SECTION D

SILVICULTURE STUDIES

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DO LARGE TREES ALWAYS HAVE HIGHER WOOD PRODUCT VALUE?

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ABSTRACT

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

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

INTRODUCTION

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

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

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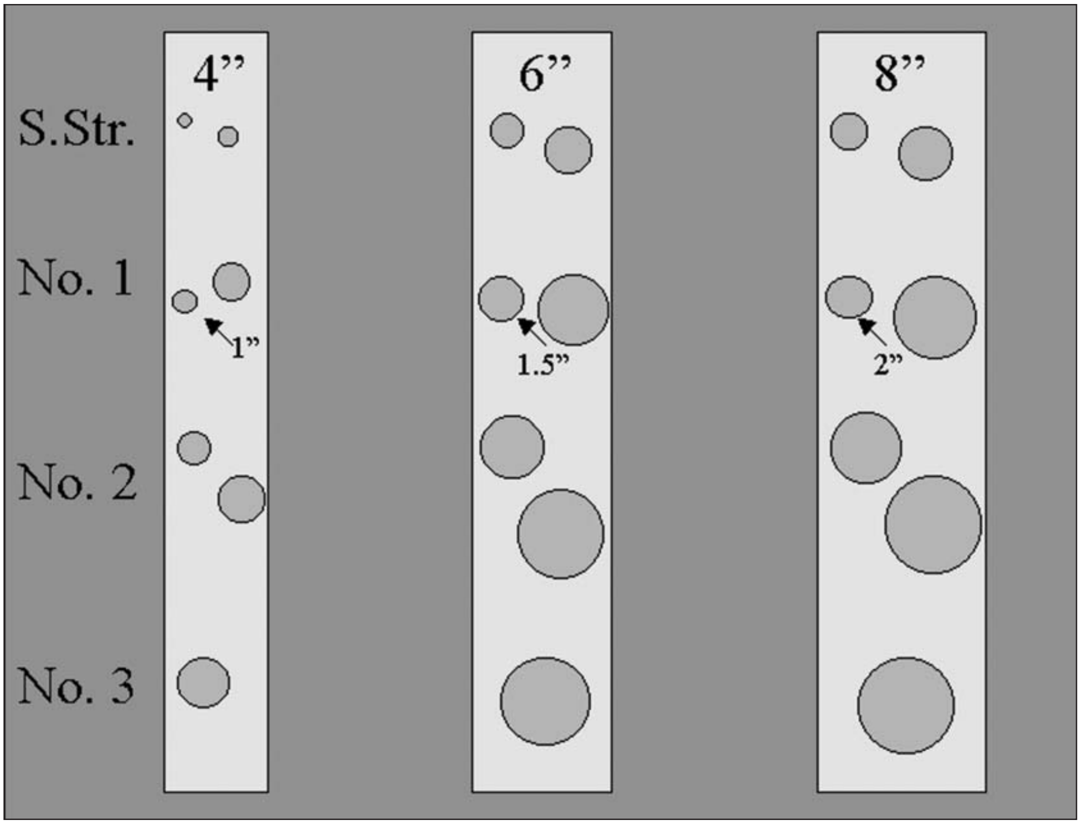

Figure 1—Influence of lumber width on acceptable knot size measurements based on the American Lumber Standards (Western Wood Products Association 1998).

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

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

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

[5] The “matrix” as defined under the Northwest Forest Plan is the land between the other land allocations and it is where most timber management is expected.
[6] Late Successional Reserves (LSRs) are areas designated under the NWFP to support species associated with late successional forests.

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

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

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

Log size, together with the number and size of knots, is therefore important for determining the mix of products manufactured from a given resource. The way public and private landowners choose to manage stand density will influence both stem size and the number and size of knots (Briggs and Fight 1992). In this analysis, we compare differences in lumber grades that are potentially expected from large trees with different ages and management histories. Specifically, we use data from empirical wood product recovery studies to illustrate the product options that are possible from large trees grown under different management scenarios. Subsequent analyses should examine the volumes of logs in different size and quality classes to provide information about the potential structure of the region's future industry.

METHODS

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

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

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

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

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

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

RESULTS AND DISCUSSION

Influence of Age

The age of the older T100 trees increased substantially over the target diameter range (Table 1). Although there is no documented stand level information for the T100 trees, based on their age and when the study was conducted it is likely that they came from mature and old-growth stands that developed without management. The relation between tree age and diameter for the trees in the study from which the T100 trees were selected (Figure 2) is similar to that found in old-growth stands in the Oregon coast range by Tappeiner et al. (1997). Tappeiner et al. (1997) showed that old-growth stands can have a wide range of tree ages, diameters and growth rates, but in most cases the growth rates of the main canopy trees were greater than the understory trees. The trees selected for this analysis presumably came from the younger cohorts and therefore probably had slower growth rates than the main canopy trees.

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

Influence of Knots

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

[7] Lumber manufactured to thickness appropriate for Factory lumber but not meeting the requirements for the No. 3 Shop grade.

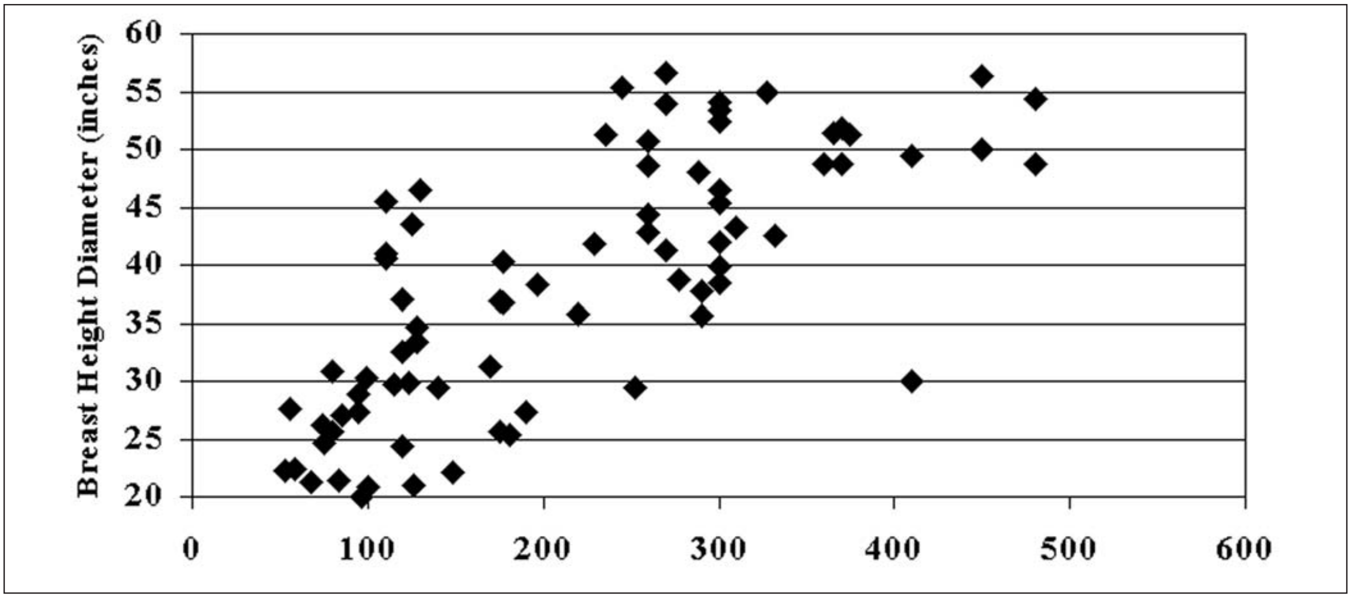

Figure 2—Breast height diameter in inches versus stump ring count for all trees with ages from the T100 data set (Willits and Fahey 1987). These trees display a diameter to age relation similar to that described for old-growth stands in Oregon's Coast Range by Tappeiner et al. (1997).

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

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

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

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

Lumber Grade Yields

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

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

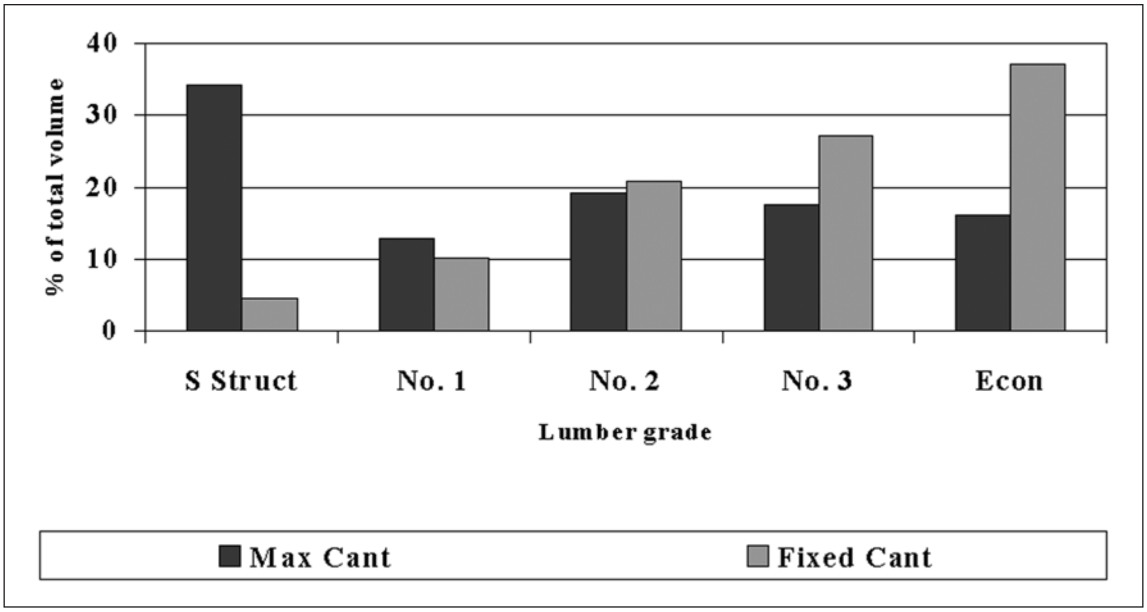

Figure 3—Effect sawing pattern on lumber grade from plantation-grown Douglas-fir logs greater than 20 inches in diameter when they are sawn to a fixed 4 and 6 inch cant widths or to the maximum cant that would fit into the log up to 12 inches (data from McConchhie et al. 1995, Kimberley et al. 1995).

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

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

The results illustrate the point that large young trees grown in ways that maintain fast growth rates might not yield much in the way of high value wood products. These results, however, are not definitive because there were numerous differences in the design and implementation of the empirical studies, the groups of trees were not paired, and the target products from each mill was different. The results do suggest that alternatives to the NWFP that result in harvest of older trees grown under relatively conservative regimes (Carey et al. 1996; Cissel et al. 1999) could result in timber with a wider range of product potential and, therefore, greater economic value, than those grown under the current Northwest Forest Plan.

Financial Implications

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

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

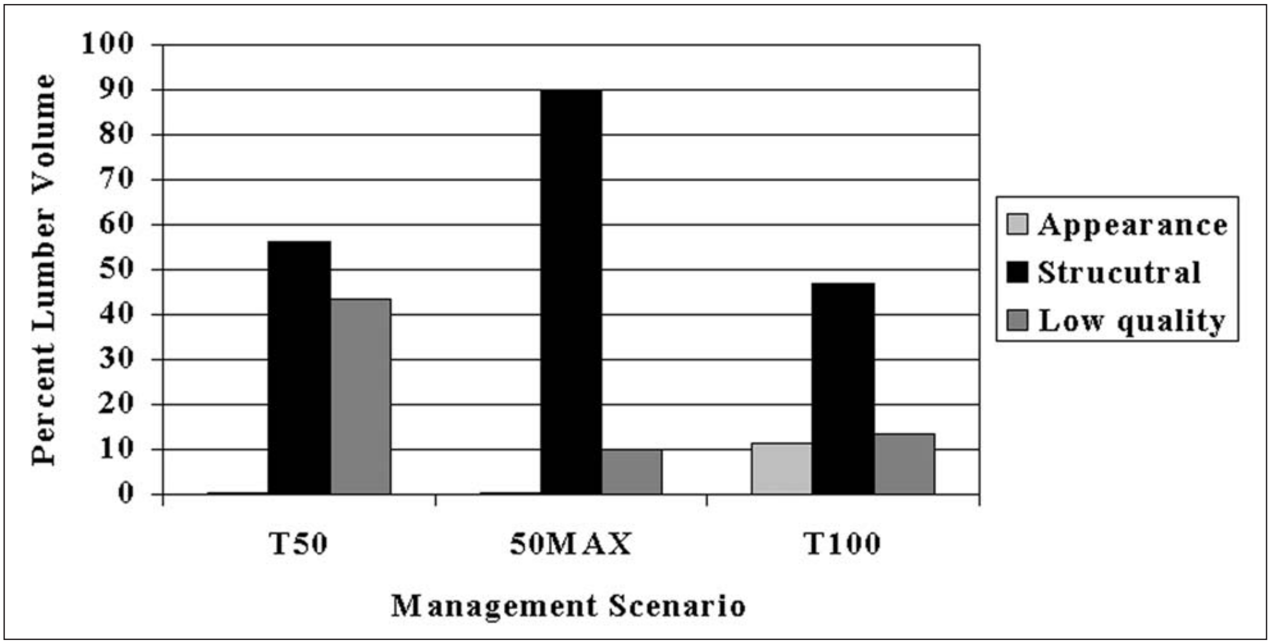

Figure 4—Percent lumber volume for each of three management scenarios used to demonstrate the financial implications of high and low quality lumber (see Figure 3). The T50 represents actual data for large 50 year-old trees sawn into 4 and 6 inch dimension lumber, 50MAX represents the likely yield if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

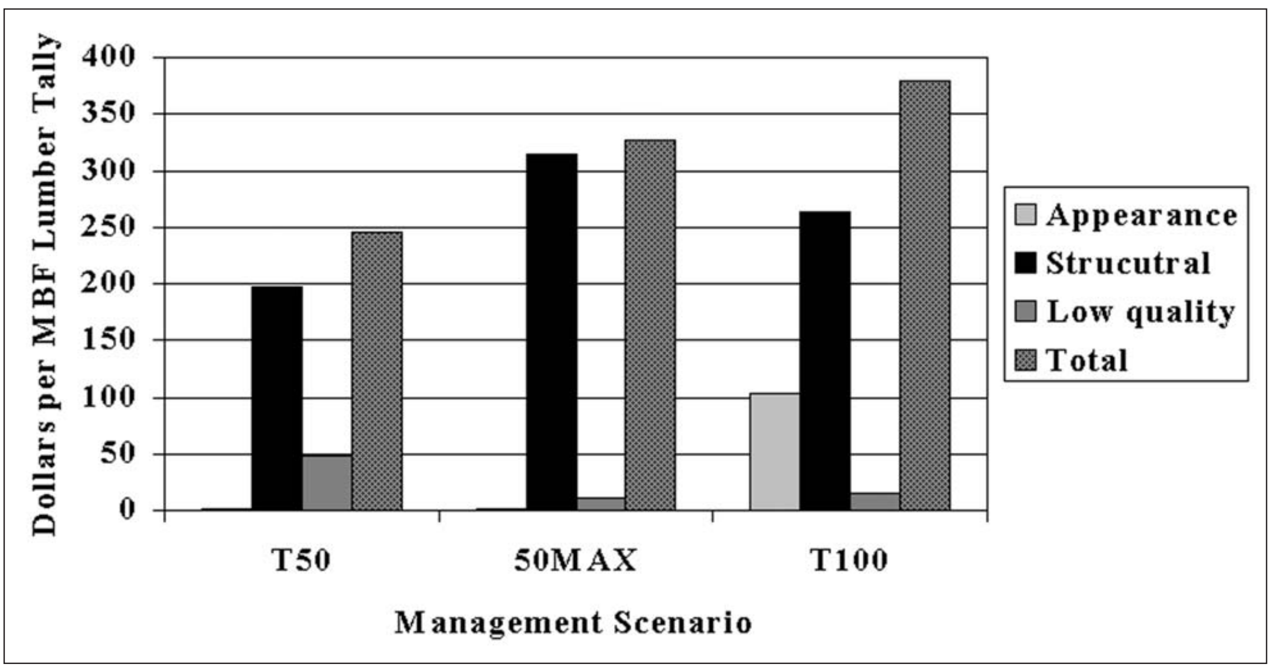

Figure 5—Gross product value for lumber recovered under three management scenarios. The T50 and T100 scenarios represent the gross product value for the corresponding data sets described in the text. The 50MAX scenario represents the T50 scenario where low quality lumber volume was reduced to 10% to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

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

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

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

On the other hand, if attention is paid to product potential and a high proportion of the volume from large trees was in logs, such as those from the later lighter thinning trials described by Barbour and Parry (2001), their processing might not be a problem. Sufficient supply of larger, higher value logs might spur wood processors to find innovative manufacturing options to recover the high value material from the older more slowly grown trees. Alternatives to the existing Standards and Guidelines in the Record of Decision for the NWFP (USDA and USDI 1994) such as those suggested by Cissel et al. (1999) or Carey et al. (1996) might yield large trees with these more desirable characteristics and also meet the other objectives of the NWFP.

CONCLUSIONS

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

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

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ABSTRACT

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

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

INTRODUCTION

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

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

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

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

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

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

EVALUATING WOOD QUALITY AND POTENTIAL SILVICULTURAL IMPACTS

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

Of the species that are found in the northwest, most of the information about wood quality and potential impacts from silvicultural practices is for Douglas-fir. There are several studies which used this information to predict future trends in value. Ernst and Fahey's (1986) analysis suggested that the major impact of the change from old-growth to young-growth logs would be a decrease in log size and a decrease in appearance grade lumber. They suggested pruning to increase the production of clear wood for appearance grades and thinning to increase average size and average recovery. They also pointed out that thinning might also produce larger limbs and a greater proportion of juvenile wood resulting in a decrease in quality. Juvenile wood is the column of wood that forms around the pith of a tree; it has inferior mechanical properties and dimensional stability (Senft et al. 1985). The transition from juvenile to mature wood is not well understood and probably refers to a zone, but this transition is thought to occur about 20 years from the pith in Douglas-fir (Megraw 1986). Maguire et al. (1991) developed models to predict maximum branch size and juvenile wood core for Douglas-fir. Projecting stands with different thinning strategies (both residual density and structure) they found that stand density management could impact branch size, whorl frequency and the amount of juvenile wood produced. Briggs and Fight (1992) used these methods and the TREEVAL model to predict the quality and value of products produced from two stands with widely differing initial spacing (370 and 1,876 trees per hectare). They found that if they ignored tree characteristics other than tree size, the larger trees produced by the wider initial spacing had greater value (1.06 times greater at age 70). However these wider spaced trees also produced larger limbs, had a greater proportion of juvenile wood and lower density wood. Considering the associated tree characteristics and wood properties of the trees produced by silvicultural regimes, the resulting value at age 70 of the denser stand was 1.31 times greater than the widely spaced stand. Barbour et al. (1997) also used these methods to analyze the potential impact on wood quality from ecosystem management on federal lands. They found that management strategies could be designed to accelerate the development of important ecosystem structures while producing wood comparable to that grown in commercial plantations. However, they also concluded that early heavy thinnings would produce greater proportions of lower grade lumber. Use of lighter and later thinning treatments could reduce this impact. To date, little research has been done for Douglas-fir on how fertilization and genetics impact crown lift, juvenile wood formation, branch size and clear wood production.

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

EXAMPLES OF SILVICULTURE AND WOOD QUALITY INTERACTIONS

To demonstrate the importance of considering potential impacts on wood quality from silvicultural practices, we provide four examples of current research. While these results are preliminary, they demonstrate the practical importance of considering wood quality when evaluating silvicultural option. The first two examples demonstrate the importance of stem characteristics and their relationship to wood quality using western hemlock and red alder. This is followed with two other examples that demonstrate how wood properties impact wood quality for black cottonwood (and hybrid poplar) and western redcedar.

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

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

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

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

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

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

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

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

CONCLUSIONS

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

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

Robert A. Monserud[1] and Andrew P. Robinson[2]

ABSTRACT

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

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

INTRODUCTION

After a half century of relying on the economic efficiencies of clearcutting and intensive plantation management (Curtis et al. 1998), the Douglas-fir region of western Oregon and Washington is undergoing a paradigm shift in public perceptions of forest values (Committee of Scientists 1999). The focus has shifted toward old-growth mixed-species management and multi-resource ecosystem management, with related goals of protecting endangered species and fish habitat and promoting biodiversity (FEMAT 1993; Clayoquot Scientific Panel 1995). There is great interest in, and need for, science-based silvicultural practices and management regimes that will reduce conflicts among user groups while providing concurrent production of the many values associated with forest lands on a biologically and economically sustainable basis (Curtis et al. 1998; Committee of Scientists 1999). Silviculturists are examining new management methods, including alternatives to clearcutting such as variable thinning, green tree retention, and variable retention (Arnott and Beese 1997, Coates et al. 1997; Monserud 2002). Often, the goal is to increase rather than decrease structural heterogeneity within a stand and a watershed. In a strong break from the uniform plantation management of the past, these silvicultural alternatives often include mixed-species compositions and an attempt to obtain uneven-aged structures (e.g., retaining legacy trees). The ability to simulate stand growth under increasingly heterogeneous structures and mixed-species compositions is an important aspect of evaluating the compatibility of management alternatives.

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

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

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

CRITERIA FOR EVALUATING MODEL ADAPTABILITY

Robinson and Monserud (in press) developed several criteria that assess the adaptability of forest growth simulation models for extension into new populations and applications. The most important criteria summarize the infrastructure of the model: portability, extendibility, source code availability, and adequate documentation. If these four criteria are met, then all other omissions can be compensated for, if the motivation and resources are sufficient. If lacking, they are the most difficult to compensate for. The next layer of criteria is concerned with model inputs. These criteria are very useful for simulating forest management and reasonably universal in implementation and application. They include site calibration, supporting a variety of sample designs, and imputing unmeasured tree dimensions for a subsample of the trees (e.g., missing heights and crown ratios). The third layer of criteria speaks to the conditions under which simulation is likely required. This is again relatively broad, and generally useful, such as the ability to simulate the effects of silviculture, regeneration, and disturbance. The final and least critical criteria cover the output information required for decision-making. They are the ability to report biomass, wood volume, wood quality, and economic state variables. These outputs would be the easiest to compensate for if lacking.

CANDIDATE GROWTH MODELS

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

CACTOS

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

FPS

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

FVS

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

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

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

ORGANON

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

SORTIE

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

SPS

The Stand Projection System (SPS) is a proprietary forest growth model complemented by a suite of forest management tools, called the Stand Inventory System (SIS) (Mason, Bruce and Girard, Inc. 1988). The system requires that Microsoft Access® be installed, and relies upon and benefits from its database handling capacities. SPS is unusual in that it projects the growth of top height first, with diameter growth following as a function of relative tree size.

ZELIG.PNW

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

RESULTS AND DISCUSSION

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

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

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

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

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

Spatial Information

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

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

ACKNOWLEDGMENTS

This research was supported by a research grant from the Wood Compatibility Initiative, PNW Research Station of the USDA Forest Service. We thank Richard Haynes for his support.

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

Constance A. Harrington[1], Karl R. Buermeyer[2], Leslie Chandler Brodie[3], and Bryan W. Wender[4]

ABSTRACT

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

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

INTRODUCTION

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

DEVELOPMENT OF UNDERSTORY VEGETATION AFTER THINNING

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

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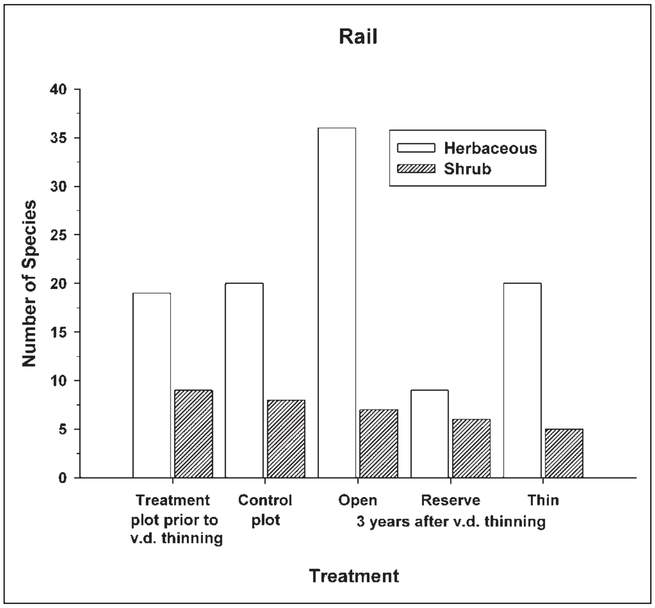

Figure 1—Number of herbaceous and shrub species at the Rail study area of the Olympic Habitat Development Study in an untreated control plot and in a thinned plot, before and 3 years after, implementation of a variable-density thinning. The "open," "reserve," and "thin" designations represent the three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

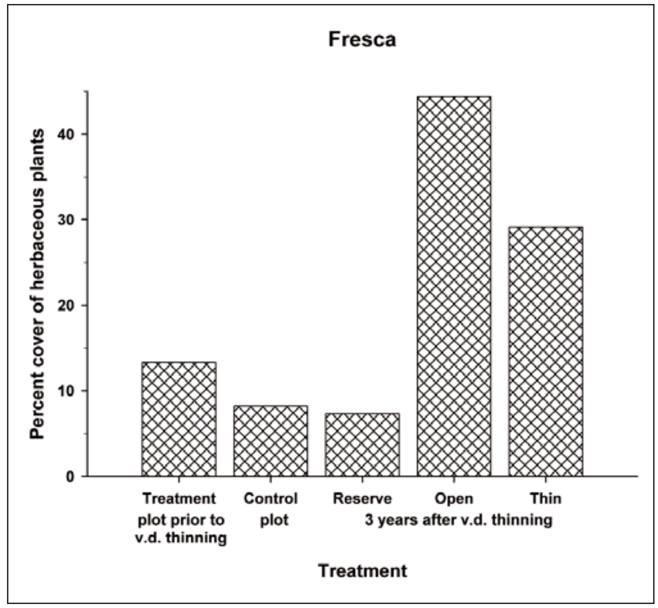

Figure 2—Percent cover of herbaceous plants at the Fresca study area of the Olympic Habitat Development Study in an untreated control plot and in a thinned plot, before and 3 years after, implementation of a variable-density thinning. The "open," "reserve," and "thin" designations represent the components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

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

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

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

1. Number of herbaceous species was least in the unthinned areas (control plots and uncut or reserve portions of thinned plots), greatest in the openings or gaps, and intermediate in the thinned areas (Figure 1).

2. Number of shrub species did not differ among the unthinned areas, the gaps, or the thinned matrix (Figure 1).

3. The greatest numbers of tree seedlings in both blocks were western hemlock. Bigleaf maple seedlings were only found in open areas.

4. Percent cover of herbaceous plants was greatest in the openings (Figure 2).

5. Percent cover of shrubs at the Fresca block prior to variable density thinning was low (< 2%); shrub cover post-thinning remained low but exhibited the expected pattern of % cover in the open > % cover in the thinned areas > % cover in the uncut areas.

6. Percent cover of shrubs at the Rail block prior to treatment was patchy but overall was much higher than at the Fresca block; shrub cover 3 years after treatment at Rail

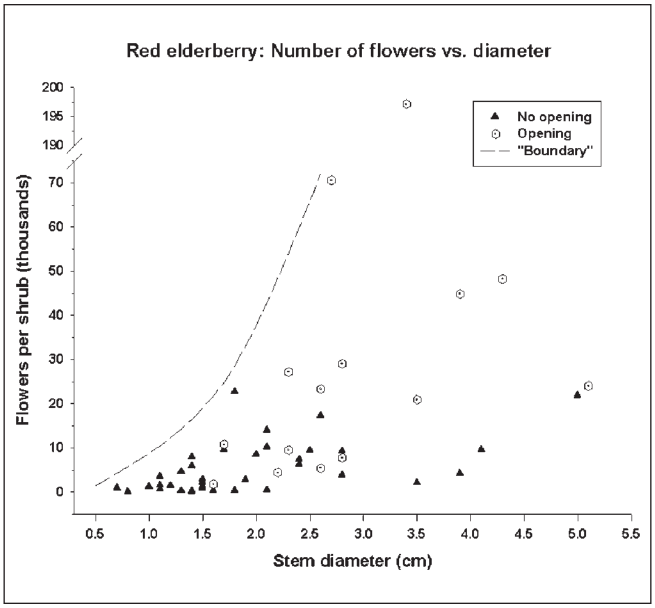

Figure 3—Relationship between number of red elderberry flowers per plant and stem diameter. The dashed line represents the upper boundary of the data. Note the tendency for plants in canopy openings to be larger in diameter than those not in openings and, for the same stem diameter, for plants in openings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

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

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

FLOWERING OF SHRUBS IN FOREST UNDERSTORIES

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

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

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

Results from the flowering study indicated:

1. These species are adapted to growing in forest understories and the majority of plants flowered regardless of the light conditions.

   a. About 65% of plants flowered for Oregon grape, vine maple, and evergreen huckleberry,
   b. 85-90% of plants flowered for Indian plum and hazelnut, and
   c. 96-98% of plants flowered for salal, red huckleberry, and red elderberry.

2. Ages of sampled stems ranged from 1 to 64 years (not all plants were aged); four species had sampled stems > 20 years old (vine maple, hazelnut, evergreen huckleberry, and red huckleberry).

3. Species with the greatest maximum sizes had the greatest range in diameter or height.

4. The line that passes through the highest value of the dependent variable at each level of the independent variable defines the upper boundary of the points and may reveal the underlying relationship between the variables when other factors are not limiting. Boundary lines indicated possible relationships between number of flowers and some of the measured variables (Figure 3).

5. Predicting number of flowers from shrub size or age, overstory characteristics, light, and site variables was not very successful (R^2 values were never > 0.50 for models with one or two variables).

6. Characteristics of shrub size, especially stem diameter, were almost always the best predictors of number of flowers (Figure 3). Large shrubs were not only more likely to flower and produce seed, they also contribute to vertical structure in forest stands (Figure 4).

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

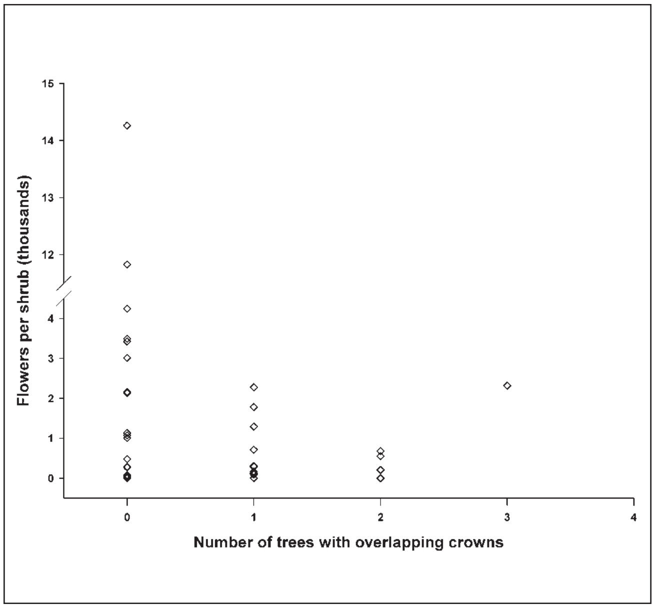

Figure 5—Relationship between number of evergreen huckleberry flowers per plant and number of trees whose canopies overlap the huckleberry plant canopy.

7. Three species—Indian plum, red huckleberry, and evergreen huckleberry— had improved prediction models for number of flowers if percent light, presence of a canopy gap or overstory characteristics were included; overall, these species also had the best fit models (Figure 5).

8. Salal, Oregon grape, and vine maple had the poorest fit prediction models for flowering. These clonal shrubs may share resources among above-ground stems, thus allowing stems in poorer environments to persist and flower. See Management Implications for more information on clonal shrubs.

9. Analyses that predicted which plants flowered did not select the same variables as the models predicting number of flowers (based on plants which *did* flower).

10. Direct measurement of light was only significant for Indian plum; thus, direct measurements (which require specialized equipment) may not be necessary to predict flowering.

HEIGHT GROWTH OF UNDERSTORY TREES

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

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

Results were:

1. Trees in understory positions were found for all three species (Douglas-fir, western hemlock, and western redcedar) on several plant associations (except no Douglas-fir was present on the wettest plant associations).

2. For all three species, height growth was best on the "moist" sites.

3. For all three species, height growth prediction equations were better when done individually for the four moisture classes than when all moisture classes were combined.

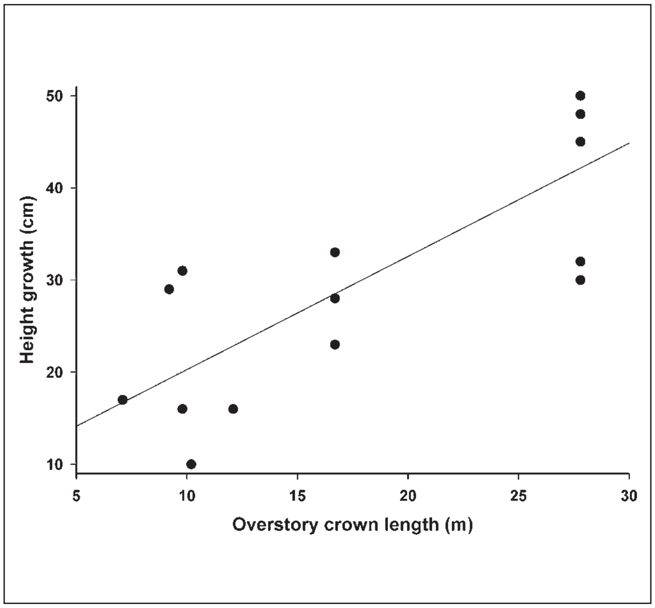

Figure 6—Relationship between 3-year height growth for Douglas-fir seedlings and saplings and mean of overstory trees crown length on plant associations classified as "dry" ($R^2 = 0.64$).

4. For 7 of the 11 species-moisture class combinations, a variable measuring tree size or size ratio was the first or only variable in the models predicting 3-yr height growth.

   a. Length of the live crown or live crown ratio was the best variable for predicting growth in several of the species-by-moisture-class models.
   b. Height/diameter ratio and stem volume were also selected but used in fewer models.

5. The model fit varied substantially among the species-moisture class combinations.

   a. Models were least successful for western hemlock (the best models had R^2 values of 0.35 and 0.37 for western hemlock on wet and mesic sites, respectively).
   b. Best-fit models were for Douglas-fir on dry sites ($R^2 = 0.71$) and western redcedar on moist sites ($R^2 = 0.83$). See Figure 6.

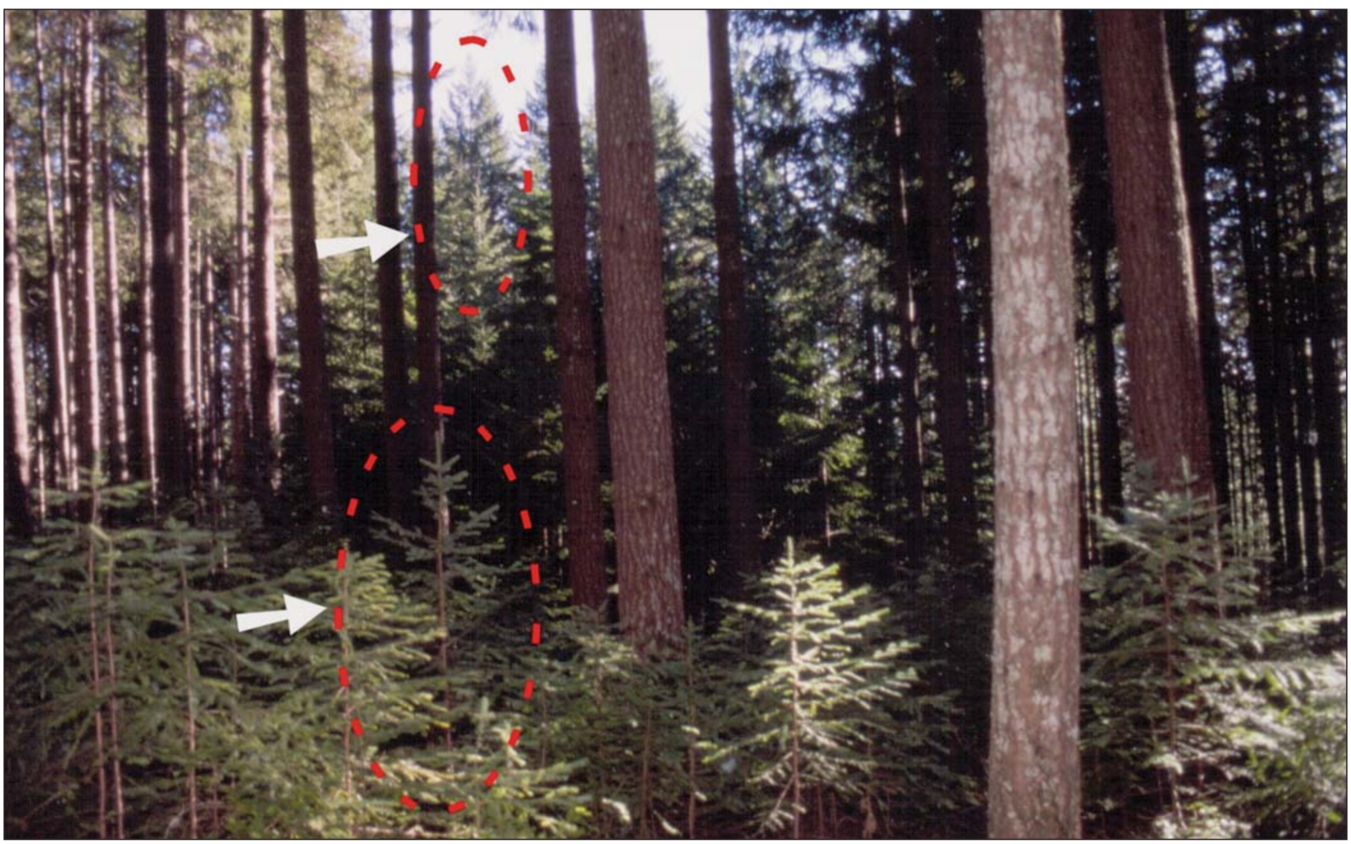

Figure 7—Many tree species will regenerate under a forest canopy but their future growth will depend on both overstory characteristics as well as site conditions. For example, the two groups of Douglas-fir saplings, indicated by the arrows above, are the same age but differ substantially in size.

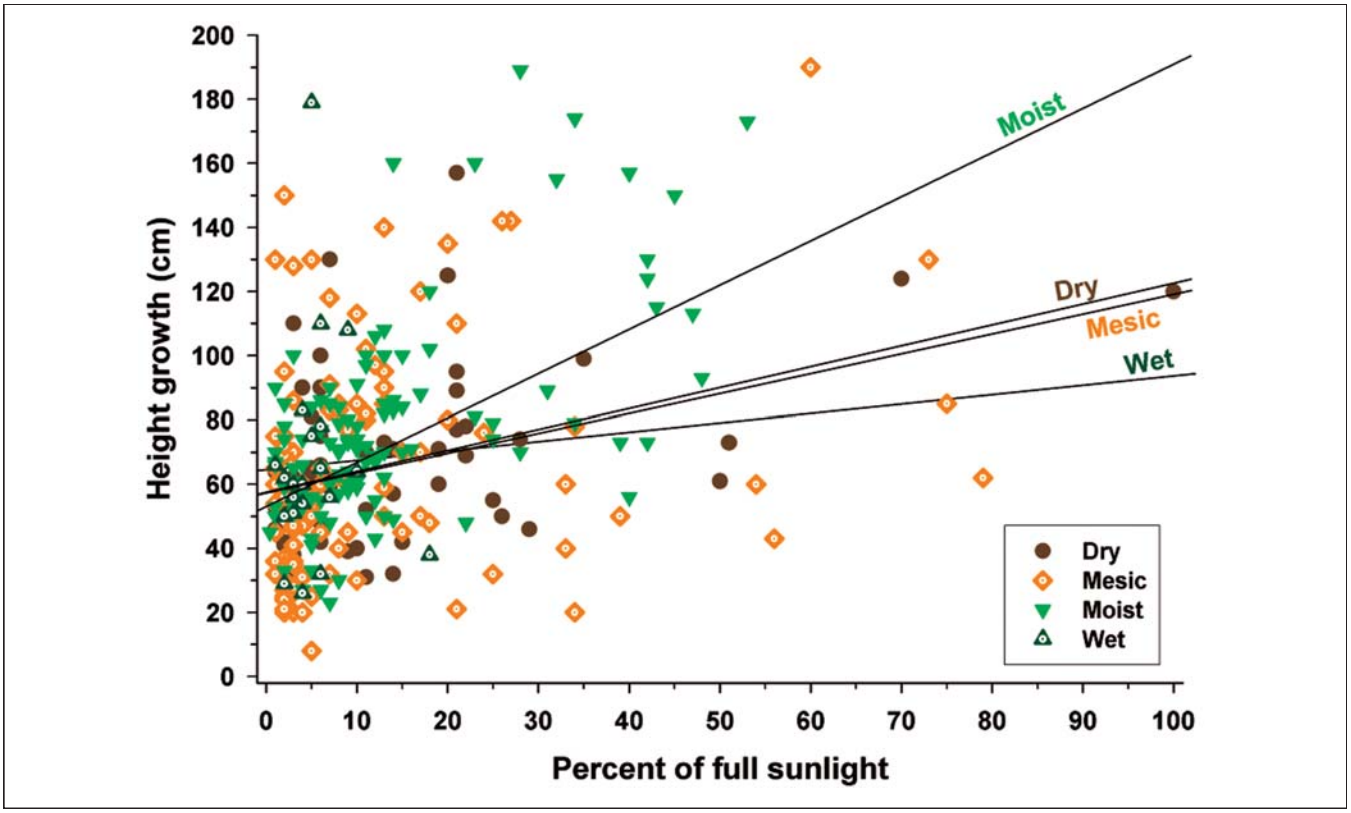

Figure 8—Relationship between 3-year height growth for western hemlock and percent of full sunlight by moisture class. Note that the regression line is steepest for the "moist" moisture class and the relationship is weak for the other three moisture classes.

6. Overstory characteristics were important variables in some height-growth prediction models, but the overstory characteristic selected varied among the species by moisture class combinations.

7. Growth rates of understory trees can differ substantially based on overstory conditions (Figure 7).

8. Overstory characteristics selected for models may provide clues to the factors limiting tree growth. For example, the fact that the best-fit model for western redcedar on dry sites includes basal area may indicate root competition is important as basal area is probably correlated with below-ground competition. On the other hand, selection of mean overstory crown length in the Douglas-fir model may indicate that light is more limiting growth than moisture on these sites; this would be consistent with the lower shade tolerance of Douglas-fir compared to western hemlock or western redcedar.

9. Five of the 11 models selected a light variable but the light variable selected the most, sunpath, was one that does not require specialized measurement equipment or software, or favorable weather and sun conditions.

10. Effects of light were most important on moist sites (Figure 8). This does not mean light was not a factor influencing growth on drier sites, merely that other variables were more strongly correlated with growth on the drier sites.

MANAGEMENT IMPLICATIONS

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

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

- Short-term understory response is strongly influenced by pre-treatment conditions (environmental conditions, presence of established plants, and seed sources) as well as type of treatment.

- Substantial spatial variation can exist in pretreatment cover and species composition; post-treatment response can be assessed more sensitively if pretreatment information is collected and used in the analysis.

- Salal, Oregon grape, vine maple, and salmonberry are examples of clonal shrubs. Although they reproduce by seed, they also reproduce vegetatively (via rhizomes, underground stems, or layering) to form large clonal colonies. Clonal shrubs (especially salal and salmonberry) can expand in cover very quickly when environmental conditions are favorable.

- Clonal shrubs may share resources so variations in growing conditions may be “averaged” within the clone.

- Thinning often favors expansion of clonal shrubs; thus, when they are present, different prescriptions may be necessary to achieve desired understory conditions.

- Large, older individuals of desired shrub species should be considered as legacies to be protected during thinning or other forest operations.

- Repeated thinning will accelerate the production of large diameter trees but may also introduce non-native species and promote development of dense understories. These conditions could delay or prevent the development of plant communities associated with late-successional stands. On the other hand, individual species characteristic of late-successional stands—such as western hemlock—will benefit from thinning. Managers need to determine which species, communities, or structures to target in prescriptions for individual stands.

- Variable density management, practiced on a stand basis (variation in density within a stand) or a landscape basis (varying density from stand to stand) has the potential to accelerate production of large diameter trees in some areas while maintaining optimal conditions for specific vegetation in other areas.

- Release of individual trees rather than a general thinning may prevent undesirable understory conditions from developing on some site types or plant associations.

- “No cut” patches within stands or uncut stands should also be “no entry” areas to prevent ground disturbance to reduce spread of exotic plants and expansion of less desired native species. No-cut patches may also be valuable to protect older shrubs.

- Adoption of one or a few “best guess” management prescriptions over a large portion of the managed forest landscape could result in producing many stands with undesirable vegetation characteristics. Responses to prescriptions should be monitored to verify that they are effectively meeting management objectives.

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

- Models predicting growth or percent cover for plants in understory or midstory positions are often more complex and less accurate than models for overstory tree growth because plants below the main canopy are growing in a more complex competitive environment. Predicting functional attributes, such as flowering, is even more difficult.

- Models will vary by species and most will be improved by inclusion of variables that assess site conditions (such as moisture class) or variables that assess overstory competition. Variables selected in prediction models may provide clues to indicate which growth factors are limiting.

- A simple inexpensive technique of measuring light availability (“sunpath”) gave superior results in models predicting height growth to techniques that require expensive specialized equipment and software.

SUGGESTIONS FOR FURTHER READING

New Management Ideas or Techniques
Carey et al. 1999
Curtis et al. 1998
DeBell and Curtis 1993
Franklin 1989

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

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

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

Exotic Plant Species
Heckman 1999
Soule 1990
Duncan 2001

Other Topics
Franklin et al. 1986
Lieffers et al. 1999

ACKNOWLEDGEMENTS

We thank the following organizations for allowing access to their land: Olympic and Mt. Baker-Snoqualmie National Forests, Southwest Region Washington State Department of Natural Resources, Simpson Timber Company, Green Crow, Cowlitz Ridge Tree Farm, City of Hoquiam, Quinault Indian Nation.

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

Randy Johnson[1] and Sara Lipow[2]

ABSTRACT

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

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

INTRODUCTION

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

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

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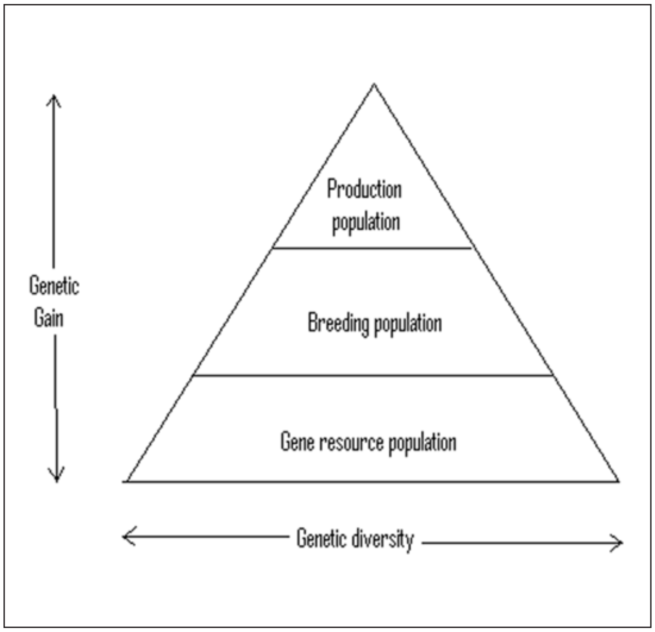

Figure 1—Conceptualization of gain versus genetic variation for a gene resource management program (from Burdon 1995[3]).

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

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

In the Pacific Northwest, the Pacific Northwest Forest Tree Gene Conservation Group has supported an effort to document the status of the gene resource and breeding populations of eight commercially important conifers (St. Clair and Lipow 2000). For all eight species (*Abies procera* Rehd., *Picea sitchensis* (Bong.) Carr., *Pinus ponderosa* Dougl. ex Laws., *Pinus lambertiana* Dougl., *Pinus monticola* Dougl. ex D. Don, *Pseudotsuga menziesii* (Mirb) Franco, *Thuja plicata* Donn ex D. Don, *Tsuga heterophylla* (Raf.) Sarg.), extensive and sufficient genetic resources are conserved *in situ* through much of the species regional range. However, for *Pinus monticola* and *Abies procera* there are a few local areas that may warrant additional gene conservation.

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

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

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

[3] Presentation given at the Western Forest Genetics Association meeting, 28 August 1995, Victoria, British Columbia.

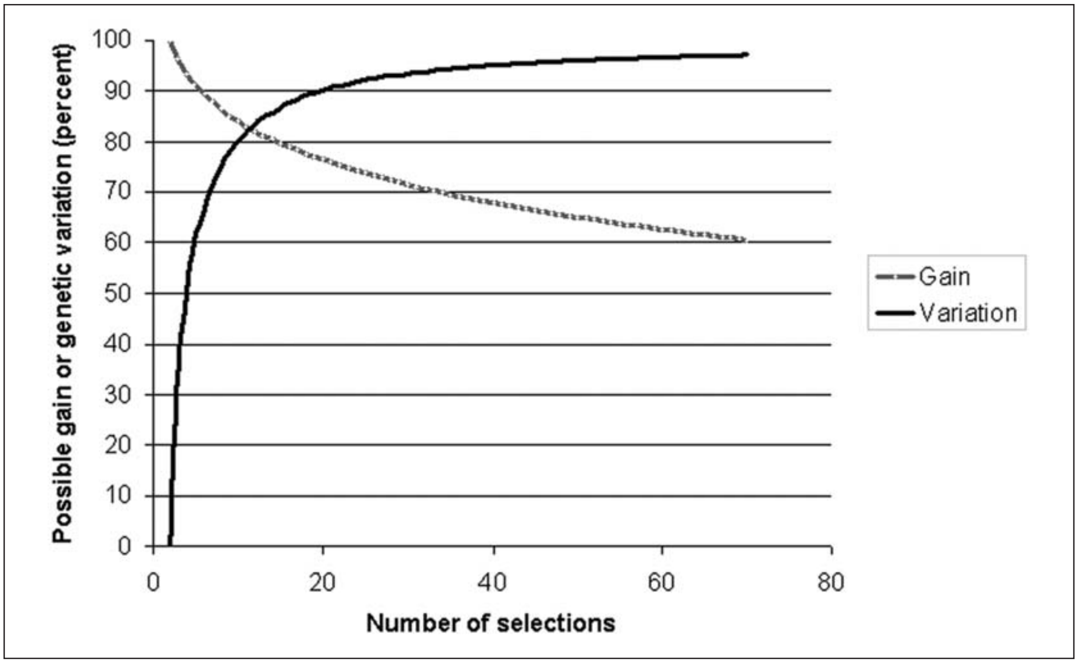

Figure 2—Example of genetic variation and genetic gain associated with seed orchards of differing numbers of clones. Genetic variation is modeled for Ne=N/2.

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

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

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

Theoretical Calculation of Genetic Variation

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

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

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

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

(Johnson 1998).

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

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

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

Direct Measures of Genetic Variation Coming from Seed Orchards

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

- Percentage of polymorphic loci (%P) –the percentage of loci that have more than one detected allele. The %P is partly a function of the population sample size, because low-frequency alleles are more likely to be observed in larger samples.

- Allelic diversity–the mean number of alleles (A) and the mean number of alleles per polymorphic locus (A_p).

- Expected proportion of heterozygous loci per individual (H_e)–reflects the heterozygosity that would be expected in a population experiencing Hardy-Weinberg equilibrium. It is a function of the proportion of polymorphic loci, the number of alleles per polymorphic locus, and the evenness of allele frequencies within population. It is computed as

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

where p_i is the mean frequency of the ith allele and is averaged over all loci.

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

Studies Confirm Similar Genetic Variation in Seed Orchards and Natural Populations

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

In most studies, the values of %P and allelic diversity (A and A_p) did not differ substantially between the means of the natural populations and the seed orchards. This is exactly as theory predicts. Moreover, the capture of genetic variation in the seed orchards was likely enhanced by differences in sampling methods between the natural populations and the seed orchards. Sampling of natural populations was typically restricted to a single stand, whereas the selections in seed orchards were usually chosen from numerous stands, adding additional opportunities for picking up alleles. Indeed, when selections in a Sitka spruce orchard were sampled across an atypically large area, the %P and A were actually higher in the orchard than in any one sampled natural population (Chaisurisri and El-Kassaby 1994). Additionally, contamination by alien pollen led to higher allelic diversity in the seed produced by an interior spruce orchard relative to the mean of the natural populations (Stoehr and El-Kassaby 1997). Pollen contamination also may have been responsible for the novel alleles detected in the seed orchards of the other species (El-Kassaby and Ritland 1996b; Godt et al. 2001).

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

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

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

Only one study has directly compared genetic variation in seed orchards at various stages of improvement. El-Kassaby and Ritland (1996b) examined allozyme diversity in 12 first-generation Douglas-fir seed orchards before and after roguing, as well as in four second-generation seed orchards. They report that H_e, %P, and A did not differ significantly among the various orchard populations. Nevertheless, at each stage in the domestication process, some rare and local alleles were lost. These results are backed up by two studies of simulated roguing of first-generation seed orchards (Godt et al. 2001; Stoehr and El-Kassaby 1997), both of which show that expected heterozygosity remains high even if up to 50 percent of the orchard parents are removed. The number of alleles per locus drops more rapidly with roguing than does expected heterozygosity, as would be expected with any genetic bottleneck.

RISKS

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

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

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

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

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

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

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

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

Table 1 (continued)—Means and population ranges (in parenthesis) of percentage of polymorphic loci (%P), mean number of alleles (A), mean number of alleles per polymorphic locus (A_p), expected proportion of heterozygosity (H_e), and observed heterozygosity (H_0) from seed orchards (SO) and the natural populations (NP)

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

[a] 300 progeny per population with 50 families X 6 progeny.
[b] In Szmidt and Muona 1985 embryos and not adult tissue were examined in both the SO and NP. Also, 3 seed crops from 3 different years were studied per SO.
[c] El-Kassaby and Ritland (1996a, 1996b) considered a locus to be polymorphic only if the frequency of the most common allele was less than 0.95.

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

CONCLUSION

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

ACKNOWLEDGMENTS

We thank Rich Cronn, Nancy Mandel, Frank Sorensen, Cheryl Talbert, and Alvin Yanchuk for their helpful comments.

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SECTION E

NONTIMBER FOREST PRODUCTS

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Proceedings from the Wood Compatibility Initiative Workshop, number 19.

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

Nan Vance[1], Andrew Gray[2], and Bob Haberman[3]

ABSTRACT

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

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

INTRODUCTION

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

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

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The Forest Service has conducted resource assessments for over 60 years mandated by the McSweeney-McNary Forest Research Act of 1928. Authorized by Congress to inventory the forest resources of the United States, the FIA program, under the Deputy Chief for Research and Development, completed at least one inventory of forest resources for each of the 48 conterminous states. Focusing primarily on the timber resource, statewide inventories were conducted over varying intervals averaging about 10 years nationwide until the 1960s and 1970s. In response to the need for more frequent inventories that provide information about other resources besides timber, the 1974 Resources Planning Act and the1978 Resources Research Act began to change inventory scope and frequency.

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

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

BACKGROUND

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

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

Forest Inventory and Analysis plot data is effective when used with other resource inventories to fill in sampling gaps and broaden the scope of information (Ohmann and Spies 1998). The data have been used (about one third of all the plots used) with other resource inventory data from sampled plots on Bureau of Land Management (BLM) districts and national forests to develop regional-scale patterns of woody plant community structure (Ohmann and Spies 1998). The authors demonstrated that, despite some limitations in direct gradient analyses, multivariate analysis of the data enabled the quantification and mapping of regional ecological patterns of a subset of forest vegetation. The FIA data were also used to develop predictive models for the distribution and abundance of shrubs (Kerns 2001). Explanatory variables differed by land ownership (public, private industrial, private non-industrial); nevertheless trends in shrub abundance in relation to stand closure and different successional stages were found. Environmental variables also were correlated with deciduous shrub abundance. Kerns concluded that on FIA surveyed lands, variable site and disturbance histories, and other factors precluded developing strong regression models of shrub abundance based on the forest stand data used in the analysis. For selected understory species, life form, or functional groups, data produced under the sampling protocol is perhaps not sufficient for statistical analyses to make reliable inferences or predictive models.

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

A multiple regression approach used on the database assumes that correlations between independent and dependent variables, such as stocking and species cover, are derived from a sampling scheme that represents the range of stocking in which the species is found. It also requires a sufficient number of plot samples to span a range of environmental and forest stand-specific variables, such as stocking conditions, within the species' range. In addition, stratification by such factors as stand type or ownership may reduce variation, but meaningful analysis requires that each factor be sufficiently distributed across the sampled landscape to include enough variation in forest conditions and a large enough range of environmental values for correlating with abundance and cover.

METHODS AND APPROACH

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

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

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

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

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

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

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

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

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

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

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

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

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

DISCUSSION

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

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

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

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

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

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

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

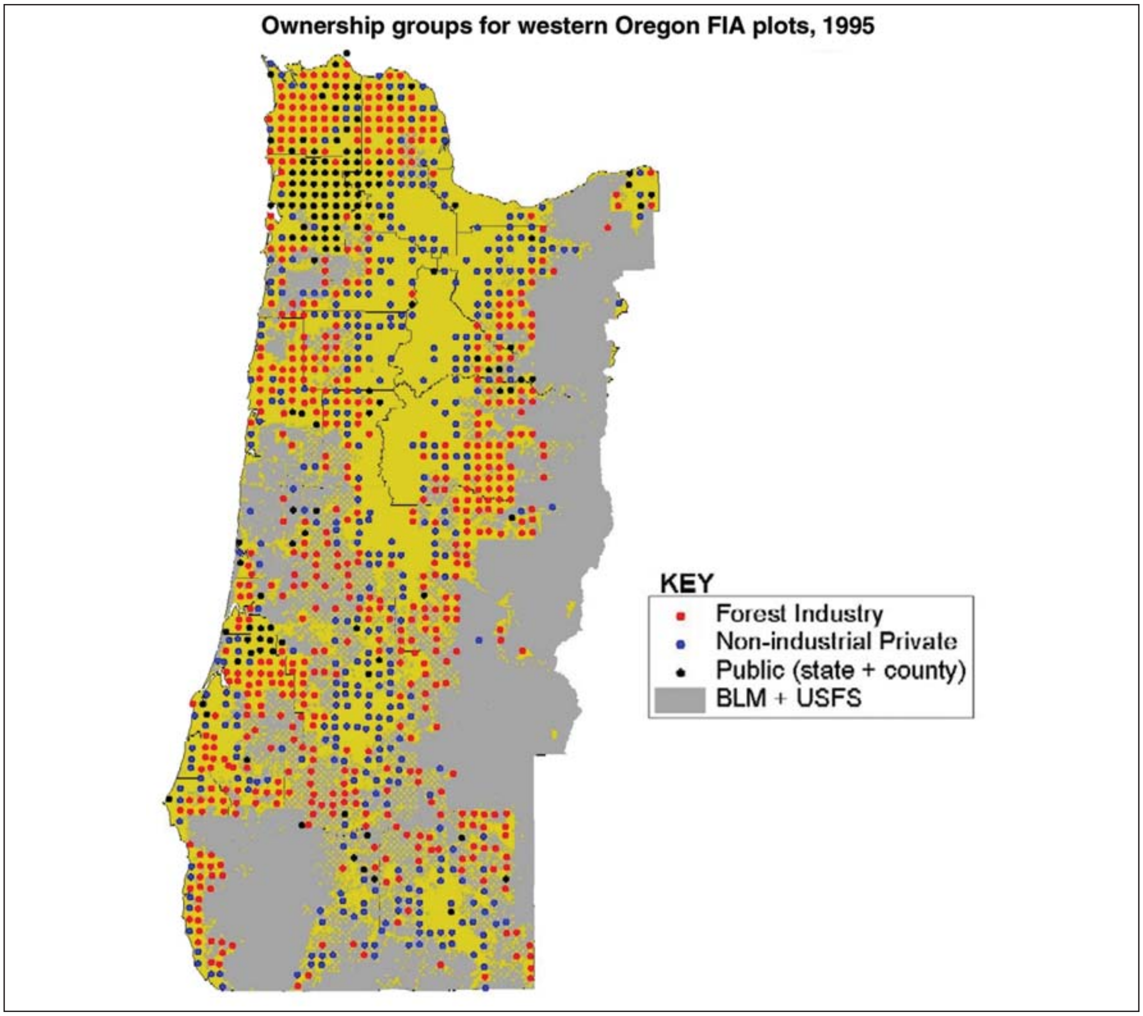

Figure 1—Map of Forest Inventory and Analysis (FIA) plots by land ownership groups in western Oregon.

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

CONCLUSIONS

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

ACKNOWLEDGMENTS

We wish to thank Vicente Monleon for his comments and advice on the statistical analysis, and Pat Cunningham, Joe Donnegan, and Becky Kerns for their helpful reviews of the manuscript.

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Proceedings from the Wood Compatibility Initiative Workshop, number 20.

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

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ABSTRACT

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

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

INTRODUCTION

Nontimber forest products (NTFP) are derived from biological resources collected in forests and grasslands for personal, educational, commercial, cultural, recreational and scientific use. Examples include foods such as huckleberries (*Vaccinium membranaceum*), floral greenery such as salal (*Gaultheria shallon*), and medicinal products like cascara (*Rhamnus purshiana*). In the Pacific Northwest, the harvest and sale of understory species is a multimillion-dollar commercial industry that employs over 10,000 persons in seasonal and permanent positions in this region (Blatner and Alexander 1998; Schlosser et al. 1991). For example, since 1992, the value of U.S. moss and lichen exports has been increasing steadily, with as much as $13 million worth of moss and lichens exported from the Pacific Northwest in 1998. The greatest value in U.S. foliage exports comes from fresh foliage; salal is one of the most significant wild-harvested understory species exported from the Pacific Northwest. Because many of these exports are wild-growing, mostly native species (Alexander et al. 2002, Vance et al. 2001), exact amounts are often difficult to calculate from U.S. Census export data.

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

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

NONTIMBER FOREST PRODUCTS INVENTORY ASSESSMENT

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

Inventory and Monitoring Methodology

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

Strategies used to assess resource conditions and trends can be broken into three key areas: (1) descriptive and nonstatistical, (2) statistical, scientific and research (hypothesis testing), and (3) holistic. Descriptive and nonstatistical approaches include using local knowledge, ethnographic methods, species checklists (presence/absence) and historical photos. For example, in an ethnobotanical study, a researcher might conduct interviews to compile a list of plants used by local people that occur in a particular area. Some biodiversity assessments, such as Conservation International’s Rapid Assessment Program (e.g., Killeen and Schulenberg 1999), include only species’ presence and absence because quick assessment of an unknown area is the primary goal. Historical photos and repeat photography are commonly used to document vegetation change (Hall 2001; Hasting and Turner 1965). Descriptive and nonstatistical inventories yield important information regarding species distribution and abundance, are generally relatively inexpensive to conduct, and provide a context for local use, history and customs. These types of studies provide limited or no information for specific objectives such as quantitative biometric analyses and predictive modeling.

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

For monitoring activities, sampling designs and measurement techniques should be selected so that error values are low. This is particularly true when it is important to detect small changes. Monitoring also requires that accurate measurements be made on plant species or products to detect changes that are biologically, ecologically and/or socioeconomically significant. Consultation with a statistician is highly recommended before starting a new monitoring project. Additional information on monitoring is in Ferriss-Kaan and Petterson (1992), Goldsmith (1991); Elzinga and Evenden (1997); and Elzinga et al. (1998).

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

Using Existing Databases

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

The 1998 Agricultural Research, Extension, and Education Reform Act contained several mandates that directed the USDA Forest Service FIA Program to make significant changes in inventory methods, including switching to annual surveys, developing a core program that will be implemented consistently across the USA, including the USDA National Forests, and producing comprehensive state reports at five-year intervals (Gillespie 1999). Achieving consistency and linking databases in federal agency resource monitoring programs is now a high priority (Olsen et al. 1999). In the Pacific Northwest, implementation and merging of FIA/FHM and NFS inventories is currently underway.

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

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

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

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

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

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

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

FOREST MANAGEMENT, SILVICULTURE AND UNDERSTORY SPECIES

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

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

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

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

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

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

CONCLUSIONS

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

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

Achieving consistency among and linking databases in federal agency resource monitoring programs is another high priority issue and is currently in progress. Yet it is unclear if this will be cost-effective for the type of nontimber information that is collected (Kerns et al. 2002). Federal resource inventories contain limited or no information on temporally and spatially ephemeral species such as edible mushrooms, bryophytes and lichens, many herbaceous species, and rare and low cover species. Moreover, data are not currently collected regarding product quality and spatial grids and temporal scales are frequently inadequate for local planning efforts. Lack of fine scale inventory and monitoring data, coupled with complex social and biological interactions that are poorly understood, currently hampers the development of both local and broadscale measures for nontimber products.

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

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

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SILVISHROOMS: PREDICTING EDIBLE ECTOMYCORRHIZAL MUSHROOM PRODUCTIVITY

David Pilz[1], Randy Molina[2], Eric Danell[3], Richard Waring[4], Catherine Rose[5], Susan Alexander[6], Daniel Luoma[7], Kermit Cromack[8], and Charles Lefevre[9]

ABSTRACT

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

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

INTRODUCTION

Edible mushrooms have been harvested from forests for as long as humans have foraged in woodlands, but in the later part of the 20th century, commerce in forest mushrooms became global, and annual international trade is now worth billions of U.S. dollars. A large portion of this trade is derived from the sporocarps (fruiting bodies) of fungi that grow symbiotically with trees by forming ectomycorrhizae (Figure 1), a nutrient and water exchange structure consisting of fine tree roots and an enclosing sheath of fungal tissue. Ectomycorrhizal (EM) fungi act as an extended fine root system for trees and, in return, they obtain carbohydrates from host tree photosynthesis. These carbohydrates are one reason that EM fungi can fruit copiously each year if weather is favorable. Depending on the species, sporocarps of EM fungi can be mushrooms that fruit above ground or truffles that fruit below ground. Well-known edible EM fungi include chanterelles, matsutake, boletes, and truffles. Some edible EM fungi occur in the tropics and in inoculated plantations in the Southern Hemisphere, but most grow in temperate and boreal forests of the Northern Hemisphere with tree species in the Pinaceae and Fagaceae. Work is underway to cultivate edible EM fungi in plantations (Hall et al. 1998), but inoculation and establishment of most EM species has proven difficult (Danell 1994). Even if widely cultivated, forest mushrooms are likely to remain a viable commercial product for the foreseeable future.

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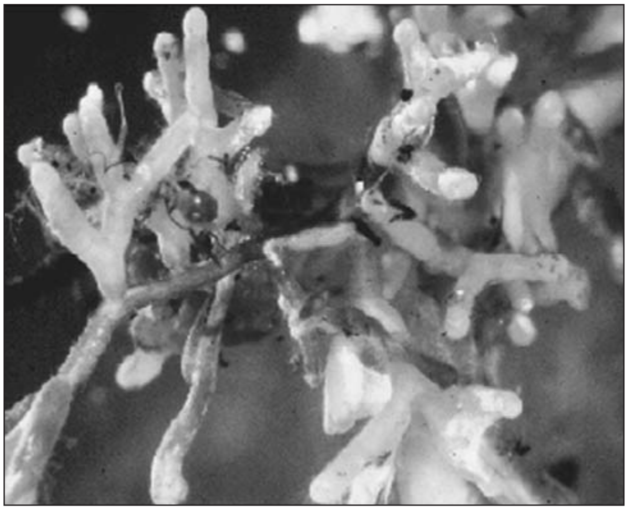

Figure 1—Chanterelle ectomycorrhizae. Photo by Eric Danell.

Figure 2—Young stand thinning operations in chanterelle habitat.

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

Types and amounts	50-year rotation - no commercial thinning	80-year rotation - commercial thinning at ages 35 and 55
	U.S. dollars per hectare per year[a]	
Chanterelles (2 kg $ha^{-1}yr^{-1}$)	29	34
Chanterelles (5 kg ha^{-1} yr^{-1})	73	86
Chanterelles (20 kg ha^{-1} yr^{-1})	292	343
Douglas-fir timber	8,420	7,049

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

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

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

[a]Adjusted to year 2000 U.S. dollars.
See Pilz et al. (1999) for assumptions inherent in this analysis.

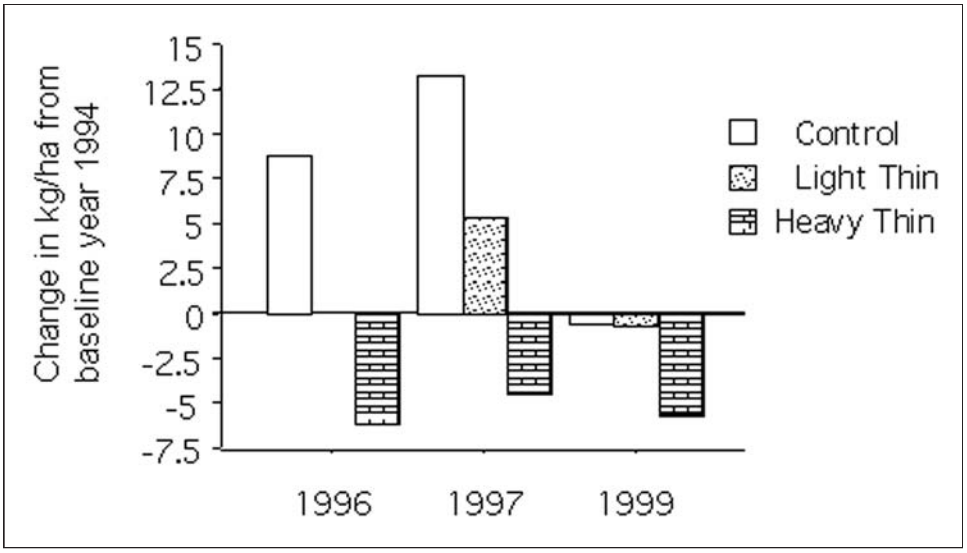

Figure 3—Change in chanterelle productivity for 3 of 4 years after thinning young Douglas-fir stands.

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

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

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

CENTRAL HYPOTHESIS (See Figure 4 for definitions and acronyms)

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

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

- **Gross primary productivity (GPP):** Total quantity of carbon fixed through photosynthesis in the form of carbohydrates or other metabolic compounds.

- **Net primary productivity (NPP):** Net quantity of carbon available to the tree or its mycorrhizal fungus partners for growth or other functions after subtracting the amount used for tree respiration (maintenance metabolism). NPP is a relatively constant 47%, of gross primary productivity across a wide range of forest types and conditions.

- **Belowground allocation:** The proportion or amount of net primary productivity that the tree allocates for large structural roots, fine feeder roots, and mycorrhizal symbionts.

- **Fruiting potential:** The maximum productivity that is possible on a given site in a given year if weather is favorable for mushroom development during the fruiting season.

- **Average site productivity**: The average mushroom productivity (kg per ha per yr) of a site over 4 to 10 years. This variable provides a mean of expressed fruiting potential by averaging across years with variation in weather patterns during the fruiting seasons. Conversely, 4 to 10 years is a sufficiently short interval so that natural changes in stand conditions should not unduly interfere with deriving correlations for our model.

- **Site occupancy**: The percentage of potential habitat that is occupied by the edible EM fungal species of interest relative to competing ectomycorrhizal (EM) fungi as measured by the percentage of EM root tips colonized by the species of interest or by the spatial extent of its mycelium.

Figure 4—Definitions and acronyms.

CARBON ALLOCATION MODELING

One scientific development that makes our proposed model possible is the recent development of a simplified carbon allocation model. The acronym 3PG stands for physiological principles predicting growth. It is a generalized forest carbon allocation model, Landsberg and Waring (1997), that works with any forest biome and can be run as an Excel[10] spreadsheet by practicing foresters given a few days of training. The model uses relatively simple and readily available inputs such as species growth tables, latitude, aspect, weather records, edaphic variables, stand age, and stand density to derive monthly estimates of gross primary productivity, carbon allocation, and stand growth. The model has the capacity for specifying thinning regimes, although the function needs further refinement. In recent iterations, the 3PG model has been linked to satellite imagery of canopy photosynthetic capacity to model forest growth across landscapes (Coops et al. 1998). Intended as a practical management tool, the model is under constant revision to incorporate new research data, simplify application, and broaden its usefulness. Belowground processes and allocation are one of the least developed aspects of this model, and our envisioned research will contribute to the model's development and range of applicability. Web sites discussing the model and current applications are listed in the acknowledgment section.

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

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

- Modify rotations, thinning densities, thinning intervals, or tree species selection to retain or enhance mushroom productivity in forests predominantly managed for timber production.

- Manage stands in areas with convenient access for mushroom picking to enhance long-term mushroom production.

- Lengthen rotations or refrain from harvesting timber in areas identified as having low timber value and high mushroom productivity.

- Manage stand conditions to promote mushroom production in forests not intended for timber production (for example, carbon sequestration).

- Provide continuous mushroom harvesting opportunities across watersheds, land ownerships, or bioregions as the mosaic of forest conditions and age classes shifts across the landscape.

- Maintain mushroom harvesting opportunities in the coming centuries by anticipating the shifts in forest biomes as they respond to global warming or other human caused factors.

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

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

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

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

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

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

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

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

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

METHODS

Estimating Site Occupancy

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

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

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

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

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

Field Sites

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

- At least some fruiting of chanterelles or matsutake so that productivity and site occupancy can be estimated.

- High fertility versus low fertility soils.

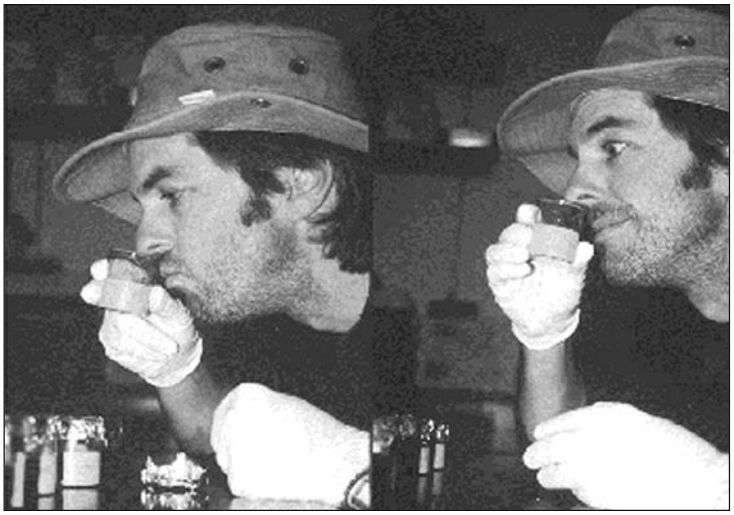

Figure 8—Tom Horton testing olfactory methods for detecting *Tricholoma magnivelare* mycelium in soil.

- Temperate versus cold (boreal or alpine) climates.

- Forests with tall trees versus forests with short trees.

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

FUTURE ITERATIONS

Current iterations of the 3PG model are designed to work with forest stands of a single tree species and uniform age. Given that the most abundant fruiting of chanterelles and matsutake often occurs in young stands, early versions of our modified model might be most applicable to recently regenerated forest stands that have timber production as one of their goals. Future revisions of the 3PG model are likely to incorporate multiple tree species of nonuniform age. Our aim is to use tree species ratios (host/nonhost tree species for each EM fungus) and dominance by those tree species (photosynthetic capacity) to modify our predictions of the amount of carbon allocated to the mushroom species of interest. These versions of the SilviShroom 3PG model would then be more applicable to natural or diverse forest stands.

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

Economic Valuation

Timber values are thoroughly understood, but mushroom values are harder to estimate and most attempts are relatively recent (Alexander et al. 2002; Pilz et al. 1998, 1999). Preliminary analyses illustrated in Tables 1 and 2 include many economic assumptions about mushroom prices and harvester costs, but they also include uncertain assumptions about how timber management choices affect mushroom productivity. Coupling analyses of mushroom values with predictions of mushroom productivity under different forest management scenarios will allow managers to better evaluate resource tradeoffs and synergies.

Scaling from Stands to Landscapes

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

CONCLUSIONS

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

ACKNOWLEDGMENTS

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

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

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

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INVOLVING STAKEHOLDER COMMUNITIES IN RESEARCH ON NONTIMBER FOREST PRODUCTS

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ABSTRACT

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

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

INTRODUCTION

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

Collaborative approaches to ecosystem management between federal agencies and locality-based groups or user groups are rapidly forming across the United States (Gray et al. 2001; Moote et al. 2000; Weber 2000). Manifested as partnerships, community-based collaboratives, watershed councils, and more, these multi-party groups often emerge out of mutual interest to manage natural resources in ways that integrate ecological, social, and economic objectives and to escape the paralysis of agency planning followed by stakeholder litigation. Similar logic led us to the primary premise of this pilot project; involvement of stakeholder communities in selection, design, and implementation of follow-up research projects will result in management actions that better meet the needs of stakeholder communities and reduce the amount of resistance to project implementation.

WHY NTFP MANAGEMENT

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

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

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

APPROACH

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

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

IDENTIFICATION OF STAKEHOLDER INTERESTS AND CONCERNS

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

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

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

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

PROCESSING THE INFORMATION AND DEVELOPING RESEARCH PROJECTS

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

CONCLUSIONS

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

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[5] We recognize that many of the values and concerns about NTFP management transcend any type of distinction between commercial vs. non-commercial harvesters. The distinction was made here to facilitate the data collection process between two separate teams.
[6] Donoghue, E.M. [N.d.] Personal-use harvesters of nontimber forest products in the Pacific Northwest. Manuscript in preparation.
[7] Report titled "USFS SFP Collaborative Project: Mater Dialogues Issues Analysis," August 31, 1999. On file with: the Pinchot Institute for Conservation, 1616 P Street NW, Suite 100, Washington, DC 20036.

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SECTION F

SOCIAL/ECONOMIC STUDIES

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Proceedings from the Wood Compatibility Initiative Workshop, number 23.

LOGIC MODELS AS FRAMEWORKS FOR THINKING ABOUT COMPATIBILITY

Keith M. Reynolds[1]

ABSTRACT

Numerous efforts around the world are underway to apply the Montreal criteria and indicators to assess the sustainability of temperate and boreal forests. This paper describes the general structure of a logic-based model for evaluating the sustainability of forests at regional and national levels, and illustrates how a logical formalism can be used to represent and evaluate compatibility among resource values and uses.

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

INTRODUCTION

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

Criteria, Indicators and Measurement Endpoints

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

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

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

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

Balancing Services, Uses, and Values

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

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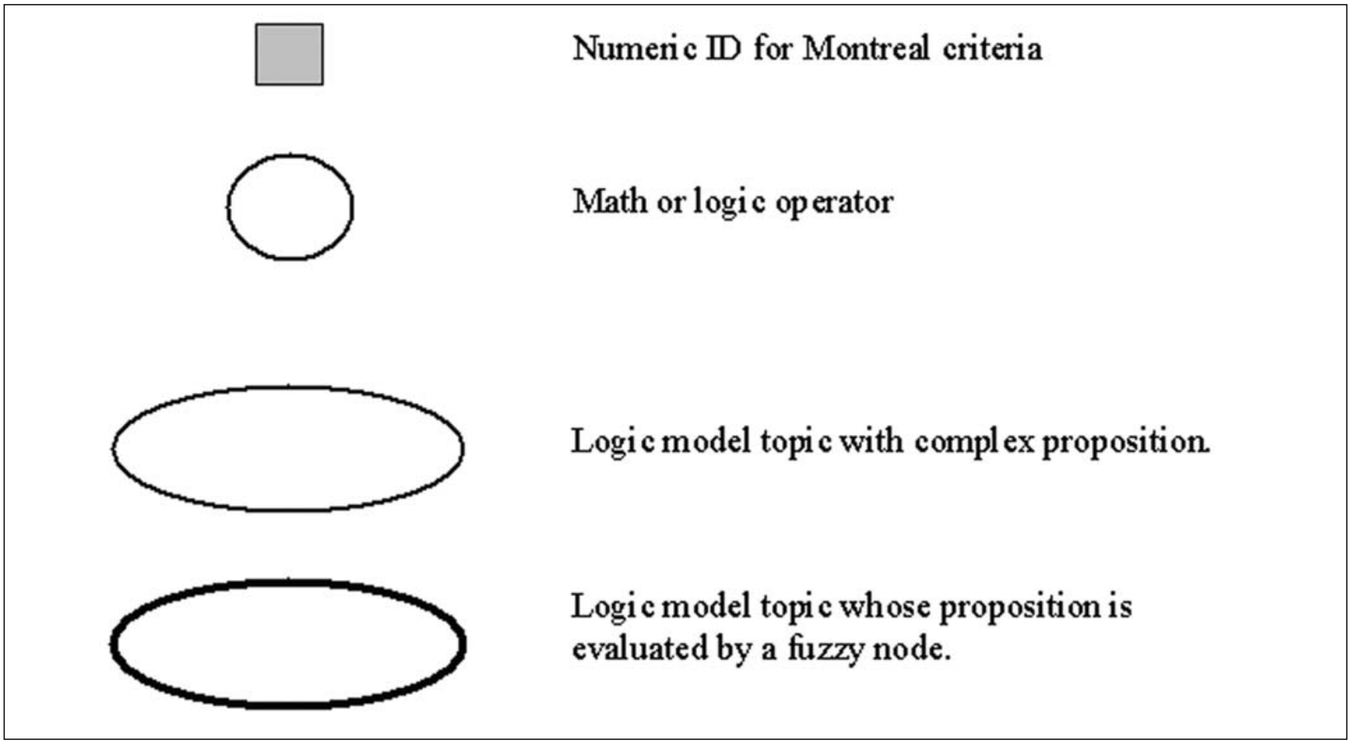

Figure 1—Key to logic symbols used in subsequent figures.

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

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

Objectives

Any indicator or criterion implies a model and set of assumptions that relates the indicator to more complex phenomena and comes with an obligation to make explicit both the metric and the underlying model (Hammond et al. 1995; Adriaanse 1993). Relatively little research to date has focused on developing formal representations of indicators and their interrelations as a basis for actually evaluating SFM despite recent widespread interest in developing and applying C&I for evaluating SFM (Prabhu et al. 2001). However, a few efforts, primarily associated with the Center for International Forest Research (CIFOR), have been experimenting with use of semantic networks and similar types of representation (Colfer et al. 1996; Haggith et al. 1998; Prabhu et al. 1999b). This paper continues that general line of investigation, considering the use of a fuzzy-logic based network representation for evaluation of the Montreal C&I at national and regional scales. Use of fuzzy logic networks is demonstrated as a way to accommodate the vagueness and imprecision inherent in natural language descriptions (Zadeh 1976).

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

ANALYSIS

Montreal Criteria and Indicators

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

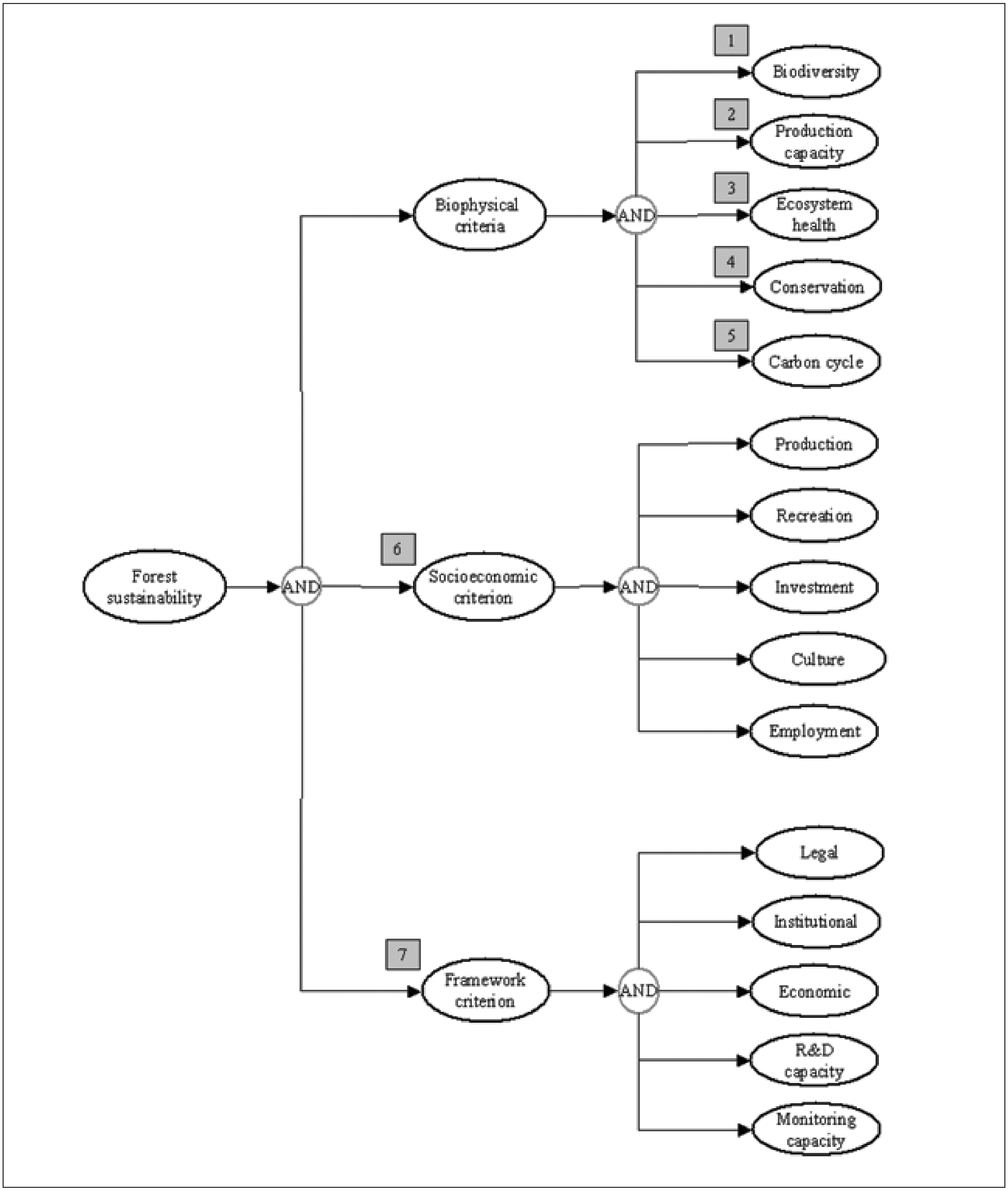

Figure 2—Partial logic specification for evaluating sustainability of a forest ecosystem. Each premise has its own logic specification that may extend many more levels. NetWeaver knowledge bases are graphically built from modular components like this, simplifying incremental development of complex models.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

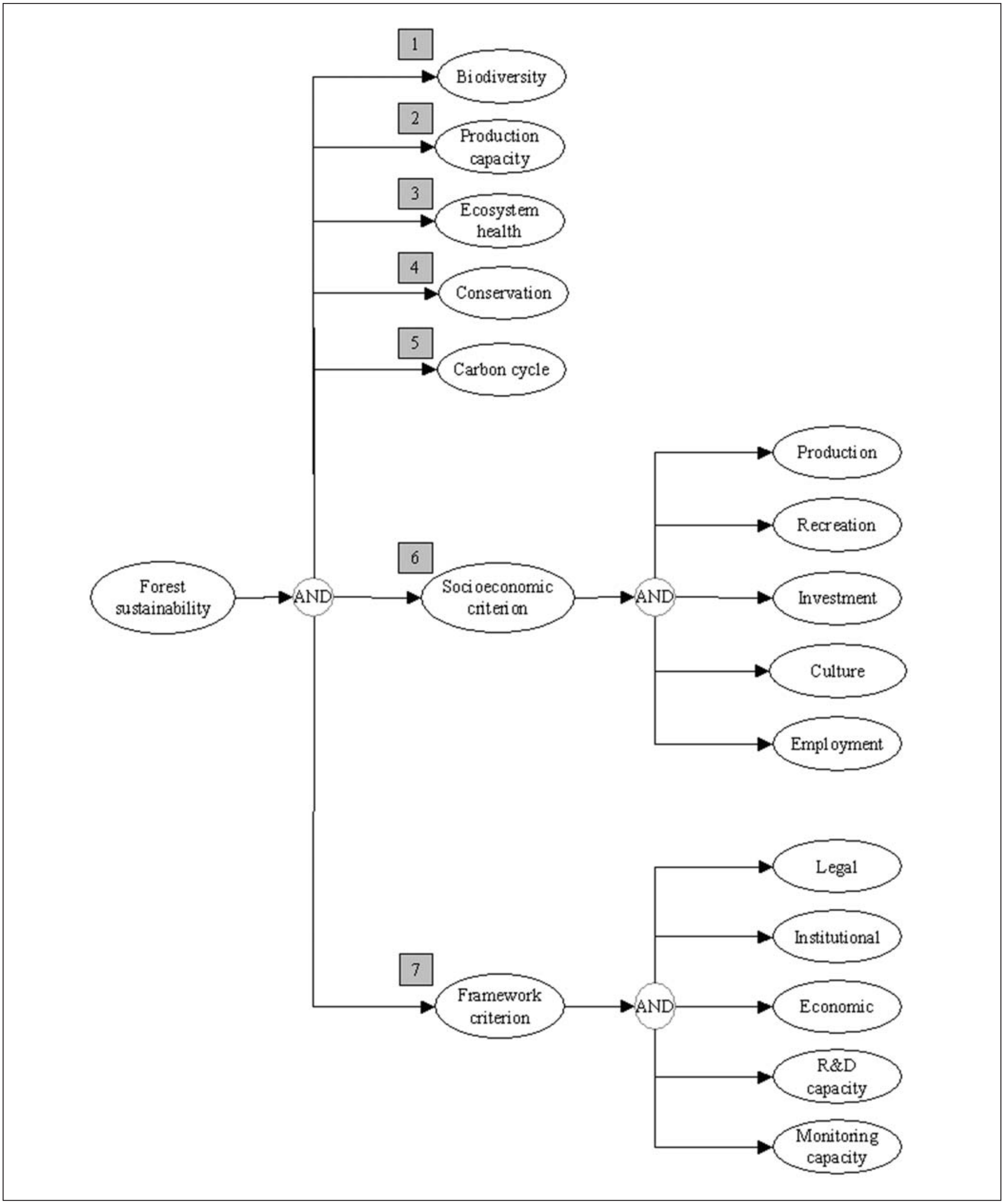

Figure 3—An alternative (partial) logic specification for evaluating sustainability of a forest ecosystem. In this representation, biophysical criteria assume more importance compared to Figure 2.

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

Logic Models as Design Frameworks

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

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

> *Stochastic uncertainty deals with the uncertainty of whether a* [particular] *event will take place and probability theory lets you model this. In contrast, lexical uncertainty deals with the uncertainty of the definition of the event itself. Probability theory cannot be used to model this* [because] *the combination of subjective categories in human decision processes does not follow its axioms…Even though most concepts used are not precisely defined, humans can use them for quite complex evaluations and decisions that are based on many different factors.*

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

Model Design Issues

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

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

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

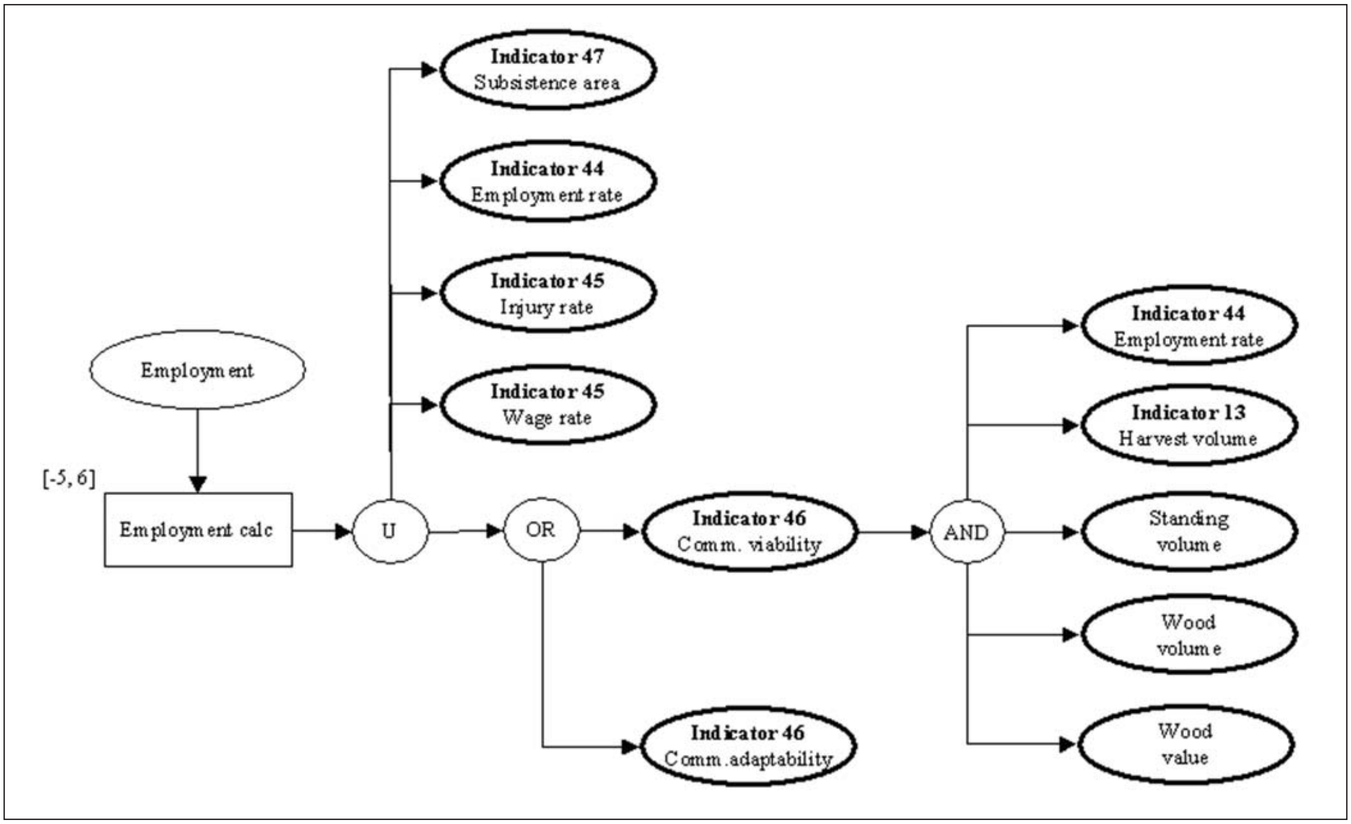

Figure 4—Logic specification for evaluation of the employment topic under the socioeconomic criterion (criterion 6). Community viability depends on (e.g., is cross-linked to) indicators 13 and 44 as well as data elements of other biophysical indicators related to wood production (indicators 29 and 31)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

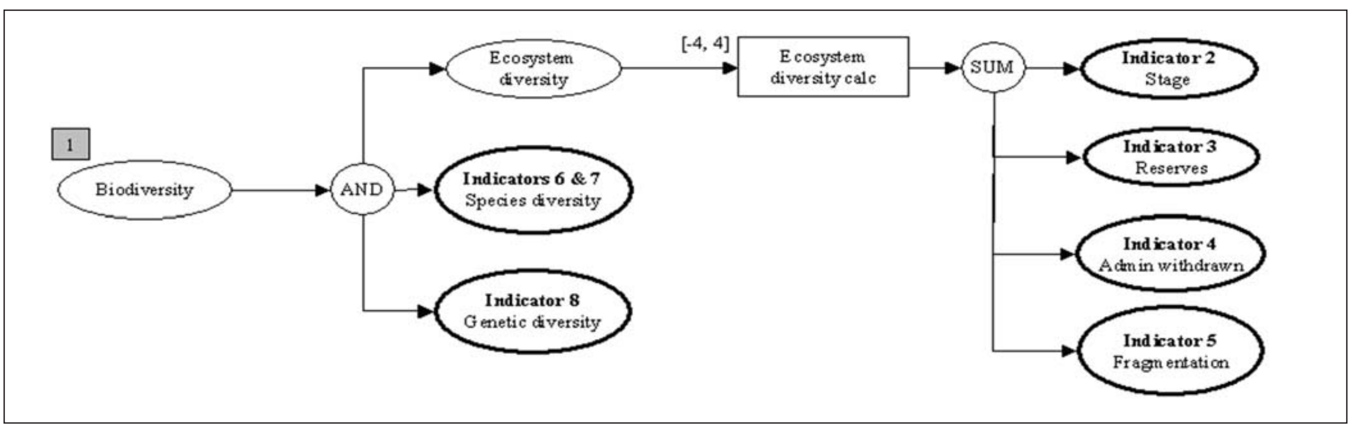

Figure 5—Additional level of detail of the logic specification for the biodiversity criterion, illustrating the AND and UNION operators which represent different philosophies about how information combines.

may, in fact, extend many levels deep (e.g., Figure 2 and 3). The specifications of the employment topic (Figure 4) and biodiversity (criterion 1, Figure 5) illustrate another design issue with significant policy implications - the choice of how to integrate information. The most commonly used logical operators for combining elements in NetWeaver are AND, OR, and U(NION). The fact that the logic model requires us to explicitly assign an operator at each step of integration reveals critical information that is often undefined in less rigorous descriptions.

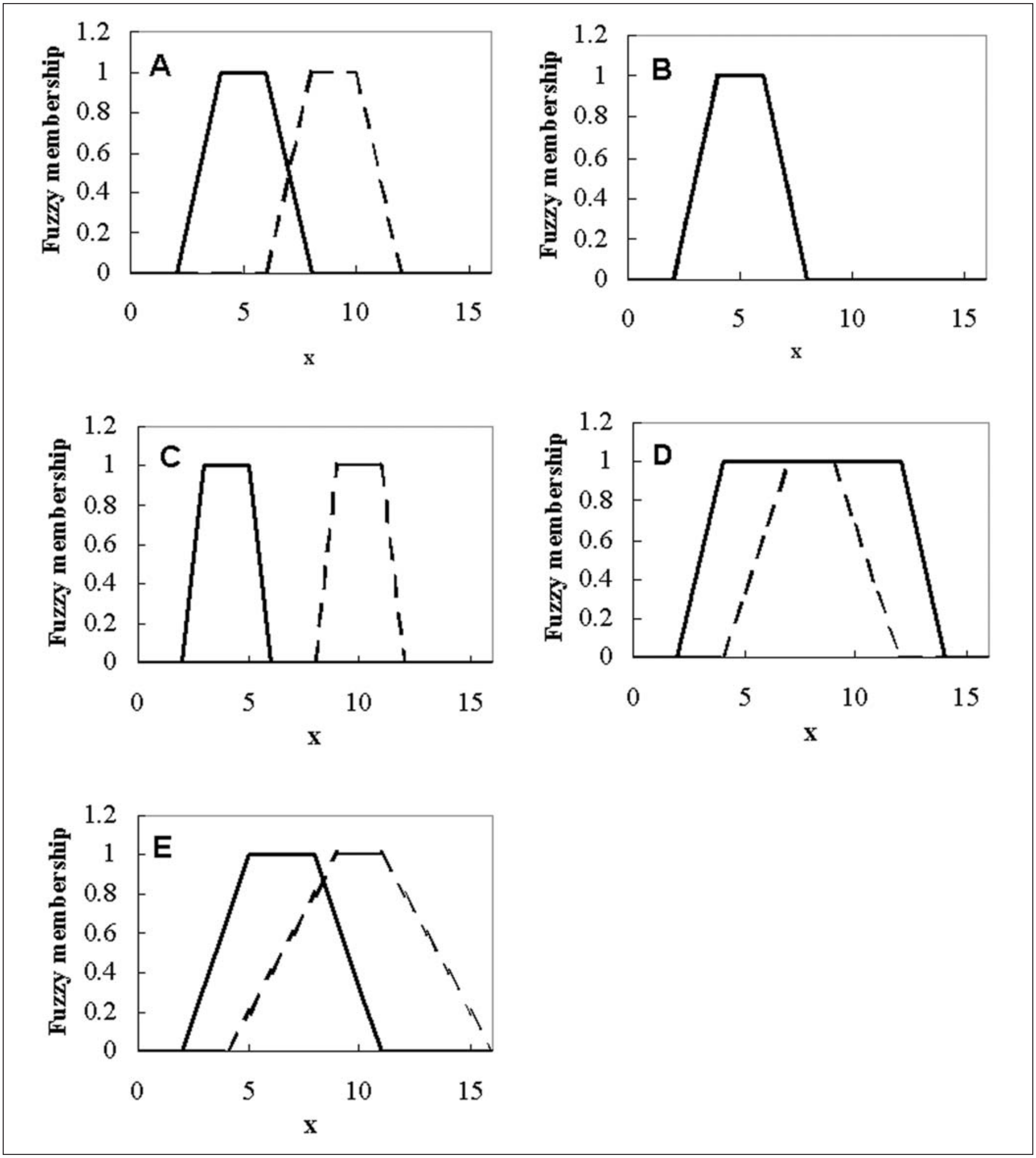

Figure 6—Prototypical relations between two fuzzy membership functions, $f_A(x)$ (solid line) and $f_B(x)$ (dashed line), for two elementary topics, A and B, respectively, illustrating trade-offs, compatibilities, and hybrid relations: A, pure trade-off; B, complete compatibility ($f_A(x) \int f_B(x)$);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

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

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

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

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

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

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

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

CONCLUSIONS

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

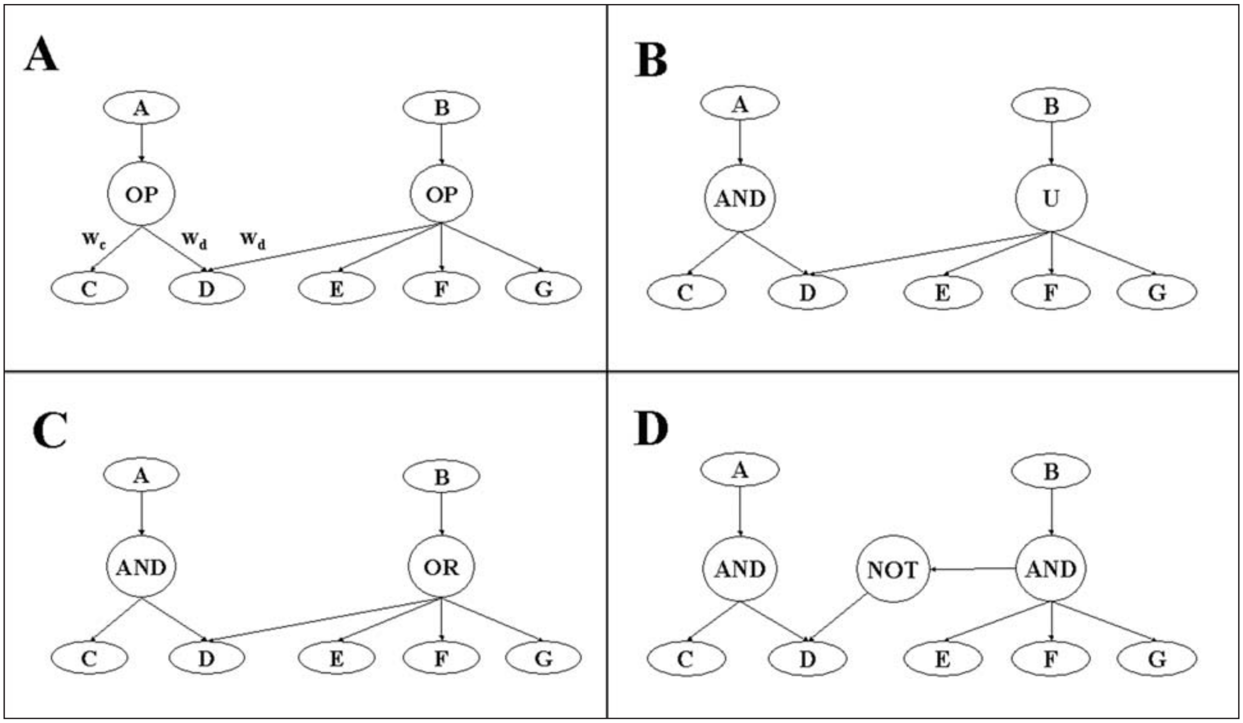

Figure 7—Prototypical relations between two topics, A and B, whose logic specifications share a common premise (topic D). A, topics A and B are compatible with respect to topic D, but topic D may have a differential effect on the two topics due to different numbers of premises or different weights applied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

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

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

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

ACKNOWLEDGMENTS

I thank Dr. Michael Saunders (Pennsylvania State University) and Drs. Bernard Bormann and Fred Swanson (Pacific Northwest Research Station) for their review of the manuscript.

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Proceedings from the Wood Compatibility Initiative Workshop, number 24.

COMPATIBILITY OF TIMBER AND CONSERVATION: TRACING THE TRADEOFF FRONTIER

Claire A. Montgomery[1]

ABSTRACT

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

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

THE PRODUCTION POSSIBILITY APPROACH

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

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

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

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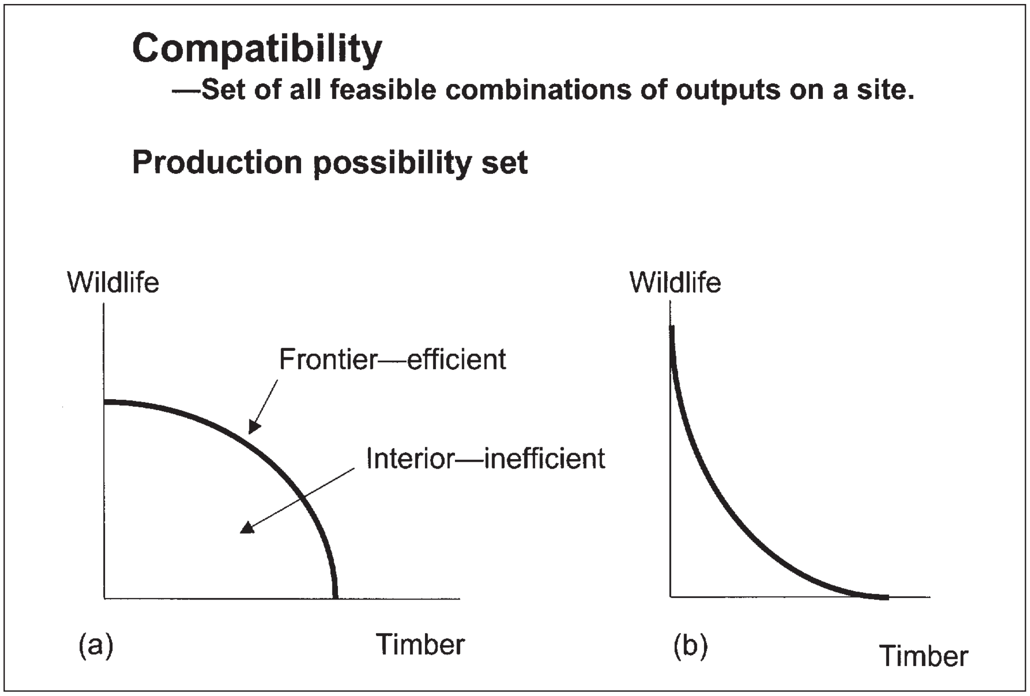

Figure 1—Two hypothetical production possibility sets illustrating efficient management on the frontier and inefficient management in the interior of the set.

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

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

Figure 1(b) depicts a production possibility set for which it is optimal to manage the site exclusively for one use or the other even though there are feasible combinations of both. The cost of increasing wildlife from zero is initially very high and, likewise, the cost of increasing timber from zero is initially very high. The two outputs are less compatible than in Figure 1(a). Again, the choice of which output is preferable depends on their value to society.

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

Now there is renewed interest in the production possibility approach to compatibility research (Rohweder et al. 2000; Shunk 2000; Calkin et al., in press; Lichtenstein and Montgomery, in press; Nalle 2001), partly because of heightened interest in the policy arena in cost-effective management for nonmarket forest uses. At the same time, there have been advances in the knowledge, methods, and technology required for realistic modeling of production possibilities and biological diversity. Examples include the development of the technology of geographic information systems (GIS) and the accumulation of spatial data about forests that support spatially explicit modeling of real landscapes; the development of simulation models that model spatial and dynamic relations between different forest uses; the development of optimization methods, such as stochastic heuristic search algorithms, that are extremely flexible; and the development of computing technology that can solve complex problems in a relevant time frame.

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

GENERAL APPROACH

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

- They integrated biological and economic models in an optimizing framework to address economic issues related to efficiency.

- They used the integrated model to estimate the frontier of the production possibility set for the modeled outputs on a particular site to assess its productive capacity—what can be produced?

- They simulated policy scenarios, particularly management under the current landowners, and compared the outcomes to the PPF to search for opportunities for improvement.

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

SINGLE SPECIES MODELS

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

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

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

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

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

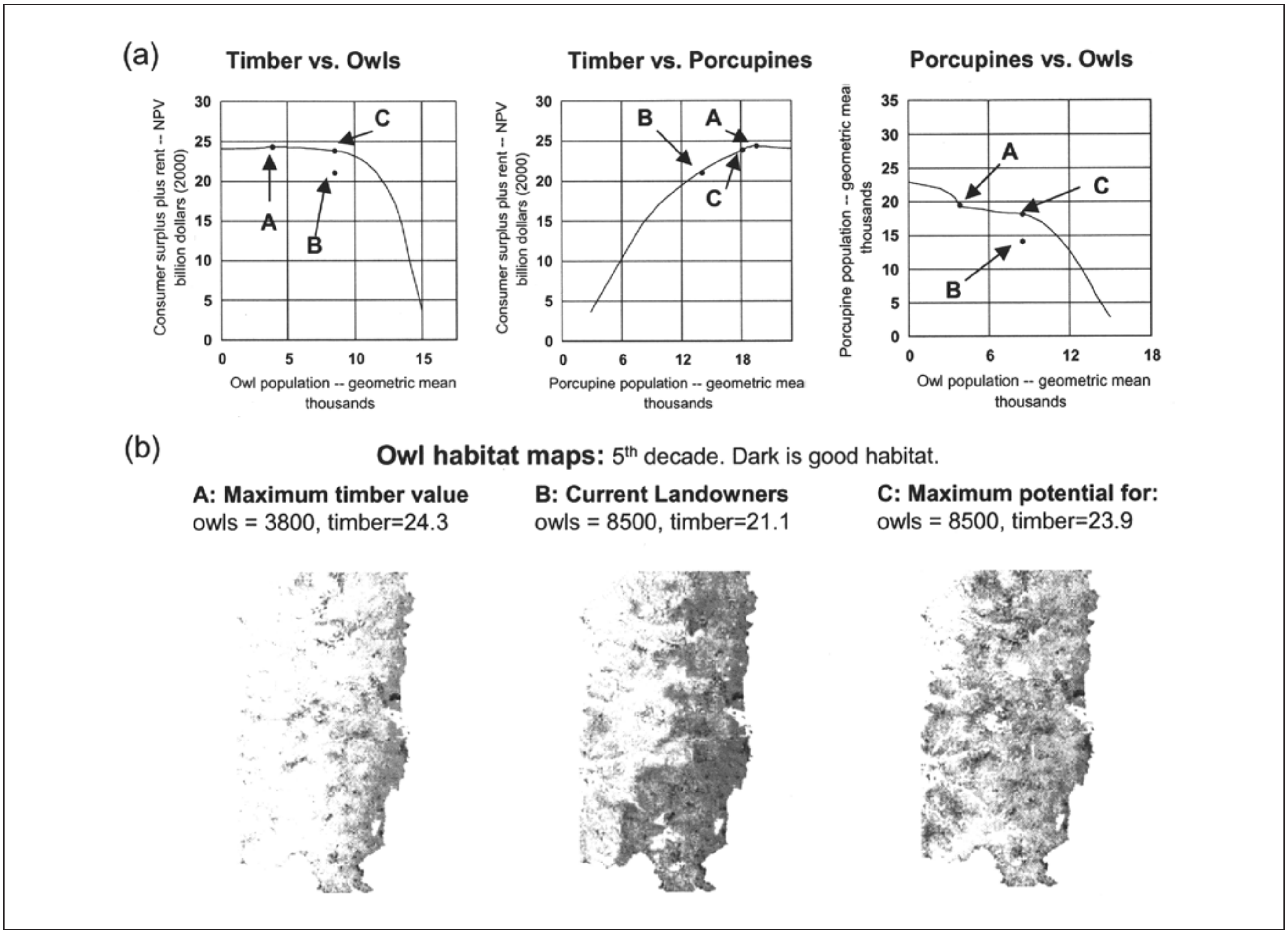

Figure 2—Pairwise production possibility frontiers between net present value of timber production, geometric mean owl population size, and geometric mean porcupine population size over 100 years in a 1.7 million-ha study area on the west side of the central Cascade Range of Oregon and owl habitat maps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

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

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

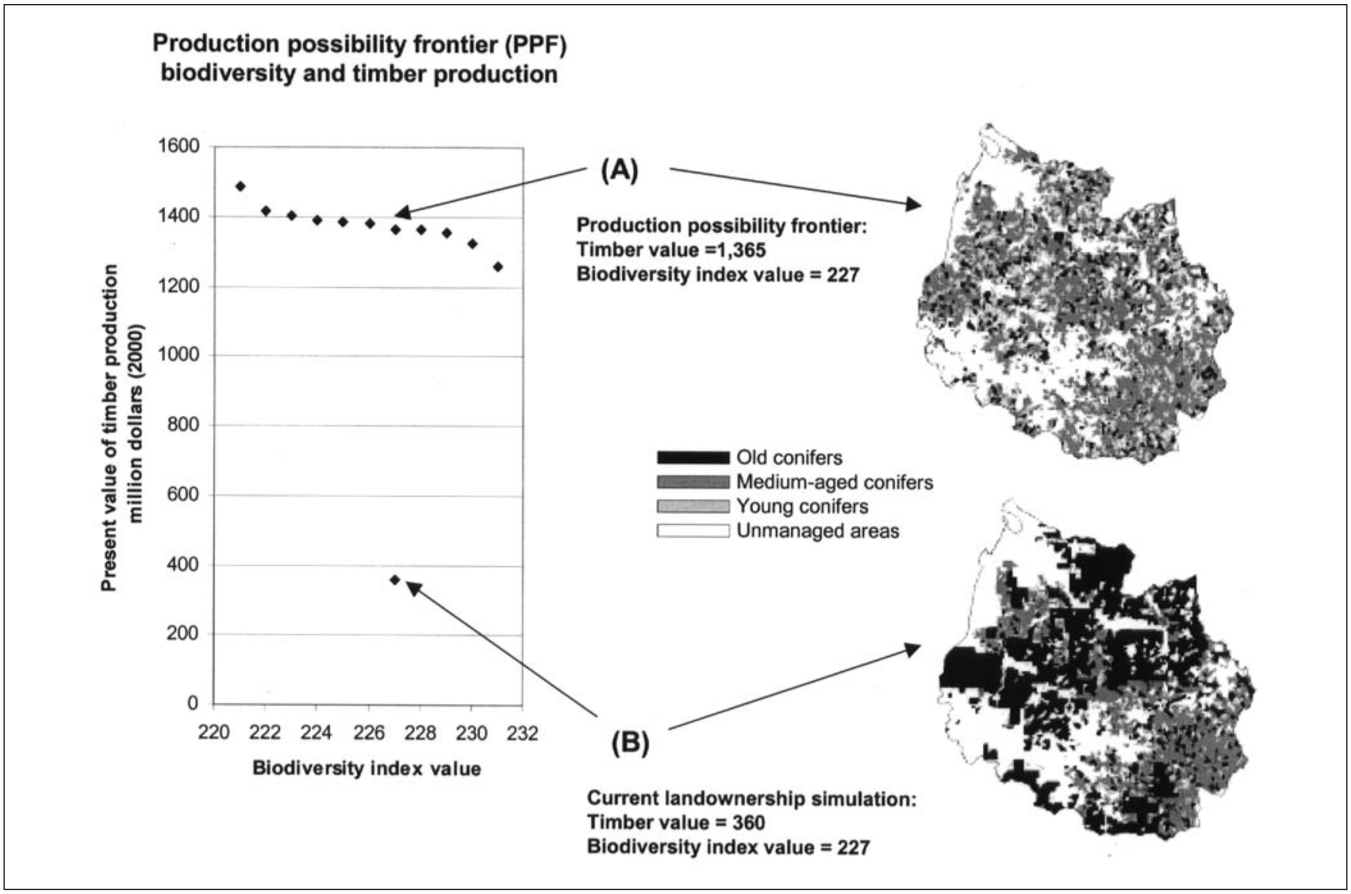

Figure 3—Production possibility frontier for an index of 167 terrestrial vertebrate species, and the present value of timber production over 100 years in a 41,200-ha study area on the west side of the Coast Range in Oregon and vegetation maps corresponding to (A) the point on the PPF with index value=227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

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

MULTIPLE SPECIES MODELS

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

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

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

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

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

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

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

$$V(y) = \left(\prod_{t=1}^{20} V5\,(X_{st}(y)) \right) V_{100}\,(X_{s,100}(y)) \qquad (2)$$

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

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

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

FUTURE RESEARCH NEEDS

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

Further work would greatly enhance the usefulness of this approach to compatibility research. Lichtenstein and Montgomery's study highlights the importance of carefully considering the outputs that were omitted from the analysis. For example, policymakers and society would benefit from a better understanding of tradeoffs between large sets of species and particular endangered species. In fact, the cost of one conservation program may well include lower achievement of other conservation goals. Other forest uses, besides wildlife and timber, may also be modeled (e.g., reductions in fire risk, recreation use, water yield, aquatic species). Some modeling issues yet to be resolved are the interaction between geographic scale and compatibility, uncertainty about model parameters, incorporation of disturbance regimes into the model, and the treatment of existing infrastructure and institutions.

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

ACKNOWLEDGMENTS

I am grateful to Roger Fight and Tom Spies for their helpful comments. The research described in this paper was supported by funding from U.S. Department of Agriculture, Forest Service Pacific Northwest Research Station and a joint initiative between the National Science Foundation and U.S. Environmental Protection Agency Star Grant R82-6619. No official endorsement by the funding agencies should be inferred.

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Proceedings from the Wood Compatibility Initiative Workshop, number 25.

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

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ABSTRACT

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

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

INTRODUCTION

Wood Compatibility Initiative

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

Criteria and Indicators

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

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

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

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

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

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

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

Forest Inventory and Analysis

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

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

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

RESEARCH QUESTIONS

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

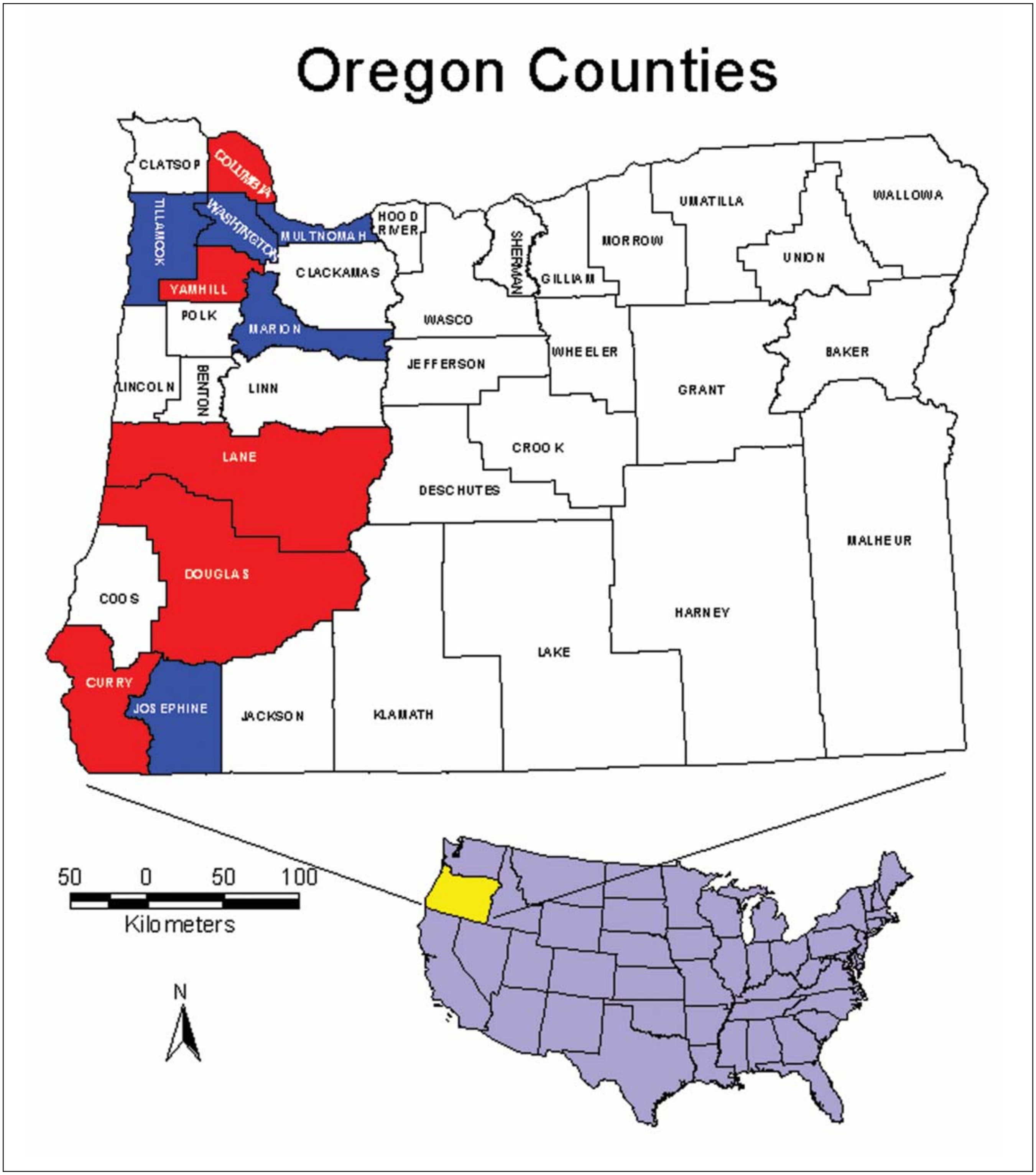

Figure 1—Oregon counties with highest (red) and lowest (blue) harvest-to-volume ratios for non-federal lands in western Oregon.

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

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

[a] Non-federal timberlands, 1962-1998; thousand board feet Scribner.
[b] Non-federal timberlands, 1930s-1990s; thousand board feet Scribner.

1. Can forest resource trends be tracked reliably at county resolution using FIA data?

2. Are there differences in the trends for timberland area and growing-stock volume between counties experiencing different harvest levels (harvest levels measured as H:V ratio)?

3. Do climatic trends coincide with changes in timberland area or growing-stock volume?

METHODS

Database Development

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

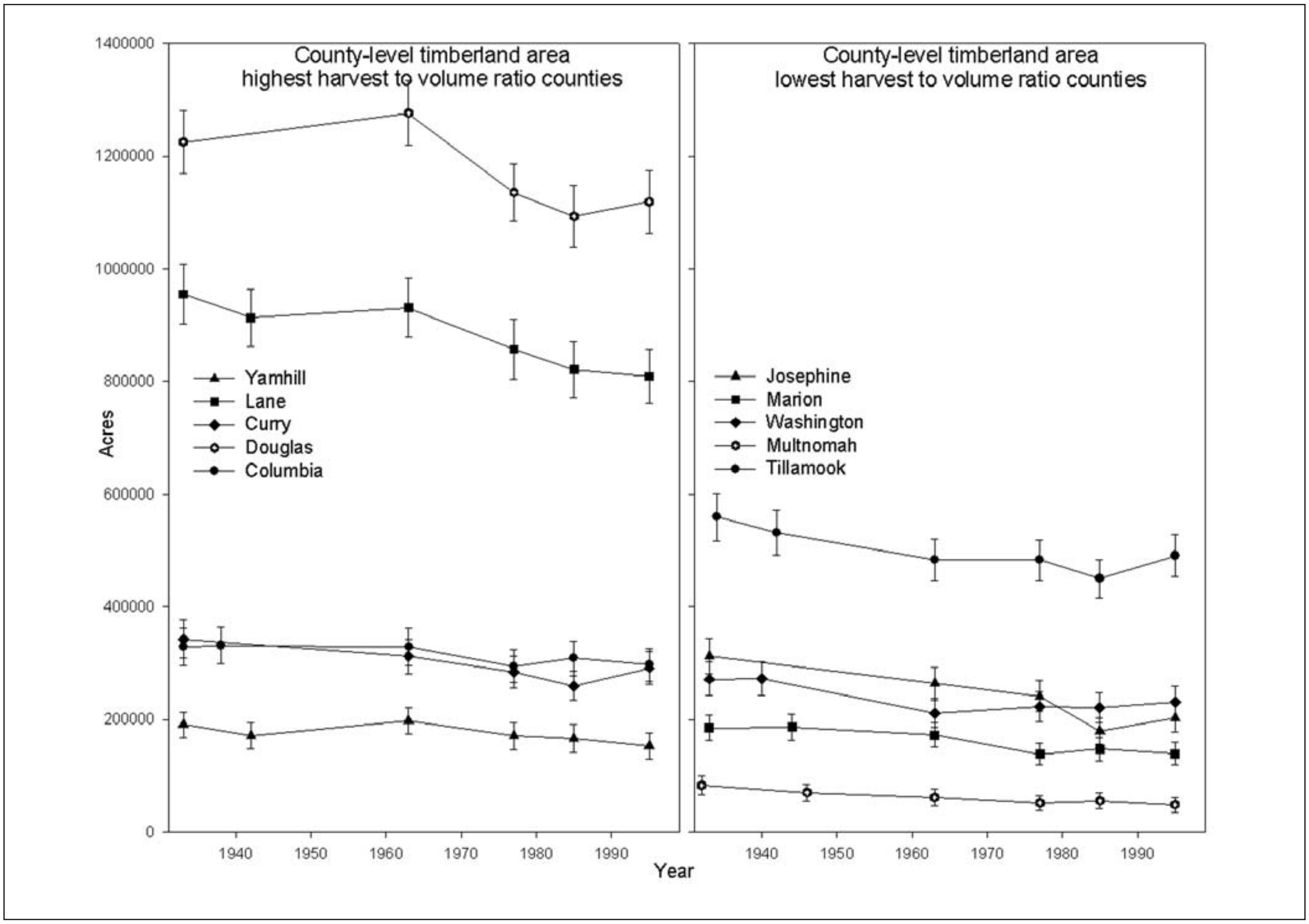

Figure 2—County-level estimates of non-federal timberland area through time. The counties in the left graphic have the highest harvest-to-volume ratios, while the counties on the right have the lowest harvest-to-volume ratios in western Oregon. Error bars for the estimates (68% confidence interval) are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

Comparing Counties

If timber harvest has a substantial influence on timberland area and growing-stock volume, we would expect area and volume for counties with high H:V ratios to differ from counties with low H:V ratios. The western Oregon counties used for this analysis, Josephine, Marion, Washington, Multnomah, Tillamook, Yamhill, Lane, Curry, Douglas, and Columbia (Figure 1), were selected to emphasize differences in forest conditions based on the ratio of harvest to growing-stock volume summarized within each county. The average harvest for a county (1962-1998) was divided by the average volume across periodic inventories and expressed as a percentage (Table 1; ~10-year intervals) for all western Oregon counties. The H:V ratios were ordered from lowest to highest by county. The five lowest and the five highest were selected for comparison. Changes in timberland area and volume were compared between the two sets of counties. County-level harvest data (Oregon Department of Forestry) were summarized for non-federal ownerships and smoothed with a centered, 11-year moving average spline. Data was smoothed to show the overall trend of harvest. The state-level, aggregated trend for timberland area and growing-stock volume across all private ownerships in Oregon (RPA data 2000) was evaluated against the separate county-level trends to show how individual counties diverge from larger, spatial-scale trends. Growing-stock volume and timberland area also were each summed across the group of highest H:V-ratio counties and across the group of lowest H:V-ratio counties to show the effect of increased sample size on the variability of the estimates. Growing stock volume-per-acre trends were compared between the high and low H:V groups of counties.

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

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

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

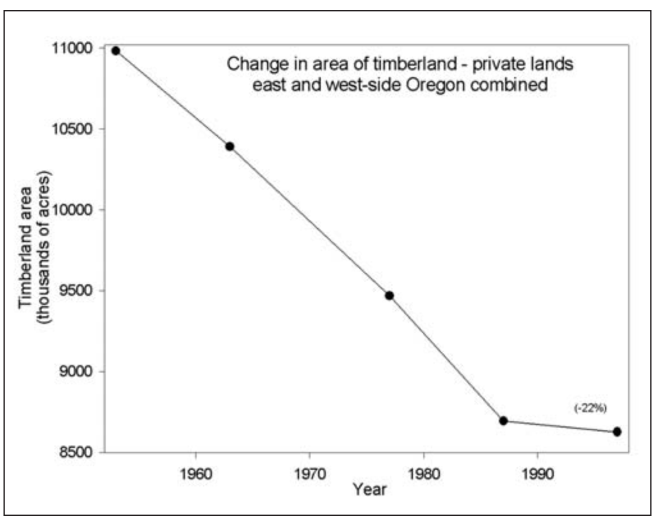

Figure 3—Change in the area of private timberland for the entire state of Oregon, 1953 to 1997. Source: Resource Planning Act data, 2000.

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

RESULTS

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

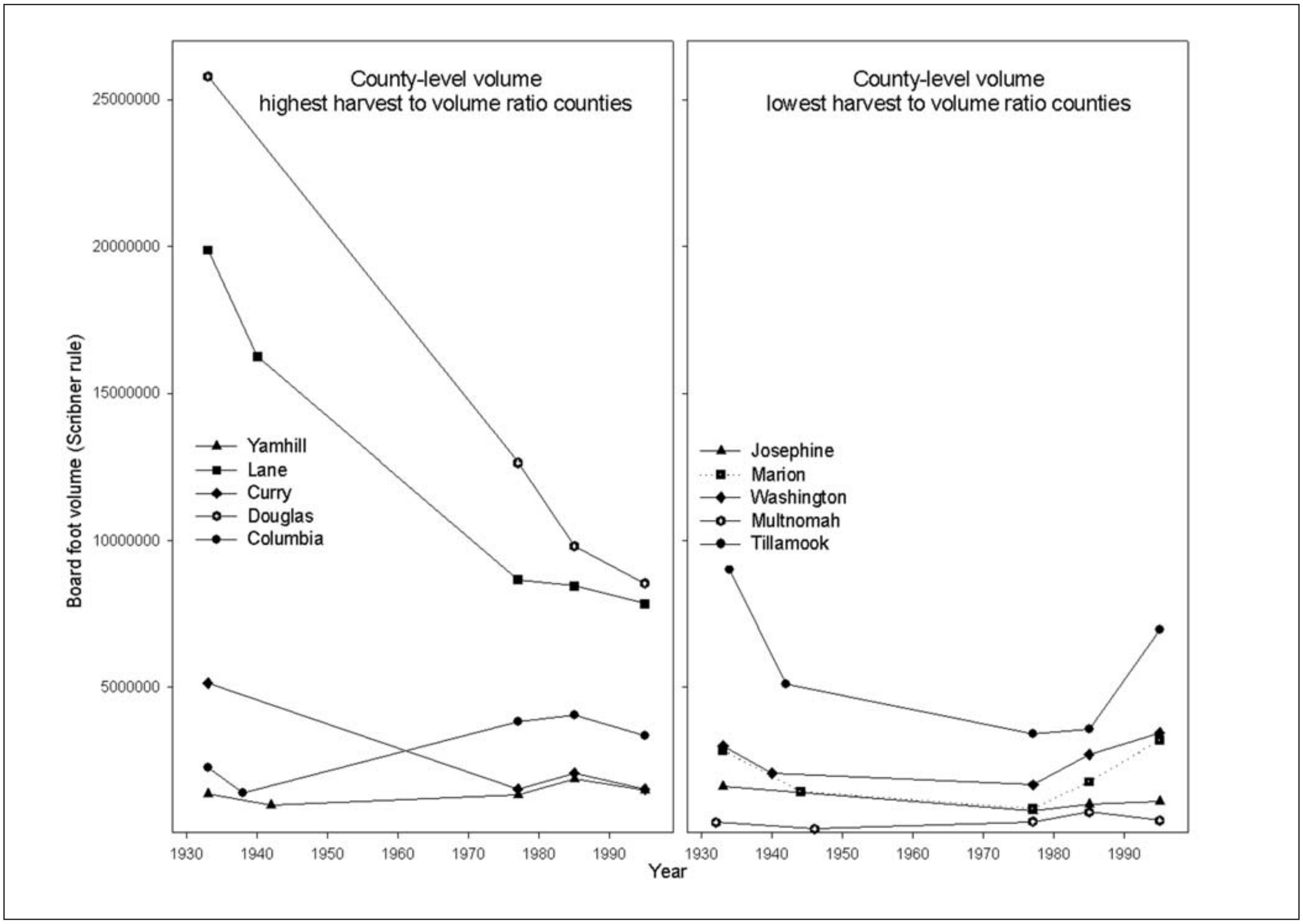

Figure 4—County-level estimates of non-federal timberland volume through time. The counties in the left graphic have the highest harvest-to-volume ratios, while the counties on the right have the lowest harvest-to-volume ratios for western Oregon.

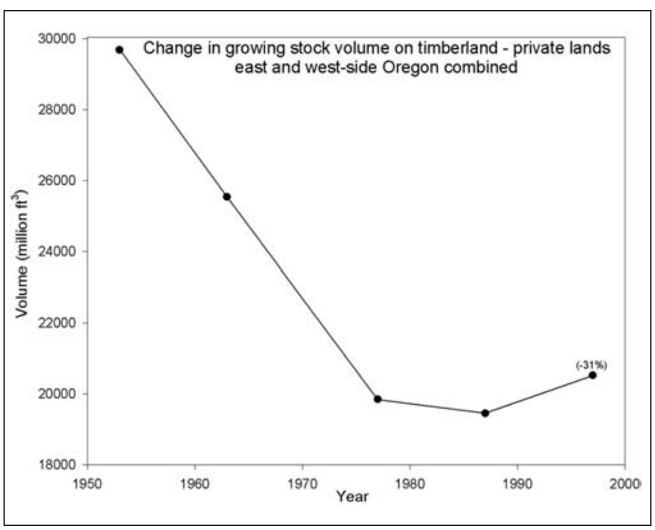

Figure 5—Change in growing stock volume on private timberland for the entire state of Oregon, 1953 to 1997. Source: Resource Planning Act data, 2000.

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

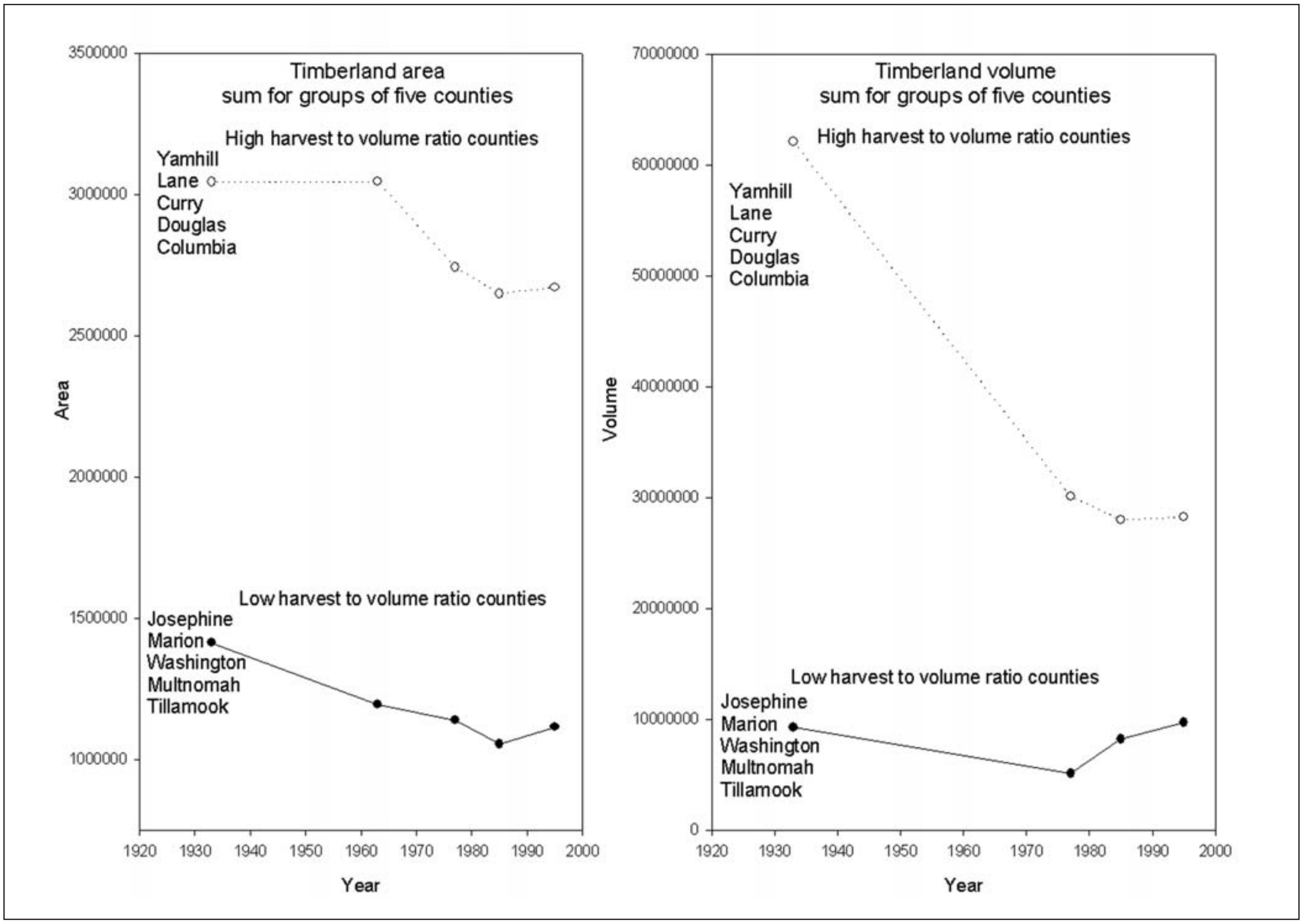

Figure 6—Non-federal timberland area (left) and growing-stock volume (right) summed across the highest H:V counties (top curves) and across the lowest H:V counties (lower curves).

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

Smoothed harvest data for the ten counties examined demonstrates mixed trends over the period 1962-1998 (Figure 7). Curry, Lane, and Douglas counties show an overall trend of decreasing harvest for the high H:V group (three out of five decreased), while Tillamook shows a decreasing harvest trend for the low H:V group (one out of five decreased). Yamhill, Columbia, Josephine, Marion, Washington, and Multnomah counties show increases in harvest over the same period.

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

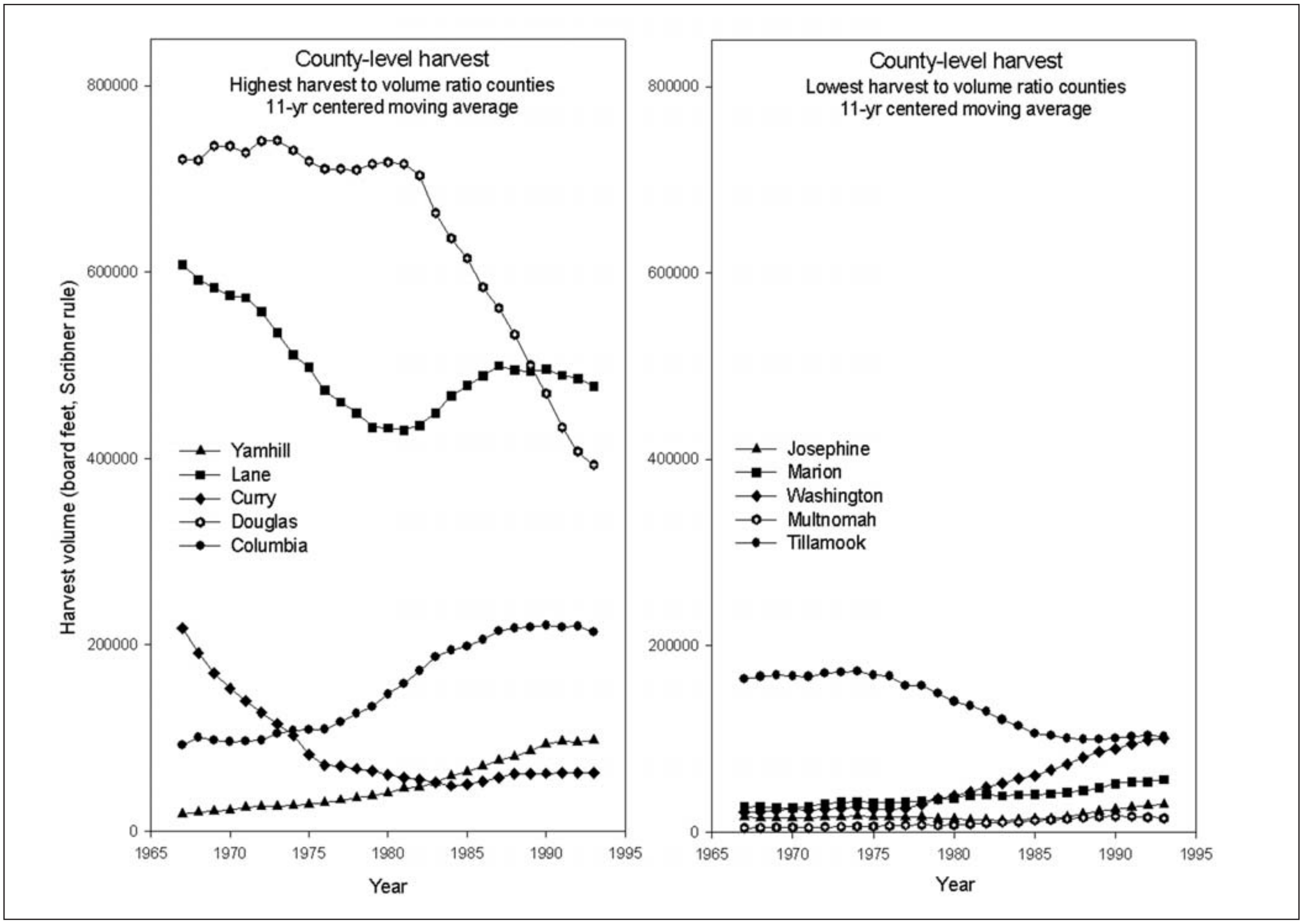

Figure 7—County-level harvest estimates for non-federal timberland smoothed with a centered, 11-year moving average spline. Base data source: Oregon Department of Forestry.

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

DISCUSSION

Tracking Change at the County-Level

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

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

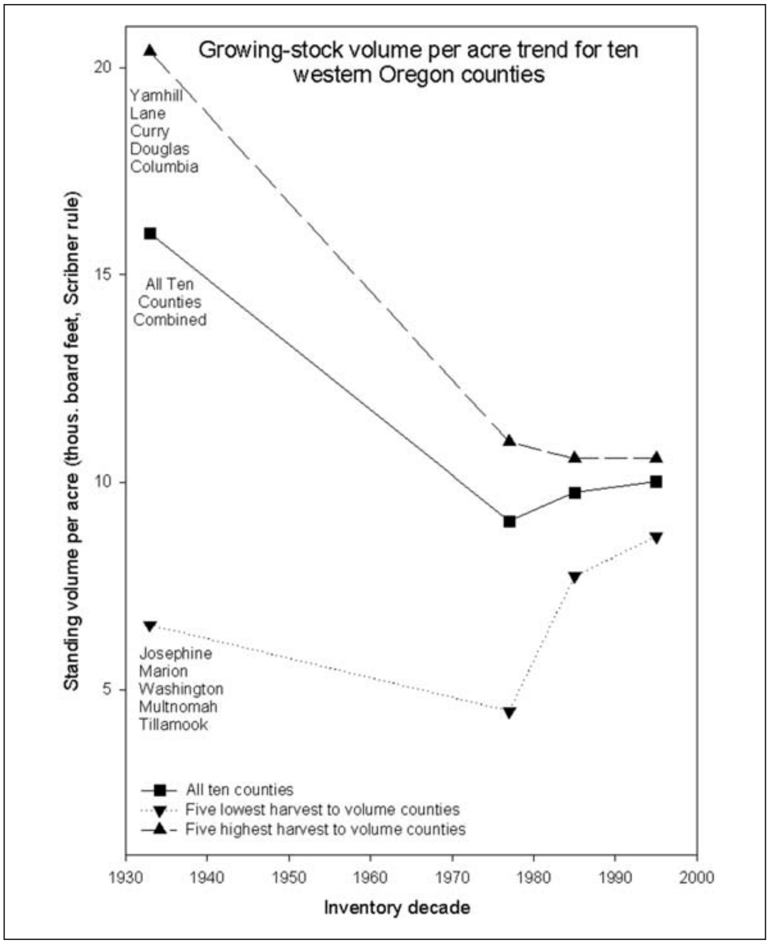

Figure 8—Growing-stock volume per acre trend for the ten western Oregon counties with the highest and the lowest harvest-to-volume ratio for non-federal timberland. The five counties aggregated for the highest harvest-to-volume ratio include: Yamhill, Lane, Curry, Douglas, and Columbia. The five with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

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

Trend Differences Between High and Low H:V County Groups

There is a difference in the trend for volume on a per-acre basis between aggregates of the five counties with the highest and lowest H:V ratios (research question 2; Figure 8). Between 1933 and 1977, growing-stock volume per acre was declining more rapidly for the high H:V group than for the low H:V group of counties. Between 1977 and 1985, the downward trend in volume per acre was slowed for the high H:V group, and reversed for low H:V group. Post 1977, the high and low H:V county groups appeared to be getting more similar to each other in terms of volume-per-acre trend, perhaps as forest managers applied similar stocking and silvicultural techniques across western Oregon. The counties with the lowest H:V ratio demonstrate an increase in volume per acre since the mid-1970s, and may contain trees that are growing to larger diameters on timberland with longer rotation times between harvests.

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

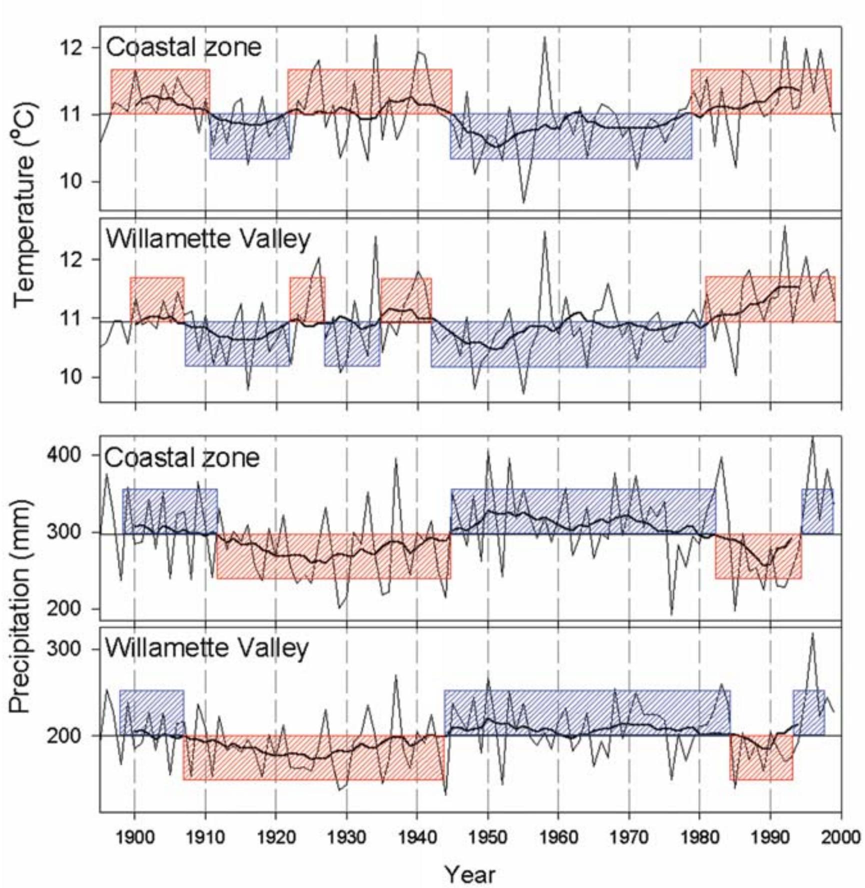

Figure 9—Temperature and precipitation trends for the Oregon Coast and Willamette Valley climatic zones. Bold line represents smoothed data using a centered, 11-year moving average spline. Red and blue boxes show trends above and below the mean for the period.

Climatic Influences on Timberland Area and Growing-Stock Volume

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

Reasons for Observed Trends

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

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

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

ACKNOWLEDGMENTS

Thanks to Dave Azuma, Jeremy Fried, Sue Willits, and Kevin Birch for providing helpful comments on early drafts of the manuscript. Special thanks to Don Gedney for his guidance and for sharing his vast experience in FIA. Thanks also to Allison Nimura, Bruce Hiserote, and Larry Bednar for help compiling the Historic Oregon Data Warehouse.

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SOCIAL ACCEPTABILITY OF NATURAL RESOURCE DECISION-MAKING PROCESSES

Keith M. Reynolds[1]

ABSTRACT

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

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

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

INTRODUCTION

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

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

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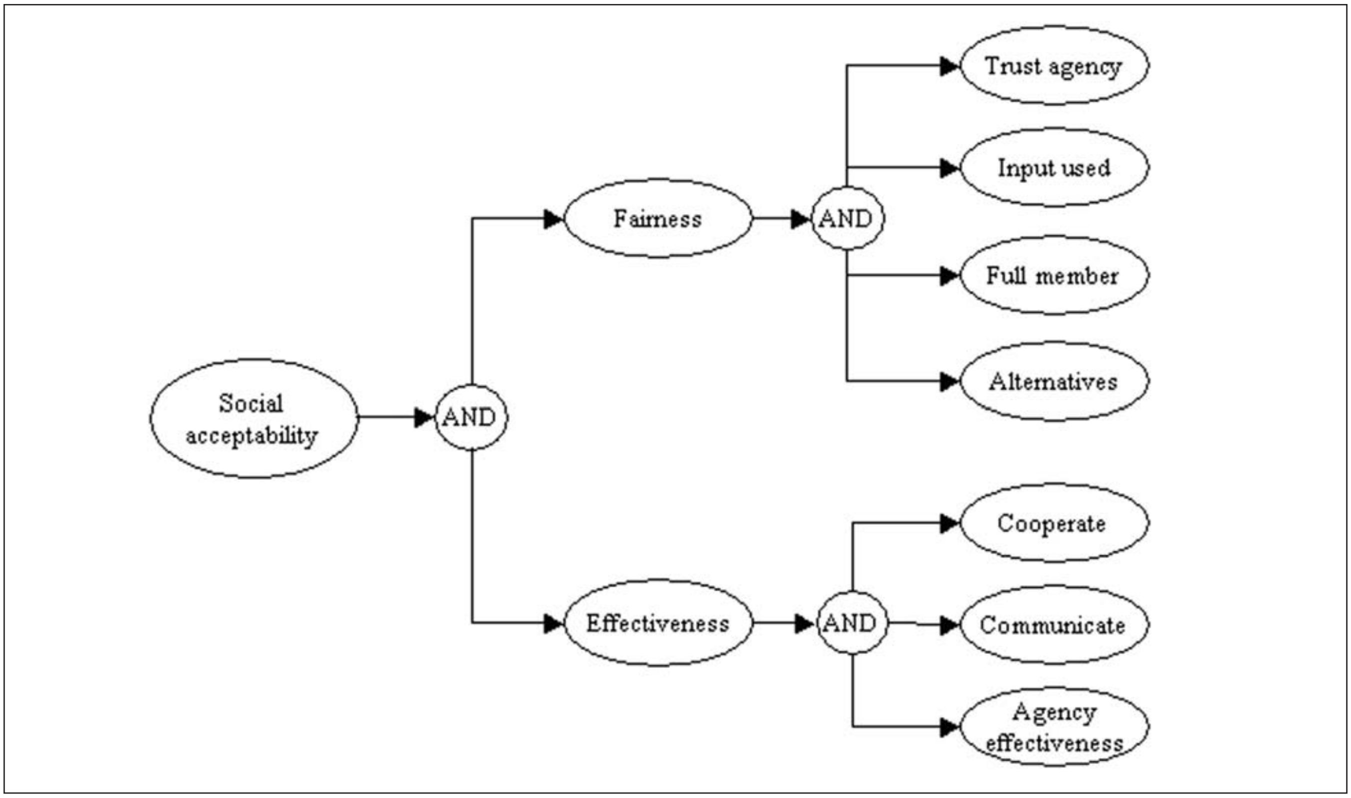

Figure 1—First three levels of propositions for knowledge-based evaluation of social acceptability of a natural resource decision-making process. The knowledge base evaluates the strength of support for a proposition based on a logical expression and strength of support for its premises. For example,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

SOCIALLY ACCEPTABLE DECISION PROCESSES

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

- insituational, spatial, and social context (Brunson 1992; Hansis 1995; Perry and Pope 1995; Steel et al. 1994; Vining and Ebreo 1991; Williams and Carr 1993),

- institutional and individual trust (Binney et al. 1996; Brockner et al. 1997; Glaser 1997; Kasperson et al. 1992; La Porte and Metlay 1996; Moore 1996; Peters et al. 1997; Pijawka and Mushkatel 1991; Shindler and O'Brian 1998; Wondolleck 1988; Wondolleck and Yaffee 1994),

- perceptions of risk (Arrandale 1999; FEMAT 1993; Fischoff et al. 1981; Hendershot 1996; Kasperson et al. 1992; Lober 1996; Slovic 1987, 1997; Sullivan 1998), and

- forms of knowledge.(Binney et al. 1996; Brothers et al. 1991; Cheek et al. 1997; Fortner and Lyon 1985; Kearney et al. 1996; Kloppenburg 1991; Shelby and Speaker 1990; Stankey 1976, 1996; Steel et al. 1990, 1994).

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

NETWEAVER MODELS IN FOREST MANAGEMENT

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

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

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

KNOWLEDGE BASE DESIGN

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

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

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

KEY SOCIAL ISSUES IN LOGIC DESIGN

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

1. Natural resource agencies focus too much on the social acceptability of their decisions as opposed to the acceptability of their decision-making processes.

2. The NetWeaver knowledge-based system allows users to adjust knowledge base design for a specific context. However, unless modifications are well documented, this flexibility can potentially reduce the transparency of the process by which the knowledge base evaluates agency decision-making.

3. Natural resource management and science programs are dominated by the technical-rational paradigm; a model of thinking and acting that rests on a rational, scientifically-based analytic process which also acts to constrain incorporation of subjective, qualitative knowledge.

4. Our understanding of the social acceptability of decision-making processes is incomplete and needs further study.

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

Acceptability of Decisions Versus Decision Processes

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

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

Recommendations

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

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

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

Transparency of Model Logic

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

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

Recommendation

Recognize the caveats associated with modifying knowledge base design.

Technical-rational Approach to Decisions

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

Kakoyannis et al. (2001) strongly urge caution against agency members entering data for evaluation based on their own perceptions of public attitudes. Various studies, describing both agency and public perspectives on the same issue, demonstrate that perception of degree of support for any particular proposition may differ widely between, as well as within, agency members and citizens. Shindler and O'Brian (1998), for example, found that agency members tended to rate their performance in various areas more highly than members of the public did.

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

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

DISCUSSION

Kakoyannis et al. (2001) offer some strong cautions concerning application of technical-rational models in general, and logic-based knowledge base models in particular, to actual evaluation of social data. Several cautions were discussed here and are well founded. Certainly, care in suitably documenting structural changes to models, and care in design of robust sampling procedures represent legitimate concerns. On the other hand, a more fundamental concern about the difficulty of adequately representing social values in a logic framework is perhaps somewhat overstated. I agree with Kakoyannis et al. (2001) that the concepts of social acceptability are very abstract and very complex, and that this first knowledge base is therefore only a rough first approximation. However, reasoning is a fundamental human activity; we do it every day in the context of almost all actions we take, including deciding how acceptable a decision process may have been. I would argue, therefore, that, to the degree that the thought processes involved draw on normative concepts and are rational in some sense, the evidence by which people arrive at their evaluations is susceptible to modeling in a logic framework. A somewhat subtler point, perhaps, is that the logic framework by which evidence is considered represents a social science specification for how to synthesize the collection of evidence into an overall conclusion. This framework, however, should not be construed as a model of how a member of the public literally reasons about acceptability.

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

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

ACKNOWLEDGMENTS

I thank Christina Kakoyannis and Dr. Bruce Shindler (Oregon State University) and Dr. George Stankey (USDA Forest Service, Pacific Northwest Research Station) for the very detailed and thoughtful analysis from which this summary draws heavily.

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Mailing address	Publications Distribution Pacific Northwest Research Station P.O. Box 3890 Portland, OR 97208-3890