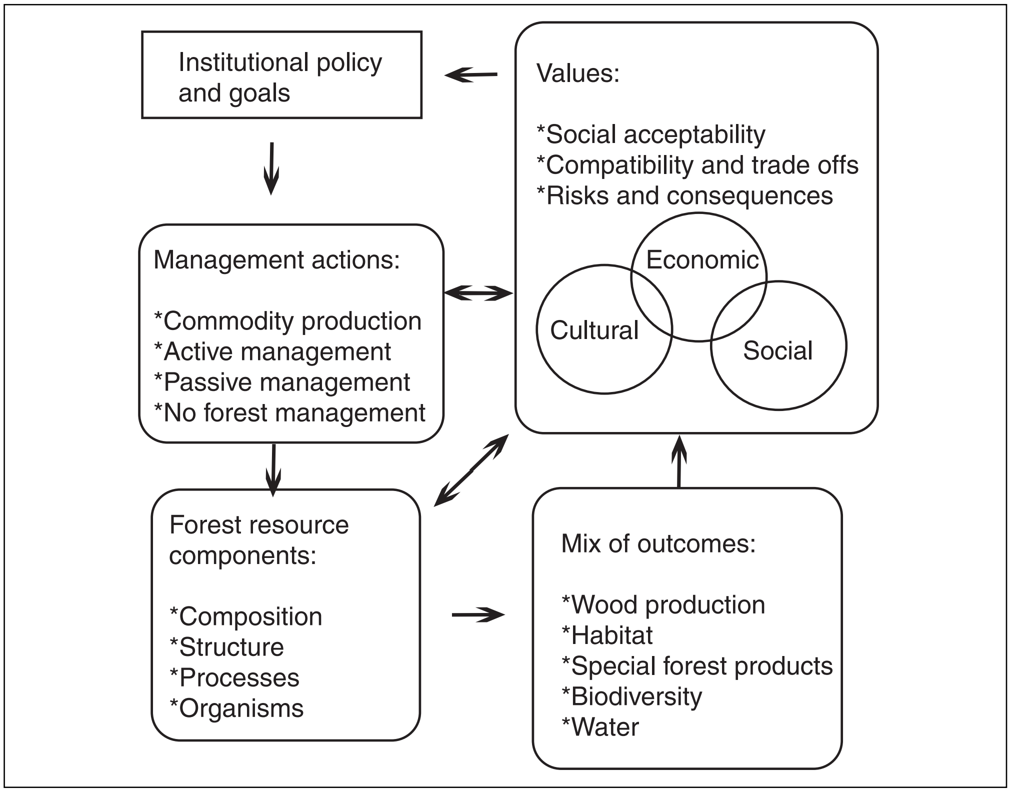

Figure 2—Wood compatibility initiative general conceptual model including forest resource components with interactions among social values, institutions, management, and outcomes.

lengths of time after the management action (spatial and temporal scale differences). This also suggests that much of the research information should be amenable to socioeconomic evaluation of risks and consequences.

We intend to address compatibility at three spatial scales using a conceptual model (fig. 2) of the various components and links. This conceptual model specifies the management regimes that we want to examine across the ownerships making up different broad-scale landscapes. Thus, questions regarding the management of public lands will be examined within the context of broader, spatially complex landscapes. Of the products that can be considered within the context of compatible production, we focus on wood production, fish and wildlife habitat, special forest products, and biodiversity. This relatively short list of products reflects our recognition of the limited information we have on understanding the relations between land management actions and outputs.

Scale of Analysis

Recall that compatibility requires that we maintain other desired attributes (functions and processes) of a forest ecosystem while producing wood commodities. When examining the key question of the WCI ("Can wood be produced in a manner that is ecologically sustainable and socially acceptable?"), it becomes apparent that the answer varies with scale. At the stand level, it is difficult to achieve compatibility between wood production and many other forest values for each stand under management. By increasing the scale of examination to the watershed, work by Cissel et al. (1999) indicates that compatibility can be increased across the watershed by relaxing constraints on certain stands in low-risk areas of the watershed. The result is a management plan that increases the ecological integrity of the entire watershed while still producing timber and other values. Moving to the larger level of an ecological province or the entire region, considerably more options are available to managers to increase overall regional compatibility between wood production and ecosystem functioning and integrity.

The first scale is the traditional stand scale of forest management. Much research and management attention addresses this scale. Though typically characterized as stand-level information, this scale often addresses processes and functions across some set of contiguous stands such as a watershed. This stand-watershed scale information also addresses structure and function of riparian areas and individual streams within stands or adjacent to stands. The cumulative effects of actions in that stand across neighboring stands also are addressed. Tradeoffs at this scale usually involve choices between management actions to achieve relatively specific land management objectives.

The second scale is composed of broader landscapes that include multiple subbasins or counties. The importance of this scale is that it sets context for the finer scales at which much of the ongoing work at the PNW Research Station occurs. In this case, most tradeoffs still involve choices among management actions but public tradeoffs or the social acceptability of specific land management actions are noticeable at this scale. The work conducted as part of the coastal landscape analysis and modeling study (CLAMS [Spies, in press]) project provides a province-level framework for examining both science and management issues at this scale.

The third scale is the ecoregion scale. An ecoregion corresponds, for example, to roughly western Oregon and Washington (the Douglas-fir region). At this scale, tradeoffs involve choices between and among different mosaics of fine- and mid-scale management objectives. Broad-scale measures are often developed from relatively coarse data to describe conditions on relatively large areas such as a subregion (see Haynes et al. 1996). The research conducted at the PNW Research Station in support of the Resource Planning Act Timber Assessment (in particular, ATLAS, the aggregate timberland assessment model; Mills and Kincaid 1992) provides analytical models that can be used to examine tradeoffs for western Oregon and Washington in the context of changes in the U.S. forest sector and to explore the links between different land management-owner strategies, broad-scale resource conditions, and various outputs.

Of these scales, the two larger scales will be addressed by using existing simulation models (CLAMS at the province level and ATLAS at the ecoregion level). Often, simulation models are developed with consideration to the hierarchical nature of various processes and rely on a mix of empirical and judgmental relations to simulate resource conditions. The explicit use of models introduces the need to consider proposals that deal with major modeling assumptions such as timber growth and yield representations and area change (that includes land area, shifts in management intensities, and shifts in forest types).

Research Strategy

The WCI research strategy involves both funding new work and the considerable body of existing research. At the PNW Research Station, this latter contribution is estimated to be slightly over $3 million per year. Most of the existing work deals with the traditional topics of silviculture, forest management, utilization, and compilation of inventory trends and projection systems. The new work either augments ongoing work or is designed to fill some knowledge gap needed to complete the conceptual model (fig. 2).

All new studies are focused on joint production of wood and at least one other forest resource. Round 1 of funding concentrated on stand-watershed level studies, with support for several large-area silvicultural experiments examining joint production. The second round of funding increased the spatial scale of analysis in many studies, adding particular emphasis on province- and regional-level analyses. This second round also increased the emphasis on wood quality and on special forest products (nontimber). The third round of funding (fiscal year 2002) will concentrate on synthesis and integration for the entire WCI.

The following tabulation shows the number of funded studies through fiscal year 2001 listed by scale of analysis and major categories as shown in the conceptual model in figure 2. Several studies focus on more than one category or scale of analysis and may be listed under several scales. Studies are listed in the appendix according to their major focus, and their role in the conceptual model is indicated in the tabulation on the following page.

Categories of focus	Scales of analysis Stand-watershed	 Province	 Region
	Number of studies		
Institutional goals	2	2	2
Management actions	19	6	4
Forest resource components	17	7	2
Mix of outcomes	20	8	4
Values	13	6	2

Synthesis Plans for the Wood Compatibility Initiative

Several synthesis efforts on joint production and wood compatibility are planned:

- A multidisciplinary approach dealing with bilateral tradeoffs of timber and other values in southeast Alaska.

- A framework for evaluating management tradeoffs between ecological and socioeconomic values for western Oregon and Washington.

- A strategic examination of recent ecosystem management strategies like the Northwest Forest Plan (NWFP) that compares the effects of alternative forest management prescriptions across relatively large ecosystems.

These syntheses will examine the strategic nature of many of the policies or programs designed to help or regulate various components of the forest sector. One focus will be the nature of the public debate over the management of public lands where many of the issues are thought of as tradeoffs (zero sum) between biophysical and socioeconomic components of ecosystems. In addition, societal interest in sustainable forest management poses further challenges to use broad-scale ecosystem measures to inform the debate introduced by the Montreal Process. The contributions of the syntheses to this debate are twofold: first, how measures for selected indicators can be developed, and second, how these broad-based measures can be used to discuss strategic questions about determinants of change in the forest sector over some explicit time.

There is a growing dilemma between specific actions taken by land managers to meet land owner objectives and broad societal expectations for forest land management. Much of the eventual synthesis of compatibility issues will be set in this context. Sometimes these latter expectations reflect owner differences, such as conflicting expectations for national forest management among different user groups. Often ownership appears indistinct and ill-defined at the broadest scales. The so-called Interstate-5 phenomena illustrates this, where perceptions of land management are based both on the scenic integrity of broad vistas and broad notions regarding sustainable forest management.

The WCI also is supporting research in two areas that should compliment these three syntheses:

- Broad-scale indicators of ecological integrity, especially in relation to forest management. Such ecosystem measures are called for by the Montreal Process and Santiago Declaration.

- Measures of historical variation in west-side forests, focusing on landscape to province scale.

Finally, the WCI is looking for systems analysis research addressing the same objective at two different scales:

1. A **watershed analysis** on a series of about eight representative watersheds across the region (west of the Cascade crest). The objective is to determine the relation between various forest management scenarios and the status of important environmental indicators. The intent is to provide information at the watershed-landscape scale that can address the key question of the WCI: "Can we produce wood in a manner that is ecologically sustainable and socially acceptable?" Specifically, we are interested in developing robust management regimes for the entire watershed; a robust regime maintains ecological integrity while producing wood and other desirable services from the forest. Thus, we seek to find what types of silvicultural practices and which conditions allow for the maintenance or improvement of the integrity of the forest system while simultaneously managing for wood production. Analysis methods will require a state-of-the-art landscape projection system (e.g., Greenough et al. 1999) to forecast stand development over time for every stand in the watershed and for each management alternative (scenario). Watershed size should be on the order of adaptive management areas (AMAs), about 10 000 to 20 000 ha, and containing roughly 1,000 to 2,000 stands. Simulation time should be for a full rotation, at least 100 years. Indicators will be related to the values emphasized in earlier WCI research and communication: compatibility between wood production and fish and wildlife habitat, special forest products, biodiversity, and social acceptance. We are interested in four general forest management strategies regarding wood production: commodity production (industrial), active management (typical U.S. Forest Service management with harvesting), passive management (reserves), and park and wilderness management. By analyzing tree- and stand-specific dynamics, the effects of management can be examined in relation to important indicators of ecosystem integrity.

2. A **province-regional analysis** of the same relations as in no.1, but using a higher scale aggregation. Ideally, this analysis would derive response functions directly from the results from analysis no.1. The region of interest is western Washington and Oregon and could include an entire ecological province such as coastal Oregon. Again we seek answers to the key question of the WCI. Thus, we want to determine the current level of compatibility between wood production and other values in the region and how we can increase it. Compatibility requires that we maintain other desired attributes (functions and processes) of a forest ecosystem while producing wood commodities. Thus, the analysis should help us evaluate the shifting balance (in time and space) between what society wants and what the biological system is capable of sustaining.

Joint Production Research Summary[1]

One hundred years of U.S. forestry research have shown that forests are highly interrelated systems. The consumption or use of one forest product or service affects other products and functions. The broad array of social benefits arising from the designation of an area as wilderness, for example, has the opportunity cost of foregoing timber production on that area. Similarly, the choice of clearcutting a mixed-age, mixed-species forest and replanting to a single species reduces biodiversity. To support these and other land management choices, an extensive base of research on tradeoffs and compatibility of production in the multiresource forest environment has evolved. The research challenge is to determine if, and at what level, timber harvest and other forest services and products may complement one another. The management challenge is to follow these science-based guidelines and to manage appropriately.

A review by Stevens and Montgomery (in press) of existing multiresource research was initiated under the WCI. Stevens and Montgomery drew distinctions between joint production research, various approaches to tradeoff analysis, and single-resource research that generally measures the amount of one resource given up by the production of a second resource (a zero-sum assumption). The review by Stevens and Montgomery (in press) raises four multiresource questions and suggests some preliminary answers:

- Are management guidelines being developed to aid managers in implementing joint production research findings?

There are some excellent examples of documents summarizing recent research for use in developing management guidelines (e.g., Curtis et al. 1998, Thomas 1979), yet most of the examples in them come from single-resource research. Although many analytical techniques have been applied to the multiresource production problem, it is less clear that these projects are directly translating into methods usable by land managers. Some changes in Forest Service standards and guidelines (such as those in the Aquatic Conservation Strategy) have resulted from the science. As analytical techniques become more sophisticated and research questions more complex, effective communication of findings to resource managers and the public becomes a greater challenge.

- At what scale are we best prepared to understand tradeoffs between wood production and other forest products and values?

While most of the single-resource research has taken place at the stand level, explicit tradeoff research primarily has been done at highly aggregated regional levels. Although this information is useful at the regional policy planning level, it is not very useful for management prescriptions.

- To what extent has multiresource research shown the production of wood to be compatible with the production and sustainability of other resources?

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[1] The original draft of this section was prepared by James A. Stevens who was a forest economist with the Pacific Northwest Research Station but now is a forest economist with the Campbell Group.

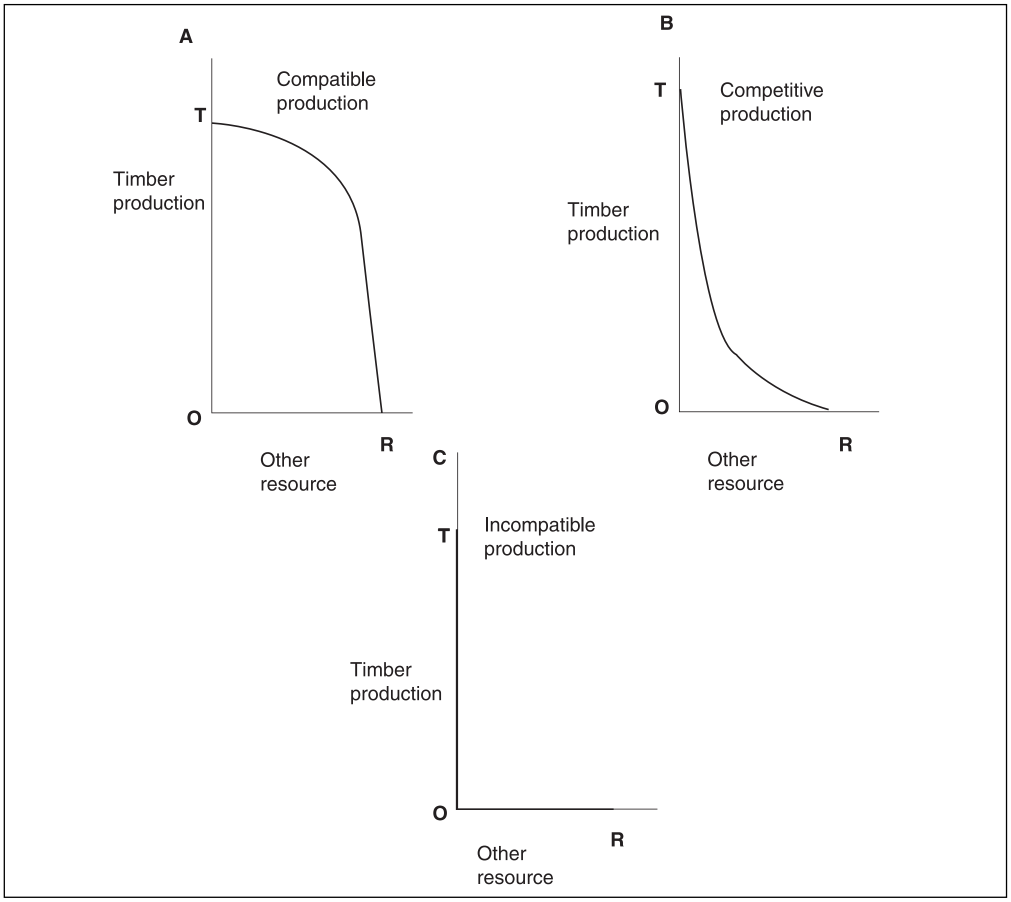

Figure 3—Possible joint relationships between timber and other resource production.

The studies that have directly addressed this question have found, in general, that production of timber and most other resources is compatible (in terms of the production possibilities frontier, fig. 3a) or in competition (fig. 3b) but only rarely wholly incompatible (fig. 3c). This is a key result because it provides support to the implied hypothesis that compatibility is possible.

- Where are the knowledge gaps in joint production research?

Although many advances in modeling to simulate management outcomes or to optimize for certain conditions have been made, major difficulties in the valuation of nonmarket resources still exist. As a result, much of the most useful tradeoff research has quantified a market resource (e.g., timber value or silvicultural costs) and a risk probability (e.g., measures of species viability or biodiversity).

Wood compatibility research has been cyclical. This cycle can be traced to changes in legislative mandates and administrative direction (as translated into research funding) as well as the inevitable ebb and flow of research interest. Although interest in interdisciplinary research continues, it is not apparent that the barriers (budgetary, institutional, or otherwise) to multidisciplinary research are low enough to encourage an increase in activity.

In the context of the conceptual model of the WCI (fig. 2), the synthesis by Stevens and Montgomery (in press) examines the institutional policies and goals that have changed public land management practices. Increased emphasis on the social, cultural, and economic consequences of different mixes of outcomes has led to a better understanding of what society wants in terms of forest resource components. Much of the multiresource research has contributed to a better understanding of the effects of management actions on the forest resource components. However, the crux of the multiresource allocation problem is to better explicate the mix of outcomes from the interaction of management and resources. Less research has emphasized how these interactions contribute to the mix of outcomes. In summary, Stevens and Montgomery (in press) come to five key conclusions:

- Few true joint production studies exist, and none have been conducted for the Pacific Northwest region in over 20 years.

- Although many general multiresource models exist, including some cutting-edge optimization models, few lend themselves to empirical application.

- Much difficulty exists in scaling up the broad number of stand-level studies to the watershed (and higher) levels; those studies that have been scaled up have not made extensive use of the available treatment-response study data.

- No metaanalysis work has been reported in the relevant forestry literature. The potential for such a cross-study analysis does exist, however, using the many large-scale silvicultural studies currently underway in the Pacific Northwest.

- Another promising area of inquiry is in the recent application of production possibilities frontier work, especially in regard to wildlife-timber tradeoffs.

One of the primary objectives of forest management is to meet the needs of the landowner. This may be profit maximization for the industrial owner, aesthetics for the exurban nonindustrial forest owner, or various protection and consumptive uses for the public landowner. Regardless of the landowner objective, an implicit belief has always been that multiple resources were being produced. At the same time, it is difficult to study and model true joint production of multiple resources. Incompatibilities of scale, time, data, method, and degree of detail have made integrated multidiscipline, multiresource research an elusive goal. It continues to be difficult to conclude, using scientific methods, that multiresource goals are being met through current management practices (Stevens and Montgomery, in press).

Compatible Wood Production: Research Examples at Several Scales

Work has been done recently that contributes to an understanding of the compatibility among wood production and other important forest values. We focus on specific studies that seek to determine the level of compatibility or joint production associated with specific forest management actions. Our examples will be categorized by the spatial scale of the analysis: stand, watershed-landscape, province, and regional.

Stand-Level Studies

Operational-scale silvicultural experiments—Even-age plantation management (clearcut, site preparation, and plant Douglas-fir) has been the dominant silvicultural system in the Douglas-fir region for the past half century (Monserud and Peterson, n.d.). 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 in the region (Curtis 1996). The consequent lack of research into alternatives to clearcutting has severely handicapped current efforts to meet changing objectives and public concerns (Curtis 1998).

Currently, several stand-level experiments with various types of partial cuts and variable retention are in the early stages. These involve various thinnings from patch cuts to variable density regimes designed to increase within-stand heterogeneity. Several of these are large-scale studies, with treatment units that are operational in size:

ATC : Alternatives to clearcutting (AK)
MASS : Montane alternative silvicultural systems (BC)
OHDS : Olympic habitat development study (WA)
FES : Forest ecosystem study (WA)
CFS : Washington DNR Capitol Forest study (WA)
DEMO : Demonstration of ecosystem management (WA, OR)
DMS : Density management study (OR)

One of the most unusual and important aspects of this collection of experiments is that the treatment units are large enough to be commercially operational (size range: 6 to 32 ha, with most between 13 and 20 ha). Using large, operational units as treatment areas has several important advantages over small research plots: (1) visual acceptance can be determined by direct observation of the treatments on the landscape, (2) management results can be generated more easily at the watershed and landscape scales because the spatial variation is accurately represented by the experimental units, and (3) larger units better allow for covering the home range of wide-ranging animals (e.g., northern flying squirrel) than small research plots.

A second notable feature of these large experiments is that each addresses some aspect of joint social and ecological objectives, in addition to wood production. All are designed to be multidisciplinary studies, and thus address some aspect of joint production of wood and some other forest resource. Scant literature is available for the Pacific Northwest to guide scientists conducting experiments on joint production (Stevens and Montgomery, in press). Furthermore, all of these studies are recent (begun in the 1990s) and have not been completed. Preliminary published reports are available for only a few of the studies (e.g., Beese and Bryant 1999, Carey et al. 1999, Halpern and Raphael 1999).

Also, all these studies are trials looking for viable alternative silvicultures that could replace clearcutting. Whether called green-tree retention (DEMO), variable-density thinning (OHDS, FES), or variable retention (MASS), the types of silviculture being examined fall between the traditional extremes of even-age plantation management and uneven-age selection management. They explicitly consider structural and spatial diversity to be a value, rather than the spatially uniform stand treatments common with silvicultural systems favored in the Pacific Northwest during the past 50 years. The goal is usually to use alternative silviculture treatments to enhance wildlife habitat, biodiversity, or the conservation of aquatic resources in a manner that is socially acceptable.

All seven studies have well-designed replicated experiments evaluating various intermediate thinning levels and alternatives to clearcutting. In time, these and other related studies will help fill the knowledge gap on nontraditional forest management. Recall that such studies are uncommon in the region, owing to the overwhelming prevalence of wood production objectives, especially plantation management, for over half a century (see Curtis et al. 1998).

Monserud and Peterson (n.d.) summarize key features of seven of these silvicultural experiments:

- Although the size of the treatment blocks is large in all seven experiments, the geographic scope of the studies differs greatly. Four studies are quite dispersed geographically (ATC, DEMO, DMS, OHDS), and can support broader inferences than the three studies with only one location (CFS, FES, MASS).

- All studies use sound experimental designs employing randomization, replication, and controls.

- All seven studies examine the effect of silvicultural treatments on both wildlife habitat and biodiversity. In almost all cases, the silvicultural treatments place considerable emphasis on accelerating development of old-forest structural characteristics and retaining biological legacies.

- Only two studies (ATC, DMS) have a major focus on the interaction of aquatics and wood production. This is the greatest shortcoming uncovered in this review. Even though the Aquatic Conservation Strategy (USDA and USDI 1994b) is an important driving component of the Northwest Forest Plan, the DMS is the only large-scale experiment examining the interaction of density management and aquatics in western Washington and Oregon.

- In only two studies (CFS, DEMO) is the interaction of social acceptance and wood production a major component. A test of the visual quality and social acceptance of silvicultural treatments is probably the easiest component to add to an existing study.

- Economic analyses of joint production are limited. Only the ATC, CFS, and MASS studies were designed to collect economic information to evaluate the wood production component of the study, and those were not joint-production economic analyses. The MASS study has comparative harvesting costs for alternative silviculture versus traditional clearcutting.

- Only the FES study is examining the direct tradeoffs between wood and any other resource (namely, the influence on wildlife of managing second-growth forest for timber with multiple traditional commercial thinnings vs. managing with legacy retention followed by protection with no active management).

Although many of these complex studies have not received much visibility to date, they collectively represent major research investments, including an equally substantial contribution from land management organizations. This suite of long-term studies is an important strategic regional capability that may provide a scientifically based mix of management options for producing commodities while maintaining or enhancing habitat, water quality, and aesthetics.

Pathways to biodiversity—The past decade has seen the ascendance of broad biodiversity elements as an indicator of forest health in Northwest forests. Often, biodiversity and wood production are portrayed as stark tradeoffs. Carey and Curtis (1996) contend that conflicts between conserving biodiversity and maintaining wood production disappear if it is recognized that the conservation of biodiversity is the foundation for sustainable forestry.

To examine this premise, Carey et al. (1996) implemented a Pathways to Biodiversity program on Washington Department of Natural Resources (DNR) trust land. The goal of their research is to find forest management strategies that will meet the public desire for reduced visual effects from forestry operations and for maintenance of species diversity, wildlife, and other environmental values, while providing continued timber production at a relatively high and sustainable level. Simply, they are trying to develop biodiversity pathways that lead to old-growth characteristics more quickly than traditional management.

Their most significant result indicates that older forest habitat is achieved more quickly by maximizing biodiversity through forest management than by other management strategies, thereby producing significant economic benefit (Carey et al. 1996). They also found that protecting an area by excluding management after a timber harvest appears to delay development of old-growth characteristics significantly longer than if thinning or other management techniques had been allowed. This no-management strategy also appears to result in fragmentation of the remaining forest.

Land management implications are clear: active management designed to produce a desired mix of conditions can be far more effective and less costly than blanket attempts at “preservation” that eliminate human intervention. Various management techniques can assist, such as a shift to extended rotations on some portion of the land base combined with increased use of commercial thinning, or a shift to regeneration systems other than large clearcuts. By adopting biodiversity management, Curtis and Carey (1996) contend that not only would long-term commodity output be maintained, but the health and function of the forest ecosystem would be protected and enhanced.

Watershed and Landscape-Scale Studies

The prognosis environmental indicators model—For some years now, public sentiment has grown in support of nontimber values in forest management planning (Greenough et al. 1999). This presents a problem for planners. Although they have sophisticated quantitative tools to project impacts on forest trees, they have no similar means to account for environmental impacts. The new prognosis environmental indicators model (prognosis EI) is designed to assist forest management planning by providing environmental impact projections that are comparable to the available timber projections (Greenough et al. 1999). The model can provide detailed, quantitative environmental impact projections and expected timber flows under user-defined scenarios for entire watersheds (up to 1,500 stands).

Prognosis (now called FVS, forest vegetation simulator) is a multispecies model that forecasts future stand conditions based on the expected growth and mortality of individual sample trees within each stand. Prognosis EI is actually a linked set of models—including prognosis, its root disease and fire model extensions, and the new environmental indicators model—all operating within a “parallel processing extension” that coordinates their operations on hundreds of stands simultaneously. As a result, prognosis EI can provide detailed, credible timber and environmental forecasts for a rich selection of alternatives. In addition, the system is designed to be readily transportable to other regions.

Greenough et al. (1999) demonstrate the model with a case study comparing 21 watershed management regimes in the West Arm Demonstration Forest (Kootenay Lake, British Columbia). Five priority management goals guided the selection of alternatives: (1) obtain a greater merchantable harvest than is forecast for the baseline regimes; (2) increase the average area of prime ungulate winter range; (3) maintain a continuous supply of prime grizzly summer foraging habitat; (4) preserve the condition of the three designated viewsheds; and (5) minimize impacts on water quality. The resulting “balanced” management regime wholly succeeded in meeting the first three goals. At the same time, this novel regime maintained a “retention” visual quality designation in all viewsheds and reduced the equivalent clearcut area (of concern for water quality) in two out of three elevation bands in the watershed.

The key to the analysis is the development of appropriate and relevant environmental indicators. The West Arm Demonstration Forest analysis used the following indicators (Greenough et al. 1999):

Stand structural indicators:

- Overstory characteristics from prognosis, including stand height, maximum diameter at breast height (d.b.h.), basal area, species composition, and both total and merchantable standing volume

- Canopy cover (for all trees, for trees greater than 5 m tall, and for nondeciduous trees only), number of canopy layers, and developmental stage

- Understory condition, including percentage of cover by species by layer in the shrub and herb layers, and total percentage of cover in the moss, lichen, and epiphyte layers

- Volume of coarse woody debris, by species class, diameter class, and hollow and solid state; number of snags, by species, d.b.h., current height, decay class, and hollow and solid state

- Seral stage

- A summary measure of structural diversity based on number of canopy layers, shrub cover, volume of coarse woody debris, and volume of snags

Wildlife indicators:

- Three habitat quality measures for pileated woodpeckers: winter foraging habitat quality (which depends on proximity to suitable roost trees), availability of drumming trees, and nesting habitat quality

- Two habitat quality measures for bats: the amount of high-contrast edge available for foraging, and roosting habitat quality

Landscape spatial indicators:

- Patch-size distribution across the watershed, based on stand age
- Location and amount of old growth in the watershed

Water quality indicators:

- Equivalent clearcut area (calculated under each of three sets of assumptions) in each of three elevation bands
- Length of streams bordered by three levels of canopy cover; and 11 of the 13 indicators defined in the *Interior Watershed Assessment Procedure Guidebook* (British Columbia Ministry of Forests and British Columbia Ministry of Environment 1995)

Visual quality indicators:

- Alteration of designated viewsheds, and resulting status (preservation, retention, partial retention, modification) of each viewshed

Timber values:

- Mean annual increment, total and merchantable harvest volumes, and diameter and species distribution of harvested timber

The case study results confirm that prognosis EI is able to provide credible, quantitative impact projections for a wide range of timber and environmental indicators simultaneously across a watershed. It is hoped that, through use of prognosis EI, management planning will benefit from quantitative environmental impact data in the way that it has long benefitted from quantitative data on timber impacts (Greenough et al. 1999).

The Blue River Watershed Management Plan—In the 1990s, landscape management in federally managed forests in the Pacific Northwest reached a crossroad (Cissel et al. 1999). Listing of the northern spotted owl (*Strix occidentalis caurina*) as a threatened species and public dissatisfaction with clearcutting culminated in the Northwest Forest Plan (USDA and USDI 1994a), the overriding plan for millions of hectares of federally managed forest land. This plan, with its roots in the old-growth and spotted owl issues, emphasizes static reserves, corridors, and standardized matrix prescriptions.

At the same time, concepts emerged concerning use of information on historical disturbance regimes and recognition of the dynamic and variable character of many forest landscapes (Cissel et al. 1998, 1999). These approaches use information on historical and current landscape conditions, disturbance history, and social goals to set objectives for future landscape structures that provide desired plant and wildlife habitat, watershed protection, timber, and other functions. The intent was not to mimic historical conditions but rather to use them as a reference in developing and evaluating management alternatives to meet these goals (Cissel et al. 1999).

Cissel et al. (1999) describe a landscape management plan based on interpretations of historical fire disturbance regimes. The study area is the 23 900-ha Blue River subwatershed, located within the McKenzie River watershed in the Cascade Range of western Oregon. The plan contains a reserve system and other landscape areas where three distinct types of timber harvest are prescribed. These timber harvest prescriptions approximate the frequency, severity, and spatial extent of past fires. Future harvest blocks are mapped and used to project forest patterns 200 years forward and to map resulting landscape structure.

Cissel et al. (1999) interpret historical fire frequency using fire events from tree origin and fire scar dates, statistically modeling point estimates of fire frequency as a function of environmental variables, and then using the resulting predictive algorithms and other observations to map predicted fire frequency over the study area. They then derive a generalized map of fire frequency. Fire regimes are further defined by assigning fire severity classes to areas of different fire frequency. Fire regime descriptions are completed by associating mortality patch size with fire frequency. Timber harvest rotation ages and corresponding cutting frequency approximate the historical frequency of stand-replacing or partial stand-replacing fires for each landscape area. Spatial pattern objectives at the landscape level are developed from analysis of individual fire event and mortality patch sizes resulting from historical fires in each landscape area. The landscape management strategy calls for a range of patch sizes (10 to 160 ha), roughly corresponding with the size of many individual mortality patches from past fires and excluding the infrequent large fires that historically created patches thousands of hectares in size.

In terms of disturbance frequency, management disturbance does not completely substitute for fire, but it does serve as a guide for the structural size distribution of forest stands across the landscape. Additional components of the plan include an analysis of selected sensitive-species habitat, an evaluation of the aquatic ecosystem objectives in the Northwest Forest Plan, and watershed restoration.

Cissel et al. (1999) compare this plan with an alternative plan for the same area based on the extensive reserves and prescriptions for matrix lands in the Northwest Forest Plan. The management approach based on historical disturbance patterns produced more late-successional habitat, more overstory structure in young stands, larger patches, and less edge between young and old forest. Although landscape structures resulting from both plans are historically unprecedented, Cissel et al. (1999) suggest that landscape management plans incorporating key aspects of ecosystem history and variability may pose less risk to native species and ecological processes.

A similar disturbance-based approach was used to develop a management plan for the nearby Augusta Creek Watershed (Cissel et al. 1998). Primary objectives included the maintenance of native species, ecosystem processes and structures, and long-term ecosystem productivity in a federally managed landscape where substantial acreage was allocated to timber harvest. Management objectives and prescriptions were evaluated in light of the long-term range of natural variability of landscape conditions and disturbance processes, including a 500-year fire history record reconstructed using dendrochronology. The Augusta Creek project is intended to provide a test of alternative management approaches through comparison of the reserve-matrix system emphasized by the Northwest Forest Plan with the disturbance-based approach developed for the Augusta area.

Rather than fragmenting management (and the landscape) by imposing the default stream buffer-width recommendations throughout the entire riparian system, Cissel's team (Cissel et al. 1998) formed landscape blocks (20 to 150 ha, based on disturbance risk and landform) as the basic management units. When contrasted with the prescriptions from the Northwest Forest Plan (200-year simulations), these two approaches result in strikingly different potential landscapes, especially with regard to aquatic reserves and timber harvest. All prescriptions are spatially linked to specific blocks of land to provide an efficient transition to site-level planning and project implementation.

Land management implications—Aquatic Conservation Strategy goals can be met by minimizing long-term risk to the watershed as a whole. This is accomplished by managing large landscape blocks rather than fragmenting management by imposing the default stream buffer-width recommendations (Cissel et al. 1998). This study provides an example of how ecosystem management could be applied in a particular landscape by using the results of watershed analysis.

Because of the work of Cissel et al. (1998, 1999), use of historical landscape patterns and disturbance regimes has emerged as an alternative to the static reserves and standard matrix prescriptions in the Northwest Forest Plan. Use of historical information to guide management recognizes the dynamic and variable character of the landscape and may offer an improved ability to meet ecosystem management objectives.

Province-Level Studies

Patterns of historical variability—Natural spatial and temporal variation have provided ecologists insight into ecological processes and the implications of ecological change. Landres et al. (1999) define natural variability as the spatial and temporal variation in ecological conditions that are relatively unaffected by people, within a period of time and geographical area appropriate to an expressed goal. A major aim of characterizing natural variability is to understand how driving processes differ from one site to another, how these processes influenced ecological systems in the past, and how these processes might influence ecological systems today and in the future (Landres et al. 1999).

Natural resource managers increasingly rely on the "range of natural variation" or simply "natural variability'" to develop plans that guide management within the range of ecological and evolutionary conditions appropriate for an area (Landres et al. 1999). Management use of natural variability concepts began out of a search for a legally defensible strategy for maintaining biological diversity and sustaining the viability of threatened and endangered species (Landres et al. 1999). An outgrowth of Aldo Leopold's idea of *vignettes of naturalness*, these concepts are now being used in situations where sustaining ecological integrity is the primary goal, where a structural stage such as old-growth forest has been significantly altered, or where key processes such as fire and flooding have been excluded.

Wimberly et al. (2000) developed a landscape age-class demographics simulator to model historical variability in the amount of old-growth and late-successional forest in the Oregon Coast Range over the past 3,000 years. Parameters describing historical fire regimes are derived from data from existing dendroecological and paleoecological studies. The model simulates temporal and spatial patterns of forest fires along with the resulting fluctuations in the distribution of forest age classes across the landscape. Their results indicate that the historical age-class distribution was highly variable and that variability increased with decreasing landscape size. Simulated old-growth percentages were generally between 25 and 75 percent at the province scale (2 250 000 ha) and never fell below 5 percent. In comparison, old-growth percentages varied from 0 to 100 percent at the watershed scale (40 000 ha). Province-scale estimates of current old-growth (5 percent) and late-successional forest (11 percent) in the Oregon Coast Range were lower than expected under the simulated historical fire regime. Their results suggest that in areas where historical disturbance regimes were characterized by large, infrequent fires, management of forest age classes based on a range of historical variability may be feasible only at large spatial scales. Note that this conclusion apparently runs counter to the fundamental premise in the finer scale watershed management plans developed and currently being implemented by Cissel et al. (1998, 1999), who did not consider very large-scale fire disturbance. Wimberly et al. (2000) conclude that comprehensive landscape management strategies will need to consider other factors besides the percentage of old forests on the landscape, including the spatial pattern of stands and the rates and pathways of landscape change. This is the detail added by Cissel et al. (1998, 1999) in working at the finer, watershed scale.

Wimberly et al. (2000) also concluded that natural variability concepts provide a framework for improved understanding of ecological systems and the changes occurring in these systems, as well as for evaluating the consequences of proposed management actions. Understanding the history of ecological systems (their past composition and structure, their spatial and temporal variability, and the principal processes that influenced them) helps managers set goals that are more likely to maintain and protect ecological systems and meet the social values desired for an area (Cissel et al. 1998). Until we significantly improve our understanding of ecological systems, this knowledge of past ecosystem functioning is also one of the best means for predicting impacts to ecological systems today.

Coastal landscape analysis and modeling study: CLAMS—A fundamental question of forest ecosystem management is "How do we distribute forest uses over space and time to provide the desired variety of goods and services?" The answer differs with spatial and temporal scale, management policies, objectives and practices, and ecological and socioeconomic context (Spies, in press). Although some different forest values may be compatible on the same sites, others may only be compatible over large areas by segregating uses in space or time. Recent forest policies such as the Northwest Forest Plan (USDA and USDI 1994a) and State of Oregon Riparian Rules (Oregon Department of Forestry 2000) have attempted to achieve a mix of forest values by spatially distributing practices over watersheds or landscapes. Because we lack quantitative information about habitat relations and the effects of different management practices on ecological and commodity values, the spatial strategies in these plans are frequently based on expert judgment rather than quantitative research. No quantitative analyses have been conducted to test the assumptions of these plans or to determine if projected future outcomes are consistent with the goals of the plans.

Developing forest policies that sustain biological diversity while providing for other social and economic values of forests and watersheds is a major challenge for policymakers and managers (Spies, in press). In the Pacific Northwest, conflicts over balancing ecological, economic, and social demands on forests paralyzed forest management on federal lands during the late 1980s and early 1990s and introduced considerable uncertainty in management on private lands. These controversies have led to major new forest polices in the region for federal and state lands and considerable modification of forest polices for private forest lands. In Oregon's Coast Range, separate new polices for federal, state, and private lands have been initiated in the last few years. The Northwest Forest Plan for federal forests has brought sweeping changes to forest management on these lands and has reduced timber sales there by almost 90 percent compared with the 1980s. Recent plans for state forests in Oregon have also shifted focus to emphasize habitat conservation. Changes in the Oregon Forest Practices Act also have emphasized greater protection for riparian areas on private timberland. In addition, the listing of salmon stocks on the Oregon coast could cast a new federal regulatory blanket over forest management of this area.

Although these policies are based on the most current scientific information, it is uncertain how well they will meet their individual goals over time and space (Spies, in press). It is even less clear if these policies will have any ecological or economic interactions among them. The CLAMS project was initiated because available conceptual and quantitative scientific models were inadequate for distinguishing among different policy approaches in a rigorous way. For example, models were unable to quantitatively project the effects of different policies on aquatic and terrestrial habitat and socioeconomic outputs across an entire multiownership province or region. Thus, the goal of the CLAMS study is to analyze the aggregate ecological socioeconomic consequences of the forest policies for different owners at the province (subregional) scale (Spies, in press). CLAMS research is designed to develop new habitat relation models, quantitatively analyze current plans, and to answer major questions about forest management at large scales. The study area is the Coast Range Physiographic Province, which contains all of the Coast Range hydrological province and part of the Willamette hydrological province.

The development of conceptual and quantitative links among various disciplines and components is critical to the success of the project. Conceptually, the ecological and socioeconomic dimensions of the project are integrated through quantitative, spatial characterizations of the landscape at various scales. Links to policies are made in the policy model after consultation with various landowners and policymakers to determine the kind of policies and practices that they would like to see simulated (Spies, in press). Additional integration both within and across disciplines is crucial to the success of CLAMS. For example, upland and aquatic ecosystems are linked through spatial simulation models that grow trees in the uplands and deliver them to the stream through mortality agents and geomorphic disturbances. Connections between measures of biological diversity and social systems are made through contingent valuation surveys of people to determine what they would be willing to pay for various levels of biological diversity.

Preliminary results from CLAMS analyses found (Spies, in press):

- The long-term effect of current forest policies in the region will likely result in highly contrasting habitat conditions across public and private ownerships. The effects of this juxtaposition of habitat and dynamics are not well known at this time. Some species, however, may occur on ownerships on which they might not otherwise be found because of the occurrence of habitat on adjacent ownerships.

- The condition of aquatic habitat within a multiownership basin will probably depend on the ownership pattern of key reaches and woody debris source areas within the watershed. Streams will not contribute equally to the quality of aquatic habitat within a watershed. Consequently, if ownership patterns are different relative to position in stream networks (which they typically are), then conservation practices will need to be based on involvement of all ownerships to meet watershed goals.

- Both fine- and coarse-scale information seem to be needed to model links of land management activities and ecological values. For example, ownership patterns at coarse scales are important drivers of habitat conditions, but fine-scale information such as slope at 10 m resolution or density of snags is needed to predict effects and variation within coarser scale strata.

- The importance of spatial pattern will differ among organisms and processes. For example, knowledge of spatial pattern of habitat does not appear to add explanatory power to models of the occurrence of some vertebrate species beyond knowledge of proportion of habitat in the landscape. It seems, however, that spatial pattern may be important in watershed issues and perhaps for other species.

- Little direct feedback exists between biological diversity and socioeconomic systems. Economic systems do not directly recognize different measures of biological diversity except through policy actions directed at biological diversity goals.

- Maps are important. Map visualization of the pattern and temporal development of watersheds and landscapes are powerful tools in the development of sustainable forest practices. Management agencies, landowners, and public groups find maps of landscapes and the potential consequences of forest management interesting. Consequently, these tools will likely have great value in landscape, watershed, and regional efforts to develop forest policies to maintain ecological and socio-economic values.

Regional-Level Studies

Projections of private inventories, net growth, and harvests in the Pacific Northwest west side—Regional timber resource assessments that include projections of timber growth and inventory levels help shape perceptions about overall changes in resource conditions and attendant changes in the mix of goods and services derived from resource endowments. As part of the current RPA Timber Assessment (Haynes, n.d.) (required by the Resource Planning Act 1974), researchers in the Forest Service use large-scale simulation models (the aggregate timberland analysis system [ATLAS]; Mills and Kincaid 1992) to develop these projections. The approach depends on assumptions differentiated by class of owner[2] about changes in timberland area, trends in future management investment, and the assignment of the current timber inventory to the various management intensity classes.

Briefly, area trends in the Pacific Northwest reflect modest declines in nonindustrial private forest ownership resulting from both direct conversion of timberland to urban and developed uses and conversion to replace cropland lost to urban and developed uses. Future area transfers between ownerships are expected to be much smaller

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[2] Private timberlands are split into two classes of owners: forest industry (FI) and the nonindustrial private forest (NIPF) lands.

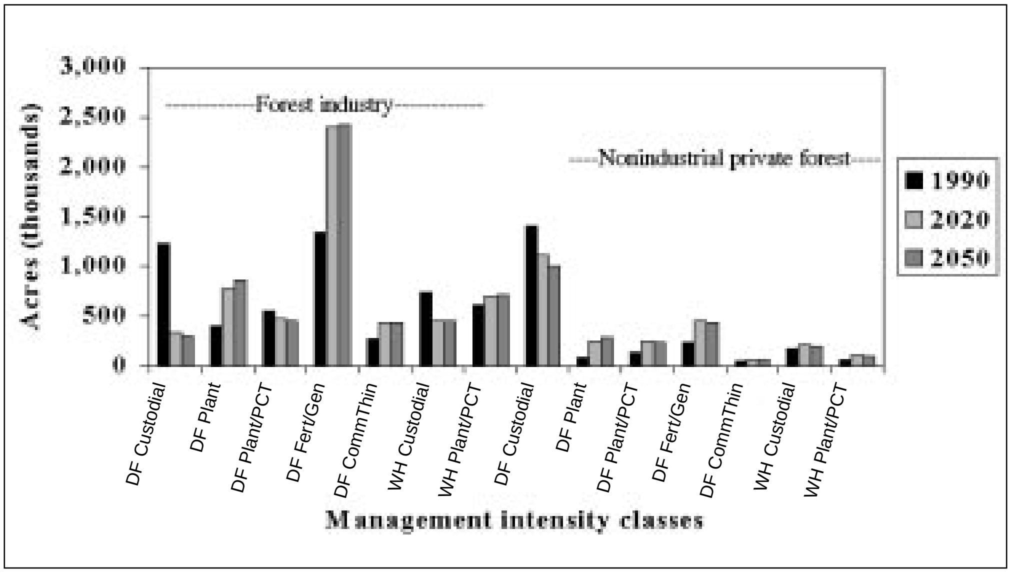

Figure 4—Pacific Northwest west side forest industry and nonindustrial trends in management of Douglas-fir and western hemlock.

than in the past four decades. The most substantial cover type changes are projected to occur on forest industry lands, as more acres are planted to Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco).

The trends in timber management are described for five management intensity classes (MICs[3]), each corresponding to a specific regime of silvicultural treatments. Douglas-fir management is identified for three site classes and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) management is identified for two management intensities. In the projections, forest industry lands generally move from lower levels of investment toward higher levels. As illustrated in figure 4, area regenerated to the Douglas-fir type is at the more intensive end of the management spectrum. By 2020, the largest shifts in Douglas-fir are expected to have occurred, with the type gaining over 260 000 ha. Western hemlock types are projected to lose some 85 000 ha to Douglas-fir during the first 20 years of the projection, and the balance of the remaining western hemlock area is projected to shift toward more intensive management. The nonindustrial private forest ownership will shift more area into Douglas-fir, but substantially fewer acres will be regenerated under intensive management. By 2020, nonindustrial private forest landowners will hold 211 000 ha compared with industry's 1.1 million ha in higher management intensities. Western hemlock gains area in the nonindustrial private forest ownership.

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[3] The resource management assumptions in the current RPA Timber Assessment were updated in collaboration with American Forest & Paper Association (AF&PA) and state forestry organizations. Two landowner surveys (one for industrial owners who were members of AF&PA and a second for nonindustrial private forest land owners [NIPF]) were used to develop management intentions. In addition, management information for NIPF owners was derived both from surveys and recent related work such as the Western Washington Timber Supply Study (Adams et al. 1992).

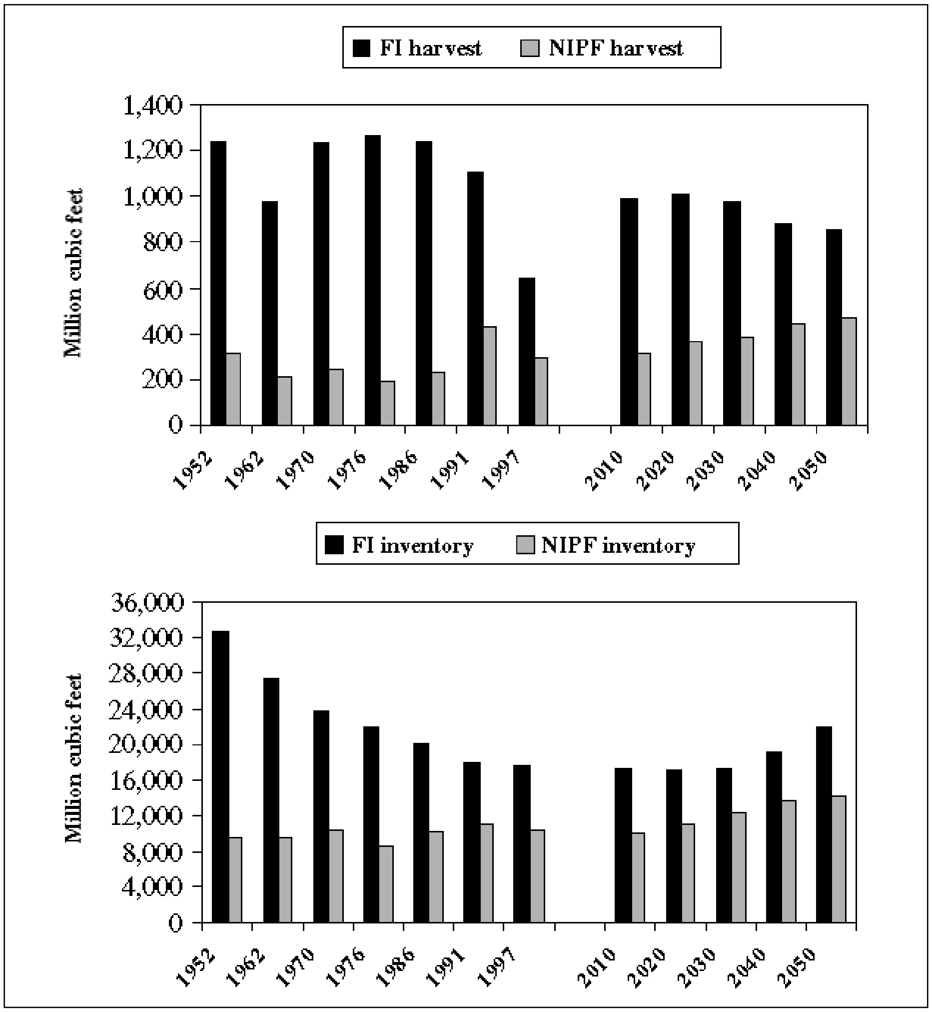

Figure 5— Pacific Northwest west side forest industry and nonindustrial softwood harvest and inventory levels through 1997 and trends projected through 2050.

Projections of the private timber inventories based on the assumptions about area trends, shifts among management intensity classes, and harvest levels projection in the current RPA Timber Assessment (see Haynes, n.d.) are shown in figure 5. On both forest industry and nonindustrial private forest ownerships, the expected increases in harvest lag behind expansion in growth. Consequently, inventories are stable to rising through the projection. By 2050, projected forest industry inventories are nearly 24 percent higher than current levels, whereas nonindustrial private forest inventories rise by 37 percent (fig. 5).

Several inferences can be drawn from the projections. First, a resurgence in sawtimber harvest and lumber production in the Pacific Northwest will result from expanding harvest levels on private timberlands. This resurgence is a function of an aging private inventory, large proportions of which will approach minimum harvest age (40 years of age) after 2010. Second, in the context of total inventories across all ownerships, these changes in private timberlands and the gradual aging of inventories

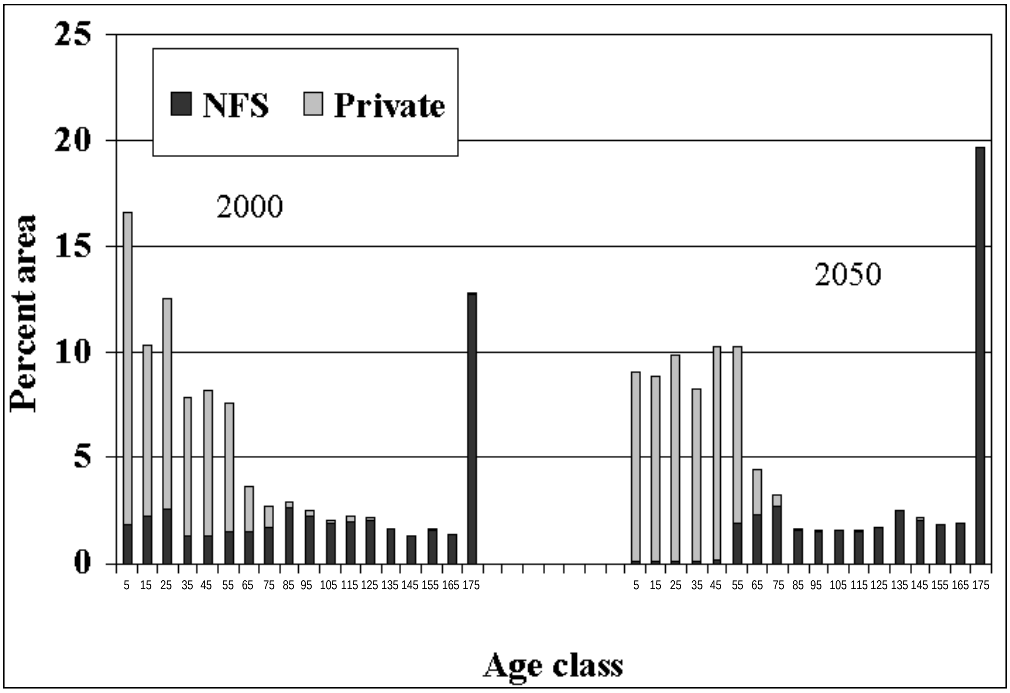

Figure 6—Age class distribution by ownership for softwood forest types on timberland area for the Pacific Northwest west side for 2000 and projected for 2050.

on national forest timberlands (developed in much the same fashion as for private timberlands) will lead to a more pronounced bimodal distribution of age classes as shown in figure 6. At the national level, these types of projections suggest that we "will be able to" meet U.S. demands for softwood products by shifting the harvest onto more intensively managed private timberlands (mostly in the Southern United States) while at the same time preserving large amounts of older western timber stands. In the Pacific Northwest, we will see the emergence of a bimodal forest resource base with evident shortages of stands in the 40- to 80-year range. Most of the younger stands (<40 years) will be on private land located typically at lower elevations, and older (>80 years) stands will be on public land typically in higher elevations and headwater areas. These projections raise concerns about compatibility in those cases where perceived age gaps raise issues about habitat for selected species and sustainable forest management.

Synthesis of analysis on the cost of regulations vs. market forces in the state of Washington[4]—Over the last decade, a series of studies in the state of Washington have been devoted to understanding the impact of managing forests to sustain both timber and other nonmarket objectives (e.g., Adams et al. 1992; Bare et al. 1995, 1996, 1997; Carey et al. 1996; Lippke et al. 1996, 1998, 1999, 2000; Lippke and Oliver 1993a). Regulations, which often cause increased costs and other economic impacts, are the primary method for requiring landowners to consider other forest values. Many studies have assessed the direct impact of regulations on the forest

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[4] The original draft of this section was prepared by Bruce Lippke, College of Forest Resources, University of Washington.

sector and subsequent downstream or indirect economic impacts. Some have quantified potentially offsetting market or nonmarket social benefits from the restoration of these other forest functions.

Early in the 1990s, timber supply studies in western Washington, reflecting a range of owner management responses (federal, state, and private), projected both job impacts and habitat indices that were linked to the age class of stands, while ignoring spatial issues (Adams et al. 1992). These studies examined the impact of various management alternatives and responses to changing regulations at the regional level, but they placed little emphasis on the use of reserves.

In 1996, the Washington forest landscape management project study (Carey et al. 1999, Lippke et al. 1996), substantially improved both habitat modeling and economic modeling. Habitat suitability for various species was shown to be dependent on stand diversity conditions as well as age. Various thinning, harvesting and retention practices was examined. The number of stand conditions used to characterize the forest was still modest, and the approach to protect threatened species could still be considered a coarse filter approach; i.e., maintaining minimum amounts of all broadly defined stand conditions.

Sessions and Sessions (1993) analyzed spatial features at a watershed level using the scheduling and network analysis program (SNAP) model. However, the spatially dependent measures such as fragmentation did not seem to be dependent on the management alternatives tested. Spatial impacts appeared to be more dependent on the size limit for treatments than the variation in management treatments. Size constraints in forest practices may be more directly associated with aesthetic considerations than the restoration of natural disturbance conditions that include large fires or windstorms. Furthermore, the size of disturbances have much larger variance than treatment possibilities under the forest practice regulations.

Pilot projects are now underway that include much finer discrimination of the stand conditions and more elaborate habitat suitability models (e.g., a management plan is being developed for SATSOP[5] site and Fish and Wildlife Department approval). The number of stand conditions and larger number of habitat suitability models seem to go beyond coarse filter strategies for maintaining species under stress.

The work in western Washington has yet to demonstrate the importance of explicit spatial information at the strategic planning level. The economic and habitat differences between nonspatial strategic plans and spatially explicit plans have not been adequately studied but might be shown to be small relative to other uncertainties. Spatial issues have sometimes been characterized by zonal definitions, retaining different levels of habitat in certain zones without regard to the spatial features within the zone or the interdependence of zones. A 1994 study of the impact of owl protection rules on western Washington essentially enumerates the acreage impacts of individual owl protection circles around owl nests. Geographic information system (GIS) analysis of owl circle overlaps provides a statistical representation of the net

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[5] The Satsop site is the land surrounding the one-time SATSOP nuclear site (i.e., mostly forest land under the management of the site). Not to be confused with the river and other things similarly named such as the SATSOP block of the Olympic Forest.

reserve acres within owl circles and reduces the importance of spatial features outside of the owl circles (Lippke and Conway 1994). A technical review of the Washington Department of Natural Resources habitat conservation plan includes an assessment of the impact of these owl circles while also developing an alternative approach relying on the statistical treatment of habitat suitability within spatially explicit zones (Bare et al. 1996). Habitat was allowed to move within a zone over time while meeting target levels.

Most recently, the focus has turned to riparian management for salmon protection. A study on western Washington (Bare et al. 1996) extends the habitat management regimes developed by Carey et al. (1999) to riparian zones with narrow buffers to protect the streambank and compares these impacts to those of wider buffers, and those of prior forest practices. In this approach, management practices are controlled by distance from streams by using GIS data to characterize stand types relative to the distance from streams. This provides a spatially explicit treatment relative to distance from each class of stream but not along the length of a stream within each class, yet another variant of using zones to capture some spatial information.

This approach also was applied to Lewis County as a pilot project to gain more thorough understanding of the impact of the new forest and fish regulations in Washington (FPB 2000) compared with prior regulations and other management approaches (Lippke et al. 2000). Various riparian management zone (RMZ) management options were examined by using GIS data to identify stream classifications and forest inventory analysis representations for stand structures as a function of distance from streams.

These different approaches for characterizing changing habitat conditions have contributed to a sequence of improvements over time in the quality of habitat projections and other environmental measures used in planning, especially at the strategic level for which the cost of spatially explicit treatments is not as critical. Upland habitat models have progressed much further than models of instream functionality to protect salmon, but streams are the current area of focus.

The quality of economic impact measures such as labor and income also has received attention. In the early timber supply studies, economic multipliers were assumed to be static and therefore based on input/output (I/O) models of the state of Washington economy and explicit treatment of the subsectors within the forest products industry (Conway 1994). It is recognized that the assumptions of static production technology coefficients are not valid when a wide range of management treatments are considered, as both the wood produced and labor required are dependent on the assumed technology. Given the changing technology in the forest sector, a more rigorous approach would require the development of technology-dependent I/O coefficients in order to properly characterize interindustry purchases appropriate to the technology employed. The Washington landscape management project developed adjustments to the job requirements for each subsector reflecting the expected changes in technology coefficients, including the impacts of more labor-intensive management operations and the changing quality of wood produced, which in turn affects the amount of value-added processing (Lippke et al. 1996). Although it is difficult to validate the impacts that are derived from I/O linked models, the simulations of several structural shocks by the Conway Washington state forecasting model (Conway 1994) have generally been considered suitable for policy analysis.

The recent work of Robertson (1999) raises even more concern on the adequacy of economic impact models. He shows that economic multipliers for forest sector activities were sometimes small and vary greatly in the rural areas of southeast Alaska. Although his results raise doubts about the validity of similar models in other rural areas, even the Conway Washington state forecasting model shows more than half of the indirect impacts are located in urban areas with the rural impacts varying by regions within the state.

Most of the timber supply assessment studies use a harvest scheduling algorithm to determine changing harvest levels, which in turn drive changes in stand conditions, product quality, and labor requirements. Harvest simulations generally show large variations in projections across owner groups over the first several decades owing to different and nonuniform age classes in the owner groups inventory. Regulations generally have had a larger impact on mature stands. This reduces the near-term harvest substantially more than the sustainable harvest, particularly for owner groups that are motivated by economics and maintain no surplus in mature inventory (Lippke et al. 1998).

Properly modeling operational constraints simultaneously with habitat constraints (or objectives) over a land area has become more critical. Modeling multiple constraint sets on smaller and smaller tracts substantially reduces economic output and in the broader context, economic efficiency. The way constraint sets are modeled can be improved substantially, as was demonstrated by the reviews of the Department of Natural Resources (DNR) habitat conservation plan (Bare et al. 1996, 1997).

Another problem in analyzing the impact of regulatory changes has been the predictability of price responses. Although short-term prices clearly increase with regional harvest declines, the increased investments and supply response from the rest of the world has been notable, and there is less evidence that prices will remain high over the longer term (Perez-Garcia and Kraley 1999).

Attempting to model spatial conditions more explicitly can easily compound the problem of developing constraints. Many attempts to develop spatially explicit harvest scheduling algorithms use integer and heuristic algorithms (Haight 2000). It is too soon to suggest that any of these approaches will add much insight to the strategic planning problem, but they should assist in developing small-scale operational planning tools.

The direct and indirect economic impacts from changing regulations to protect habitat have been great, ranging from 15 to over 50 percent for some small owners. This has motivated efforts to find more economically efficient solutions as well as to better understand nonmarket social benefits. Studies that have looked at a wide range of management alternatives, including a varying emphasis on reserves vs. active management to restore habitat, generally show active management being more efficient (Bare et al. 1995, 1996; Carey et al. 1999). This finding has increased the effort to understand whether the same is true for nonmarket values held by various publics.

An experimental choice survey among urban and rural households was conducted requiring those surveyed to select their preferred management alternative when the alternatives were described by changing levels of biodiversity (and habitat), aesthetics, rural job losses and household costs (Xu 1997). A choice model characterizing willingness to pay for biodiversity and aesthetics and willingness to accept job losses and cost increases was developed (Xu 1997). Although this model seemed robust when compared to other contingent valuation work (Lippke and Xu 1999), these procedures are relatively untested, and followup work to establish a high degree of credibility has been insufficient. For example, if it is made clear in a contingent valuation survey that it will be your job that will be lost, then your cost-benefit ratio quickly approaches infinity. A followup study including riparian zone conditions is now underway and may offer new insight.

A choice model of the values various publics place on forests provides the opportunity to determine if optimization of social values of the public produces different management strategies than the strategies that arise by limiting the search to only the net present value to landowners or jobs created. A model to maximize social welfare was tested (Xu et al., n.d.) and demonstrated the benefits of active management vs. reserve strategies.

Although most studies have focused on losses to the forest sector constituents, some market benefits do exist. Brown and Steel (1994) examine the market benefits of stream buffers on fishing compared to timber product losses noting that the timber product losses were substantially larger than the fishing gains. Recreational benefits also may exist but given the variety of recreational substitutes, it becomes difficult to estimate net impacts.

Washington’s Forests and Fish report (US FWS et al. 1999) stipulates changes to existing forest practices rules that will affect the Washington forest products sector. A small business economic impact statement and cost benefit analysis combines GIS data on water type, ownership, transportation, vegetation and site class, and economic data on timber values to construct a statistically based sample of forest acres in Washington. The impact statement (Perez-Garcia et al. 2000) measures the effect of proposed rules on small versus large businesses in the forest products sector. The cost benefit analysis (Perez-Garcia et al., in press) considers various alternatives and computes probable benefits and costs for these alternatives. These studies represent a first attempt to incorporate legislative mandates on impact assessments in implementing rule changes in Washington.

Much can be summarized from these studies:

- The ability to project changes in habitat as a function of regulations and other management alternatives continues to improve.

- The ability to estimate direct and indirect market economic impacts is limited by economic models that are not sensitive to changing technologies within management alternatives, and also may not be robust in rural areas.

- Spatially dependent factors (e.g., edge effects) may not always be adequately treated, but nonspatially explicit models are probably adequate for strategic planning (where that planning is done at higher spatial scales).

- Operation planning with explicit spatial information will show some economic loss, and this gap could be studied to better understand the error gap between these approaches.

- The ability to model RMZ impacts by using GIS data on streams does not seem to be as limiting as potential spatial issues for uplands habitats.

- Spatial models exist but are computationally limiting and probably remain less likely to contribute except at smaller spatial scales. Better understanding the error gap between spatially explicit planning models and statistical models used for strategic planning could provide better guidance on when to use each approach.

- Understanding public values as a means for developing better tradeoffs and compensation mechanisms holds promise but has not been adequately researched.

Interior Columbia basin: testing the compatibility of broad-scale land management—The Interior Columbia Basin Ecosystem Management Project (ICBEMP) (USDA and USDI 2000) in the Northwestern United States provides a useful example where scientists, managers, and the public have explored the potential for understanding the nature and extent of the assumed tradeoffs among biophysical and socioeconomic components of ecosystems. These tradeoffs are contentious and often portrayed as being a direct relation of positive environmental changes (such as gains in habitat) and negative changes in socioeconomic well-being. The policy issue often has been reduced to a two-dimensional debate such as the jobs versus the environment issue that has characterized much of the forestry debate of the past decade (fig. 1).

The composite measures developed in the ICBEMP examine the direction and extent of possible tradeoffs between ecological and socioeconomic conditions among various management strategies (Haynes and Quigley 2001). These measures address whether or not the proposition holds that increases in environmental conditions always involve reductions in socioeconomic conditions across three management options outlined in the supplemental draft environmental impact statement (USDA and USDI 2000). One alternative proposition is that compatibility exists between changes in environmental and socioeconomic changes, at least across a range of options. That is, opportunities exist for either mutual gains or increase in one dimension while the other dimension remains stable.

The composite measures used by the ICBEMP are ecological integrity and socioeconomic resiliency (Quigley et al. 2001). Ecological integrity is defined as a joint measure of forest integrity (developed from disturbance histories and inventory conditions), rangeland integrity, and aquatic integrity. Socioeconomic resiliency is developed jointly from economic resiliency and social resiliency (using proxies for community capacity and social systems) (Crone and Haynes 2001, Horne and Haynes 1999). Ecological integrity, maintaining long-term sustainability of resources and environments, gets at the heart of many legal mandates as well as social interests. A strategy might prevail in the short term while sustainability declines, but success will be marked by the ability of both ecological and socioeconomic systems to reorganize in a resilient fashion and support the conditions and flows that exist through time.

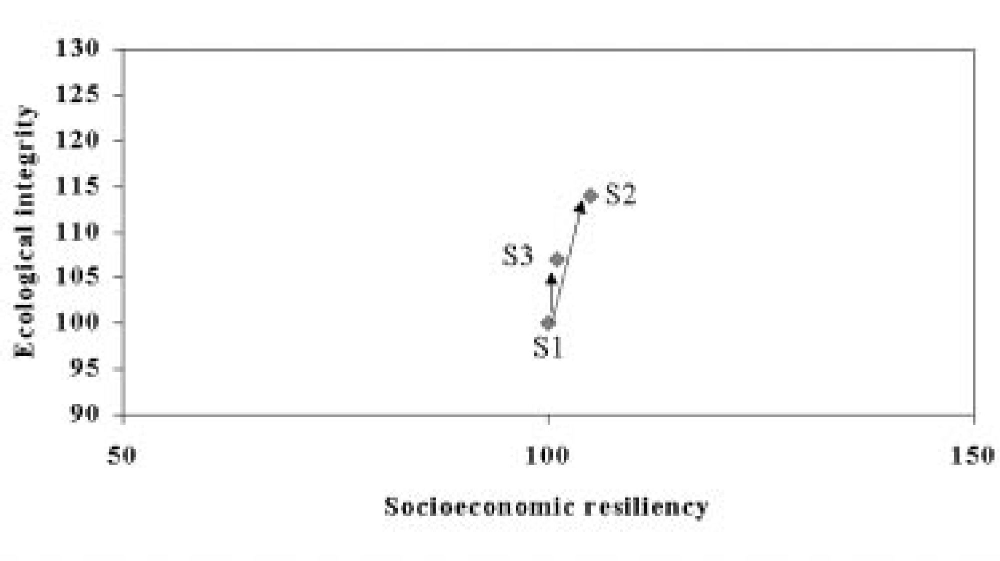

Figure 7—Tradeoff between ecological integrity and socioeconomic resiliency indices for management alternatives in the interior Columbia River basin assessment area for each management alternative (S1, S2, and S3). Alternative S1 was used as a baseline comparison to index alternatives S2 and S3.

As figure 7 shows, various interactions are abundant and potential tradeoffs exist. Two land management alternatives (S2 and S3) facilitate complementary changes in both ecological integrity and socioeconomic resiliency as compared with the continuation of current management directions (alternative S1). Both alternatives S2 and S3 lead to increases in ecological integrity and socioeconomic resiliency. The system is likely within the possible joint production frontier because the indexes for alternatives S2 and S3 move upward and to the right when compared to alternative S1 in the two dimensional space (fig. 7).

These results lead to the rejection of the initial proposition and suggest that the policy debate should be less about jobs vs. environment and more about compatibility of outputs, as suggested in the alternative proposition. Figure 7 raises many questions about the concept of compatibility—of what, where, when, and for whom? It is important to bear in mind, however, that compatibility is a social rather than scientific construct. It is also scale-dependent. Many argue that compatibility increases with scale and that the results seen are approachable only at large scales.

These results illustrate the utility of broad-scale measures in providing a framework to consider differences between alternative approaches to land management. Although not explicit, the temporal specificity of something like figure 1, reminds us of the dynamic nature of the variables that determine broad-scale measures. Changes in the underlying components would shift the relation revealed in the figure. Framing the notions of compatibility or tradeoffs creates a platform for judging the sensitivity of outcomes to different sources and magnitudes of risks. The science-policy debate during the past decade has been narrowed considerably by scientists and land managers who have asserted ecological limitations while not at the same time acknowledging the full scope and complexity of deliberate societal choices.

Progress Toward Understanding Compatibility

Stevens and Montgomery's (in press) review of classical joint production research notwithstanding, it is clear from the preceding collection of diverse studies that excellent progress has been made toward understanding the nature of compatible wood production, and at several scales of analysis. Furthermore, studies like Cissel et al. (1999) and Greenough et al. (1999) demonstrate that the practical needs of the land manager can be given proper weight while designing management plans that increase the level of key environmental indicators and other forest values and still produce wood. With this in mind, we attempt to answer the four research questions proposed in the introduction:

- To what degree can wood production occur without impairing other forest values?

- How can the links between management actions and stand levels of outputs of goods and services be developed?

- What are the methodological problems in developing broad-scale measures of ecosystem condition and performance?

- How can broad-scale measures be used to illustrate compatibility (or tradeoffs) between biophysical and socioeconomic systems at national and ecoregion levels?

These questions focus on the broad issue of managing forests for greater compatibility. The actual implementation of these concepts may be hindered by the attitudes and values of different land owners about the different types of approaches (market based or regulatory) taken to institute joint production of some ecosystem services (see Jacobson et al. 2000 for a summary).

To what degree can wood production occur?

The Douglas-fir region of western Washington and Oregon and coastal British Columbia contains the most productive forest land in North America (Curtis and Carey 1996). Forest management in this region has been evolving for over a century and experience on even-aged silviculture and plantation management accumulated in the past half-century is vast (Curtis et al. 1998). 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, the major timber species in the Pacific Northwest, can be grown at various densities. It rapidly responds to thinning at a variety of stand ages, with increased diameter growth as well as branch and crown development (Reukema 1972, 1975); stocking control is important to promote vigorous growth (Barbour et al. 1997). Two important shade-tolerant species, western hemlock and western redcedar, 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 (Duryea and Dougherty 1991), including techniques for inoculating roots with mycorrhizal fungi to promote quick establishment and sustained growth (Castellano and Molina 1989). Average survival of seedlings has increased to 85 percent or better (Curtis et al. 1998). Effective methods have been developed for controlling competing shrub and nontimber vegetation, thus promoting rapid growth of established individuals (Walstad and Kuch 1987). Various harvesting systems have been developed to reduce problems such as soil compaction (Curtis et al. 1998).

Because 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) tackled the problem of rotation length and found surprising results. It is well known that the culmination of mean annual increment is rather flat near the maximum (the point where periodic annual increment [PAI] crosses MAI). Curtis demonstrated that repeated commercial thinnings can delay the sharp decline in PAI expected from classical yield tables such as McArdle and Meyer (1961). Using results from the famous levels-of-growing-stock studies, Curtis 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 many 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 shifts in societal values that have led to major shifts 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 managing for “old-growth” characteristics, with related goals of protecting endangered species and fish habitat and promoting biodiversity (FEMAT 1993). The classic paradigm holds that the complex, multiple-story 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 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 0.8 to 4.0 ha, combined with thinning in younger stands; it is ironic that this is almost exactly one of the alternatives to clearcutting regeneration systems that Curtis and Carey (1996) proposed 70 years later. Because of harsh criticism by reasonable forestry experts of the day, partial cutting trials ended abruptly 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 various thinnings from patch cuts to variable density regimes designed to increase within-stand heterogeneity (e.g., Olympic habitat development study, Capital Forest study). The relevant literature on reproductive requirements for Douglas-fir establishment and survival indicates that openings of 0.4 ha or more are needed, or that overstory densities should be <50 percent (Isaac 1930, 1935, 1938, 1943). Worthington (1953) found regeneration success with patch cuts of 0.8-1.6 ha. Curtis (1996) cites unpublished current work on the Oregon State University McDonald Forest that found satisfactory initial establishment on small patch cuts of 0.1 ha and under residual overstories of 20 to 30 trees per ha. 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 and threatens the ability of land managers to manage the late-successional reserves according to the Record of Decision in the NWFP (USDA and USDI 1994b). Emmingham points out that without further management, those stands that have attained multilayer condition may return to single-canopy mature forests before they reach old-growth condition and thereby not attain the conditions desired for nontimber values (e.g. wildlife habitat) nor the flexibility desired for changing management objectives.

How can the links between management actions and stand levels of outputs of goods and services be developed?

A relatively rich literature exists for some products and species. For example, much is known about almost all aspects of Douglas-fir management for wood production in the Pacific Northwest (e.g., Curtis et al.1998). But in general, our knowledge is limited for many other species, and even more so for most nonwood values. Our knowledge is limited even for wood production of some key northwest forest species, such as western hemlock (a climax species over much of the Douglas-fir region). In large part, such limitations result from the singular success of intensive Douglas-fir plantation management for wood production in the past 50 years (Curtis and Carey 1996).

Limitations also result from a failure to bridge the gap between relatively abstract academic research and the high level of empiricism commonly used to manage most forest stands. Although one can view a yield table or growth model projection as an abstraction, land managers invariably combine such forecasts with as much relevant site-specific information as they can. The resulting management prescription is highly site-specific. Contrast this, for example, with work that attempts to explain ecological change based on changes in potential vegetation patterns (e.g., theoretical successional pathways) without any reference to actual current vegetation or site conditions. Another example is older growth and yield work on fully stocked stands rather than the more common case of partially stocked stands.

Progress is being made toward understanding the differences between various yield approaches, broader ranges of management regimes, and between management and a wider range of products. In the past decade, for example, carbon storage has become increasingly more important as a potential mitigating strategy to slow the rate of predicted global warming (Watson et al. 1996). The development of various carbon accounting schemes has become part of inventory modeling research.

Progress also is being made in the development of approaches used to evaluate management direction as it would reasonably be implemented for specific periods. Broad-scale models that simulate forest and range vegetation, disturbances, activity levels, and key variables related to landscape condition are being developed (Spies, in press). These simulated outcomes can be used as input into other analyses directed toward aquatic, terrestrial, and socioeconomic consequences. For both aquatic and terrestrial wildlife species, simulated forest and range vegetation conditions are inputs to empirical or causal relations among factors that influence wildlife species viability.

Less information exists however, on changing public perceptions—and how to properly deal with them—as to what is acceptable forest management. In general, knowledge about how the public makes and expresses choices about acceptability of forest management practices and the roles that different institutions play in these choices, is poor. Related to this is a need to improve understanding of the social and economic acceptability of forest management both on public and private timberlands and how policy actions on one set of ownerships affects conditions on another set of ownerships.

What are the methodological problems in developing broad-scale measures of ecosystem condition and performance?

The tendency to focus on finer scale aspects of problems that are amenable to the scientific method has led to considerable resistance within the scientific community to developing composites of individual measures as broad-scale indicators. A National Resource Council (2000) report describes many of the methodological issues. The forestry scientific community in particular has been slow to embrace the development of broad-scale measures. For example, witness the lack of progress in the United States for using a broad set of criteria and indicators of sustainable forest management. This lack of enthusiasm stems, in part, from the experience of some scientists who find that their issues become less significant—and even insignificant—when working at higher scales. For example, fire risk at the stand level can be catastrophic if there is a fire, but fire risk at the large scale such as the Columbia River basin is a small number (roughly 1 percent per year) and difficult to describe as catastrophic. Ultimately, management—like politics—is local. But policy is broad scale, and policy drives management.

Another significant methodological problem is that work at broader scales has to rest more on simulation techniques and expert judgment models rather than experimentation. Such models often rely on a mix of empirical and judgmental relations. They are used to develop estimates of how changes in input condition (especially those related to land management) result in changes in output measures of performance. Validation is difficult and often consists of examining the soundness of the process relations and the robustness of projected outcomes using sensitivity analysis.

Beliefs of scientists themselves can be a problem. For example, some of the most contentious science issues involve the potential for understanding the extent and nature of tradeoffs that are assumed to occur among biophysical and socioeconomic components of large ecosystems. Much of the framework for this debate has been provided by scientists who often view themselves as advocates for a sustainable biosphere (Risser et al. 1991) and perceive limited opportunities for mutual gains in both biophysical and socioeconomic systems. The natural resource policy debate in the 1990s was often portrayed as involving direct tradeoffs between environmental changes and socioeconomic well-being. The implicit assumption is that this is a zero-sum game, which remains to be seen. This debate has been based on assertions or piecemeal collections of data. Composite measures can be developed to examine the direction and extent of tradeoffs between ecological and socioeconomic conditions as different management strategies are considered. We can postulate, for example, if improving environmental conditions are necessarily coupled with degrading socio–economic conditions, or vice versa. An alternative proposition is that compatibility exists among environmental and socioeconomic changes, at least across a range of options. The challenge is to develop composite measures that act as proxies for discussing these two dimensions and changes that may be projected to occur in ecological and socioeconomic conditions under different management alternatives.

Can broad-scale measures be developed to illustrate compatibility or tradeoffs between biophysical and socioeconomic systems at the ecoregion and national scales?

There is a growing literature in forestry that illustrates the nature and extent of compatible wood production. The interior Columbia basin work discussed earlier, illustrates both in a policy-relevant fashion. Work on salmon and owls by Montgomery and Brown (1992) illustrates practical approaches. Much work also focuses on managing for multiple values (Lippke and Oliver 1993a) and on tradeoffs (Lippke and Oliver 1993b, Weyermann et al. 1991). The larger question is about the role of science in the search for compatibility, in terms of developing the methodological basis and dealing with issues that significantly impact broad-scale science.

First, broad-scale science poses significant challenges for the scientific community. An effective partnership among scientists, managers, and those engaged in the political tasks of governing is essential. The lack of clarity in the socioecological problems that lead to the need for comprehensive broad-scale strategies is frustrating for scientists to quantify. It becomes difficult to distinguish issues reflecting different policy preferences among the governing partnership from those attributable to the lack of information. Furthermore, this lack of clarity around the questions leads to confusion about the appropriate spatial and temporal scale of response to various issues.

Second, the science policy debate during the past decade has been narrowed considerably by asserting ecological limitations but not acknowledging the full scope and complexity of deliberate societal choices. Evidence of this includes the relatively tight grouping of values for ecological integrity and for socioeconomic resiliency shown in figure 7. Although it is true in the case of figure 7 that other alternatives might have been developed to reflect a broader spectrum of potential outcomes, public land managers often seem to have no real incentive to consider a wider array of outcomes.

Third, the shift to managing ecosystems across relatively broad spatial extents stretches the limits of traditional science and of traditional management. The key scientific tool of experimentation (including the concepts of randomization, replication, and control) is essentially impossible to use at the broad-scale. Consequently, “data” must be compiled and synthesized with not only less emphasis on the usual components of experimental science but also with little notion of its reliability.

One useful outcome of the WCI would be to better inform environmental policy discussions in the United States. But we acknowledge that these discussions can be characterized since at least the early 1970s, as a constant conflict among lack of understanding, ideology, and self-interest (see Blinder 1987 and Rolston 2000 for discussion of the roles scientists have played). Scientists can quickly be challenged beyond the limits of their scientific knowledge when asked to predict and interpret broad-scale social and biophysical consequences of management alternatives.

The conceptual model in figure 2 poses parallel challenges for both science and management. We, as scientists and managers often know more about what is in the boxes than we know about the arrows that connect the boxes. For example, management regimes are frequently described as being a sequence of individual practices. We know considerably less however, about how selected management regimes affect the various components of the forest resource base. Most commonly, we know how a management regime impacts timber volumes but relatively less about how it impacts other components. We tend to know more about the traditionally managed species such as Douglas-fir but less about important species types such as western hemlock. In addition to research focused on the traditional areas, there was fairly extensive earlier work that examined the institutional policies and goals in support of multiple use management.

Finally, one dilemma in much of the existing work is the relatively weak links between management actions, forest resource components, and mix of outcomes. Much of the existing work has focused on understanding differences in the inputs rather than the measures of outputs. For example, we have spent much of the last decade studying an aquatic conservation strategy that too often gets reduced to a discussion of buffer widths with scant mention of the results of different buffer widths in terms of habitat conditions or fish populations. This orientation has resulted from the focus of current land management around the implementation of different standards and guidelines imposed by regulatory or quasi-regulatory agencies.

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English Equivalents

When you know:	Multiply by:	To find:
Meters (m)	3.28	Feet
Hectares (ha)	2.47	Acres

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Appendix: Summary of Funded Proposals

The summary of funded proposals (FY98-01) is listed by the major categories shown in figure 2 and the tabulation. Some studies are counted more than once if they address multiple scales. The number refers to study number; the scale of analysis is indicated by S=Stand or Watershed; P=Province level; R=Regional.

Institutional Goals

1. Challenges to linking wood production, biodiversity, and other socioeconomic values at landscape and regional scales. Spies, Johnson, Reeves, Grant. $55K. Scale=P, R.

2. Analytical and empirical modeling of socioeconomic factors influencing land use change in the Pacific Northwest. Alig and Kline. $176K. Scale=R.

3. Involving communities in special forest products. Fight and Christensen. $196K. Scale=S.

Management Actions

4. Influence of silvicultural manipulation and disturbance on edible mushroom productivity. Pilz and Molina. $10K. Scale=S.

5. Augmentation of the Forest Ecosystem Study. Harrington and Carey. $85K. Scale=S.

6. Augmentation of the Olympic Habitat Development Study. Harrington and Carey. $65K. Scale=S.

7. Implementing an adaptive management strategy for young stands in the Central Cascades adaptive management area. Swanson and Cissel. $75K. Scale=S.

8. Effects of silvicultural treatments on young-growth wood quality. McClellan, Deal, Barbour, and Ross. $75K. Scale=S.

9. Density management studies: integration and synthesis. Olson, Chan, Cunningham. $87K. Scale=S.

10. Effects of Swiss needlecast on wood properties. DeBell, Barbour, Johnson, Gardner. $70K. Scale=S.

11. Synthesis of silvicultural actions and habitat. Harrington. $70K. Scale=S.

12. Synthesis of riparian buffer response to silviculture. Cunningham. $70K. Scale=S.

13. Wood compatibility and streamside issues. Boulton and Center for Streamside Studies. $125K. Scale=S.

14. Forest management compatibility at landscape to province scales—tests of approaches in the Oregon Cascade Range. Swanson and Spies. $155K. Scale=P.

Forest Resource Components

15. Compatibility of active riparian management with aquatic and riparian ecosystem integrity of headwater streams. Raphael, Bisson, and Jones. $75K. Scale=S.

16. Accelerate development of aquatic spatial databases and models. Spies, Reeves, Grant, Ohmann. $70K. Scale=P.

17. Relationship of landscape pattern to aquatic integrity. Bisson and Raphael. $171K. Scale=P.

18. Headwater stream function and productivity: response to management of upland young-growth forests in southeastern Alaska. Bryant and Wipfli. $70K. Scale=S.

19. Evaluation of understory for wildlife habitat on commercial thinning trials in southeast Alaska. McClellan, Hennon, and Hanley. $75K. Scale=S.

20. Evaluation and development of growth-and-yield models for the adaptive management of young-growth stands in southeast Alaska. McClellan, DeMars, and Hennon. $60K. Scale=S, P.

21. Analysis and synthesis of yield forecasting methods. Monserud. $169K. Scale=S, P, R.

22. Relating understory vegetation characteristics to overstory characteristics. McGaughey and Reutebuch. $80K. Scale=P, R.

23. Links between understory and special forest products. Vance and Alexander. $129K. Scale=S.

Mix of Outcomes

24. Tree characteristics and wood quality as related to silviculture options. DeBell, Marshall, Gartner, Barbour. $300K. Scale=S.

25. Simulation of wood quality and quantity at the landscape scale. Barbour et al. $88K. Scale=S, P.

26. An evaluation of the compatibility of wood production and ecological integrity at the province level. Spies and Reeves. $327K. Scale=P.

27. Managing young upland forests in southeast Alaska for wood products, wildlife, aquatic resources, and fisheries. Wipfli, Deal et al. $834K. Scale=S.

Values

28. Knowledge-based integrated assessment of compatibility of wood production with other resource values. Reynolds, Stankey, Clark, Kruger. $75K. Scale=S, R.

29. Survey of wood compatibility research: multiple use, tradeoffs, ecosystem sustainability, and joint production. Stevens. $66K. Scale=R.

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