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Beyond 2001: A Silvicultural Odyssey to Sustaining Terrestrial and Aquatic Ecosystems

Proceedings of the 2001 National Silviculture Workshop, May 6-10, Hood River, Oregon

2001
Silvicultural
Odyssey
Hood River, Oregon

Compilers

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Abstract

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Preface

The 2001 National Silviculture Workshop was held in Hood River, Oregon, and hosted by the Mt. Hood National Forest, the Gifford Pinchot National Forest, and the Pacific Northwest Research Station. The Washington Office Vegetation Management and Protection Research and Forest and Grassland staffs are ongoing sponsors of the biennial workshop, which began in 1973 in Marquette, Michigan. The general purpose of the workshop is to provide a forum for scientists and land managers to exchange ideas and information and to develop opportunities for future collaboration. The 2001 workshop focused on the role of silviculture in supporting wildlife habitat and riparian management objectives. This topic was chosen to emphasize current issues in forestry and to underscore the important contribution of silviculture to ecosystem management. Papers were solicited on projects that demonstrated the use of silviculture in achieving wildlife and fish management goals. This document contains the papers that were offered at the 2001 workshop, and are grouped according to four themes: wildlife, vegetation, aquatic systems, and social systems. Authors are presented in the order in which papers were presented at the 2001 workshop.

Nancy Lankford, Forest Silviculturist on the Mt. Hood National Forest, and Bob Obedzinski, Silviculturist on the Gifford Pinchot National Forest, were instrumental in organizing the 2001 workshop. The planning committee included Frank Burch, WO-FM; Sharon Friedman, WO-VMPR; Fred Zensen and Grant Gunderson, Pacific Northwest Regional Office; Andrew Carey, Peter Bisson, Connie Harrington, and Susan Stevens Hummel, Pacific Northwest Research Station.

S. Friedman, Washington, DC

S. Hummel, Portland, OR

S. Parker, Washington, DC

February 2002

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Wildlife

Using Individual Tree Selection Silviculture to Restore Northern Goshawk Habitat: Lessons from a Southwestern Study

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Authors

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Abstract

Stem-mapped data from six 10-acre uneven-aged Ponderosa pine (*Pinus ponderosa* var. *scopulorum* Laws.) growth plots located on a highly productive site on the North Kaibab Plateau in Arizona were used to examine the distribution of vegetation structural stages recommended for management of Northern goshawk and species in its food web. Seedling/sapling and old-forest stages were found to be lacking at the sub-stand level. Future growth of selected groups was projected to estimate residence in various structural stages under differing stocking conditions. Stagnation of untreated densely stocked groups prevented them from reaching old-forest condition. Young groups quickly grew to mature stages. Continual management for all structural conditions at a fine scale will be needed to maintain recommended goshawk habitat conditions. We present a conceptualized model of how this might be accomplished.

Keywords: Northern goshawk habitat, vegetative structural changes, ponderosa pine.

Introduction

Management for the northern goshawk (*Accipiter gentilis atricapillus*) has profoundly changed silviculture in the western U.S., particularly in the Southwest, where the goshawk has been listed as a sensitive species since 1982 (Dewhurst et al. 1995). Management recomendations designed by an interdisciplinary team of scientists to improve goshawk habitat in the Southwest have been in place for several years (Reynolds et al. 1992). These recommendations identify forest structural characteristics for goshawk nesting, post-fledging, and foraging habitats combined with habitats of goshawk prey and recommend a mix of vegetative structural stages (VSS) to be maintained across landscapes through time. Six VSS classes are defined in table 1.

The recommendations recognize that maintaining the desired mix of VSS's across landscapes will require "some form of stand replacement and density control," but do not specify specific silvicultural methodology to achieve it. Establishing and maintaining the desired mix of VSS's across a landscape as each grows into a more mature class while at the same time regenerating areas to VSS1 is no small task. It is further complicated by the necessity to maintain high canopy cover percentages (>60 percent) within clumps in portions of VSS 4-6.

Dewhurst et al. (1995) and Long and Smith (1999) have subsequently addressed this issue and suggested methodology to address the problem at landscape scales. These approaches are reminiscent of a large-scale application of group selection silviculture utilizing a combination of area control with intervening density control to achieve the desired spatial, structural, and age class mixes. We were intrigued by these papers because neither presented specific data on groups or clumps of trees existing within VSS's or what the expected growth (and therefore longevity) of the respective VSS's containing such groups might be.

Table 1–The classification of vegetative structural stages (VSS) based on stand quadratic mean diameter (QMD) at breast height.

VSS	1	2	3	4	5	6
DBH (inches)	0-1	1-5	5-12	12-18	18-24	24+

Methods

A continuing uneven-aged growth study on the Kaibab Plateau north of the Grand Canyon offered us the opportunity to explore the details of how stocking in small groups or clumps might affect the maintenance of VSS's at larger scales in ponderosa pine forests. Six 10-acre units were established in 1993 in a mesa-top forest (36.54° N. 112.33° W.). All of these forests contained a range of diameter and age classes and were very productive with an average Site Index of 95 (base age 100). Two complete replications of a control unit and two uneven-aged individual tree selection units were laid out. Basal areas of the two treated units in each replication were subsequently reduced to average basal area stocking levels of 61 to 74 $ft^2 \bullet ac^{-1}$ by using marking guidelines that specified irregular tree spacing and maintenance of clumps.

From 1998 to 2000, we mapped the location of all trees in the entire study. Figure 1a is an exact three-dimensional reproduction of Control Unit 1 drawn by using the Stand Visualization System (McGaughey 1997). Treated Unit 3 is shown in figure 1b. The multistoried, irregularly spaced composition of these forests is readily apparent. These 10-acre units are certainly not landscapes, and cannot represent VSS's on the 2-4 acre scales recommended for goshawk habitat (Reynolds et al. 1992). However, they are diverse enough to represent growth conditions within groups and clumps of trees within a spatially diverse ponderosa pine forest on the Kaibab Plateau. The control units represent conditions that existed prior to implementation of the goshawk recommendations, and the treated plots offer the opportunity to examine future growth following uneven-aged silviculture treatments that might be applied at larger scales to manage for goshawk. The spatially-mapped data from the units offered an opportunity to examine growth dynamics of small groups of trees that could represent various VSS classes at larger scales in southwestern ponderosa pine.

To quantify the variability in structure and stocking in each of the units, we divided each into a 6 x 6 grid of 36 plots (each 0.27 acre in size), calculated stem densities and quadratic mean diameters (QMD), and assigned each plot into a VSS class according to the diameter distribution presented in table 1. An algorithmic relationship developed from even-aged ponderosa pine thinning plots in northern Arizona (data on file Rocky Mountain Research Station) was used to estimate canopy cover requirements specified for VSS 4-6 (Reynolds et al. 1992):

$$\text{Crown Cover} = -57.44 + 25.5047 * \text{LN(BA)}$$
$$\text{where: BA = Basal area } (ft^2 \bullet ac^{-1})$$

We then picked subplots of interest and projected their growth forward in time using the SUPPOSE interface to the Forest Vegetation Simulator (FVS) (Crookston 1997). The Central Rockies/Southwestern FVS variant was used to estimate changes in structure and VSS's through time. We ran the model without any growth, mortality, and disease modifiers, using tree dimensions, conditions and damages that were measured on the subplots. Trees that had grown into some treated subplots between 1994 and 2000 were included to gage the effects that ingrowth after a manipulation treatment would have on groups. We also simulated the effects that thinning would have on the rate of change within groups, including the effects of new regeneration that would be stimulated by the treatment (using our observed responses following the 1993 thinning as a guide).

Results

All of the 10-acre units exhibit the varied structure illustrated in figures 1a and 1b. Boxplots of basal area distributions within the units (fig. 2) indicate that while the average basal areas in the two control units is 125 $ft^2 \bullet ac^{-1}$, basal areas of the 36 subplots within each of these units ranged from 40-190 $ft^2 \bullet ac^{-1}$. Average basal areas (measured in 1994)

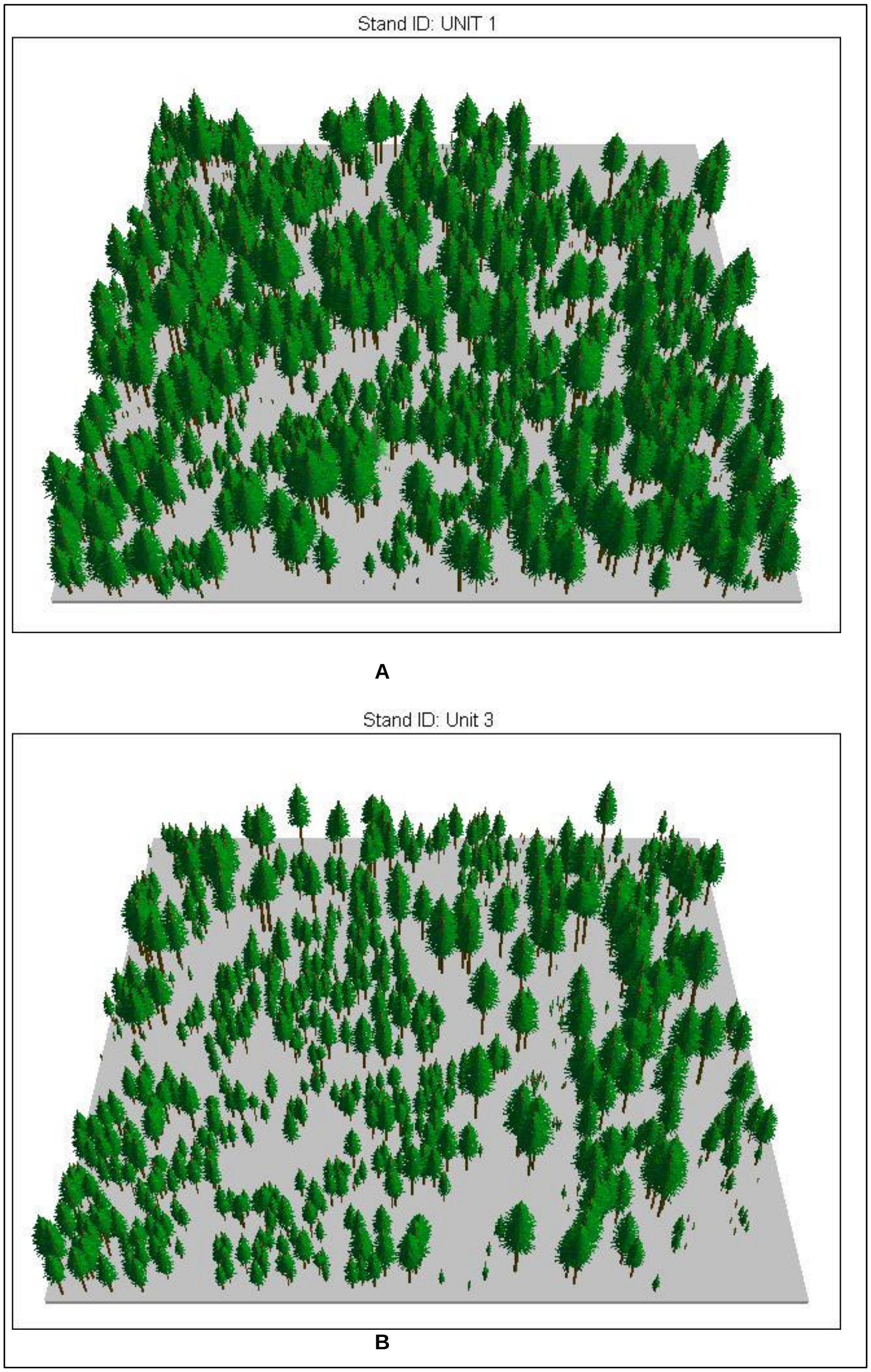

Figure 1–Graphical depiction of two 10-acre study units drawn from stem-mapped tree data (**A**) Control Unit 1; (**B**) Treated Unit 3 after uneven-aged thinning.

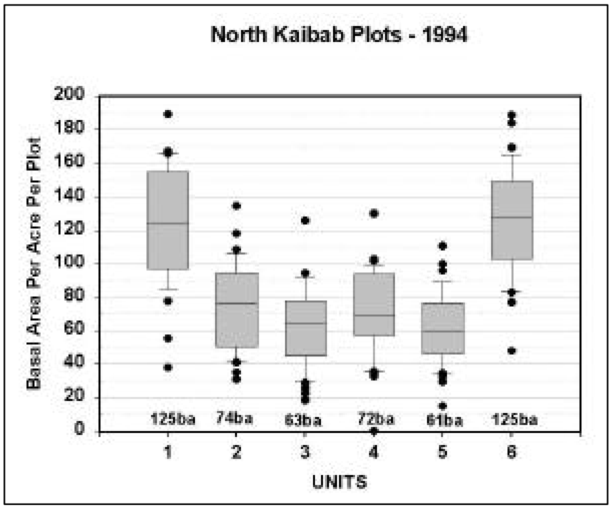

Figure 2–Boxplots of basal area distributions for Control Units 1 and 6 vs Treated Units 2-5 (n = 36 0.277-acre subplots in each unit). Means (labeled "ba") appear at the bottom.

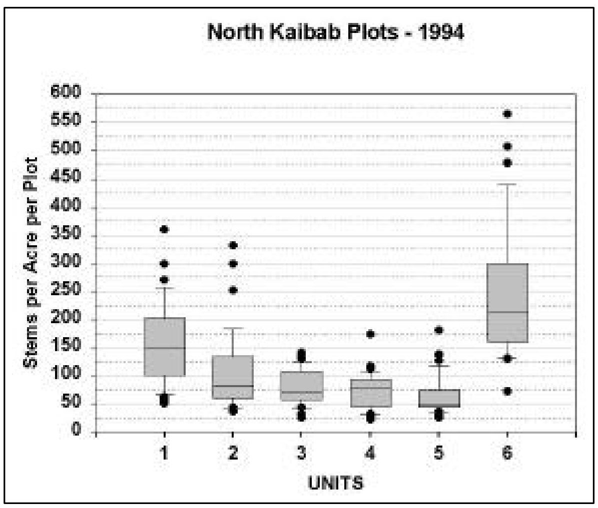

Figure 3–Boxplots of the stem density distributions for Control Units 1 and 6 and Treated Units 2-5 (n = 36 0.277-acre subplots in each unit). Means appear at bottom.

of the treated units ranged from 61-74 $ft^2 \cdot ac^{-1}$, but subplots ranged from 19-135 $ft^2 \cdot ac^{-1}$. Stem density boxplots indicate that the two control units are quite dissimilar (fig. 3). Unit 6 contains a wide range of stem densities, while those in Unit 1 are more uniform, even though both have exactly the same basal area. The ranges of stem densities in the treated units also varied (fig. 3). Stem densities in Units 3, 4, and 5 are much less variable than the control plots. The range of stem densities in Unit 2 was similar to that of Control Unit 1, even though the treatment had reduced the basal area by 40 percent.

VSS's were assigned to each of the 36 subplots within each unit for comparison to the recommended VSS distributions for goshawk foraging areas in ponderosa pine (fig. 4). The VSS distribution for subplots in all six of the units show considerable deviation from recommended conditions (fig. 4). As is typical of existing southwestern forests, neither of the control or treated units contain grass/forb/shrub (VSS1), or old-forest (VSS6) structural conditions. Instead, VSS3 and VSS4 conditions predominate. Openings created by the treatments were not large enough to convert any subplots to VSS1, although we did locate and measure numerous seedlings in some subplots in 2000. Not enough time has elapsed since the study was installed to grow any VSS5 subplots to VSS6, however.

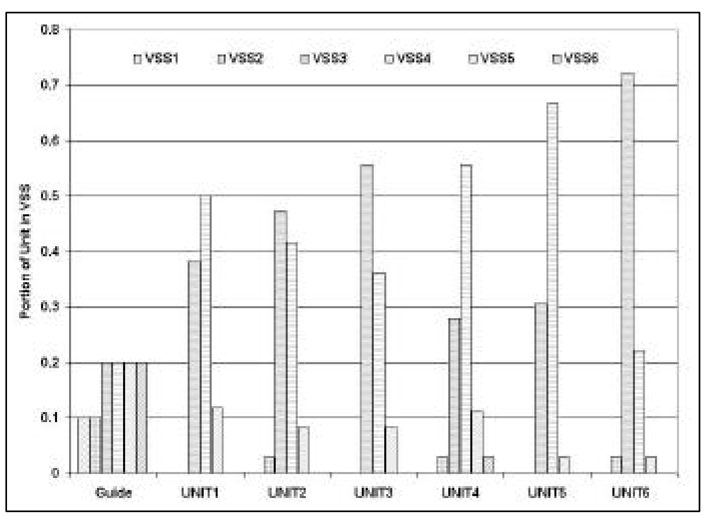

Figure 4–Distribution of VSS's in Units 1-6 and the recommended VSS distribution guideline for northern goshawk habitats (Reynolds et al. 1992).

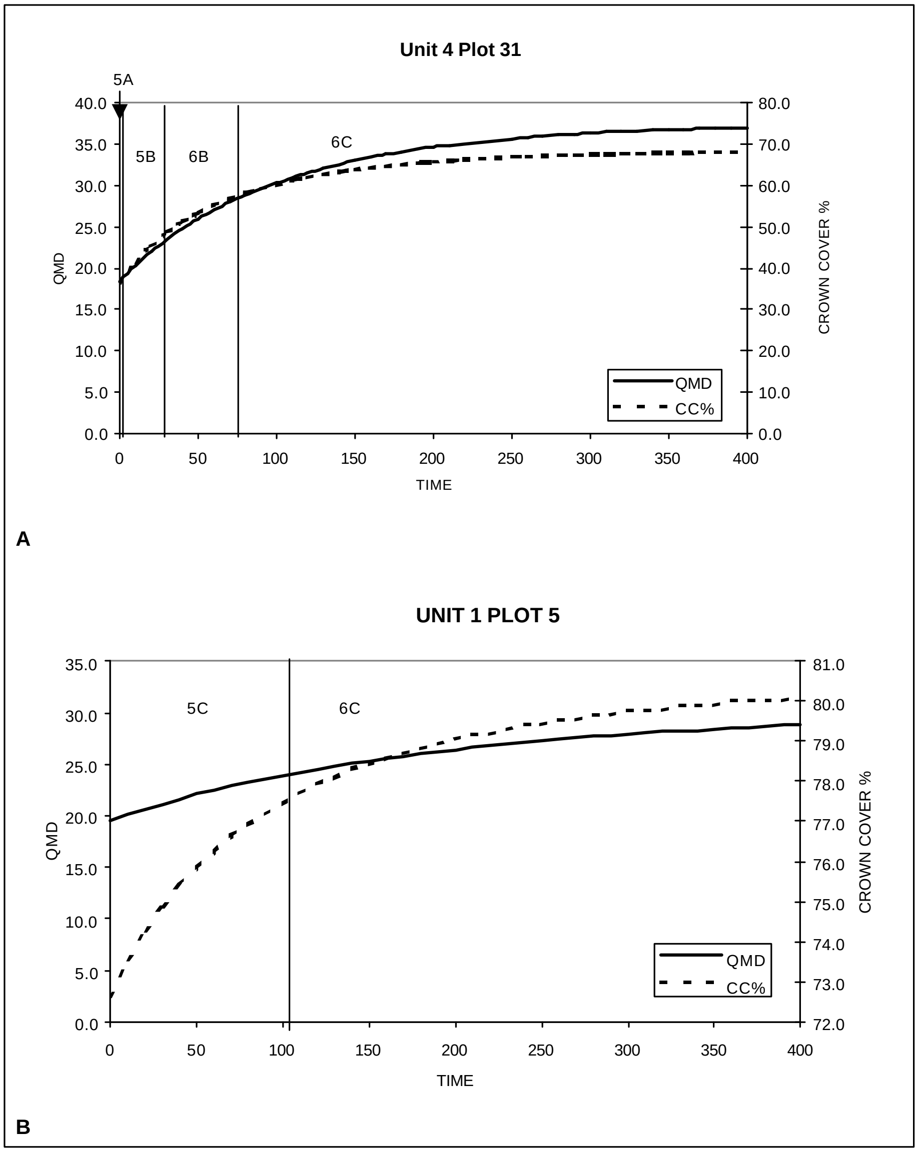

Figure 5–FVS projection of Quadratic Mean Diameter (QMD) and percent crown cover for (**A**) a mature open group; (**B**) a mature heavily stocked group. Vertical lines denote VSS boundaries.

We selected specific subplots to investigate how stocking at small spatial scales might influence the progression from one VSS to the next. Several scenarios were run in FVS:

1. To see how quickly an open, mature forest in VSS5 might grow to VSS6 on this highly productive site we selected Unit 4, Subplot 31, an open stand containing 22 trees ac^{-1} with a basal area of 40 $ft^2 \bullet ac^{-1}$ and a QMD of 18.4 inches. FVS projected that growing the existing stocking forward in this subplot would allow it to reach VSS6B (QMD > 24.0 inches, BA = 67 $ft^2 \bullet ac^{-1}$) in 35 years and VSS6C (>60 percent crown cover) in 75 years (fig. 5a).

2. To contrast how a densely stocked VSS5C (>60 percent crown cover) group might behave, we chose Unit 1, Subplot 5, which contained 79 trees ac^{-1} with a basal area of 164 $ft^2 \bullet ac^{-1}$ and a QMD of 19.5 inches. FVS predicted that this subplot would take 100 years to grow to VSS6C (fig. 5b). At that time, it would then contain a basal area of over 200 $ft^2 \bullet ac^{-1}$ and have a QMD of only 24.0 inches. Achieving this condition would be highly unlikely because both the initial stocking condition and the resulting stagnated condition would be highly susceptible to attack by Mountain Pine Beetle (*Dendroctonus ponderosae* Hopk.).

3. Moving to the younger end of the VSS spectrum, we selected Unit 2, Subplot 5, one of only three VSS2 subplots in the six units. We wanted to examine how such sapling-sized groups might persist on this highly productive site. FVS predicted that this subplot would grow to VSS3 (QMD >5 inches) in only five years and exceed 120 BA in three decades (fig. 6a), indicating a need for thinning. Because this subplot was open and surrounded by seed bearing trees, 187 new ingrowth seedlings ac^{-1} had appeared on it between 1993 and 2000. We modeled the effect that this additional stocking would have on future growth by re-running the previous projection with these trees included. This doubled the time to grow to VSS3 to 10 years, but the subplot exceeded 140 BA in the third decade. Clearly, VSS1 and VSS2 will not persist long on this highly productive site.

4. Given the apparent need for periodic thinning, we wanted to see if a densely stocked small sawlog VSS4 group could achieve VSS6 without any intervention. We used data from Unit 1, Subplot 6, (QMD = 13.1, BA = 165 $ft^2 \cdot ac^{-1}$) and ran the FVS model for 400 years without achieving VSS6 (fig. 6b)! Thinning this group from below to BA 100, FVS projected it would quickly grow to VSS6 within 25 years (fig. 7a). Using observed ingrowth from 1993 to 2000, we decided to model a second scenario where we would grow the original Unit 1, Subplot 6 for 100 years, thin it as before, then add 112 new seedlings ac^{-1} 10 years later. The inclusion of ingrowth prevented the group from growing to VSS6 (fig. 7b), primarily because the numerous smaller trees lowered the QMD, stagnated, and did not grow large enough for the overall stand to achieve VSS6. This reinforces the recommendation to manage clumps of trees as more or less even-aged (Reynolds et al. 1992).

Discussion

This exercise clearly illustrates that average stand data does not necessarily reflect the actual conditions under which trees are growing in the irregularly spaced clumpy conditions thought to be favored by northern goshawks. The existence of non-uniform growing conditions needs to be addressed when attempting to establish and maintain the spectrum of VSS's recommended for Goshawk habitat. Several factors need to be considered when planning silvicultural activity in such landscapes.

The time needed to progress from one VSS class to another will vary based on stocking at the small scale of clumps, where tree density and competition influence growth. Trees in heavily stocked groups will grow slowly and remain at similar sizes (and thus VSS) for long periods of time. They will also be more stressed and likely be susceptible to insect attack.

Trees in open-spaced groups or widely spaced clumps will grow fast, and move into larger VSS classes quickly. Open-spacing will also allow new seedlings to establish, which if not controlled through periodic under burning or thinning, will create a dense sapling understory and move the group or clump into a two-aged forest condition which is undesirable for goshawks and prey. Including the new understory in stocking calculations (which must be done because the young trees influence overall site productivity) will cause the QMD to drop, moving the group into a smaller VSS, even though the group still contains some very large trees.

On good sites, openings regenerated into VSS1 will move into VSS3 within three decades. This happens at a much faster rate than VSS5 and VSS6 portions of the landscape become decadent and need replacement. Therefore, some VSS3 and VSS4 groups will need to be harvested to create sufficient openings to maintain the recommended 10 percent of the landscape in VSS1 and 10 percent in VSS2. If natural regeneration is prolific (as we have observed it to be on this good site), precommercial thinning or under burning will be necessary to create spatial diversity and maintain a healthy condition for the groups to grow into larger VSS's.

In conclusion, managing southwestern ponderosa pine forests for northern goshawk habitat is not merely a question of harvesting trees in a manner that will create the recommended mix of structural conditions within goshawk territories. If our study site is typical of conditions existing at larger scales in southwestern landscapes, additional openings will be needed to create VSS1, which is currently lacking. These in turn will have to be allowed to grow into VSS2, which are also currently lacking.

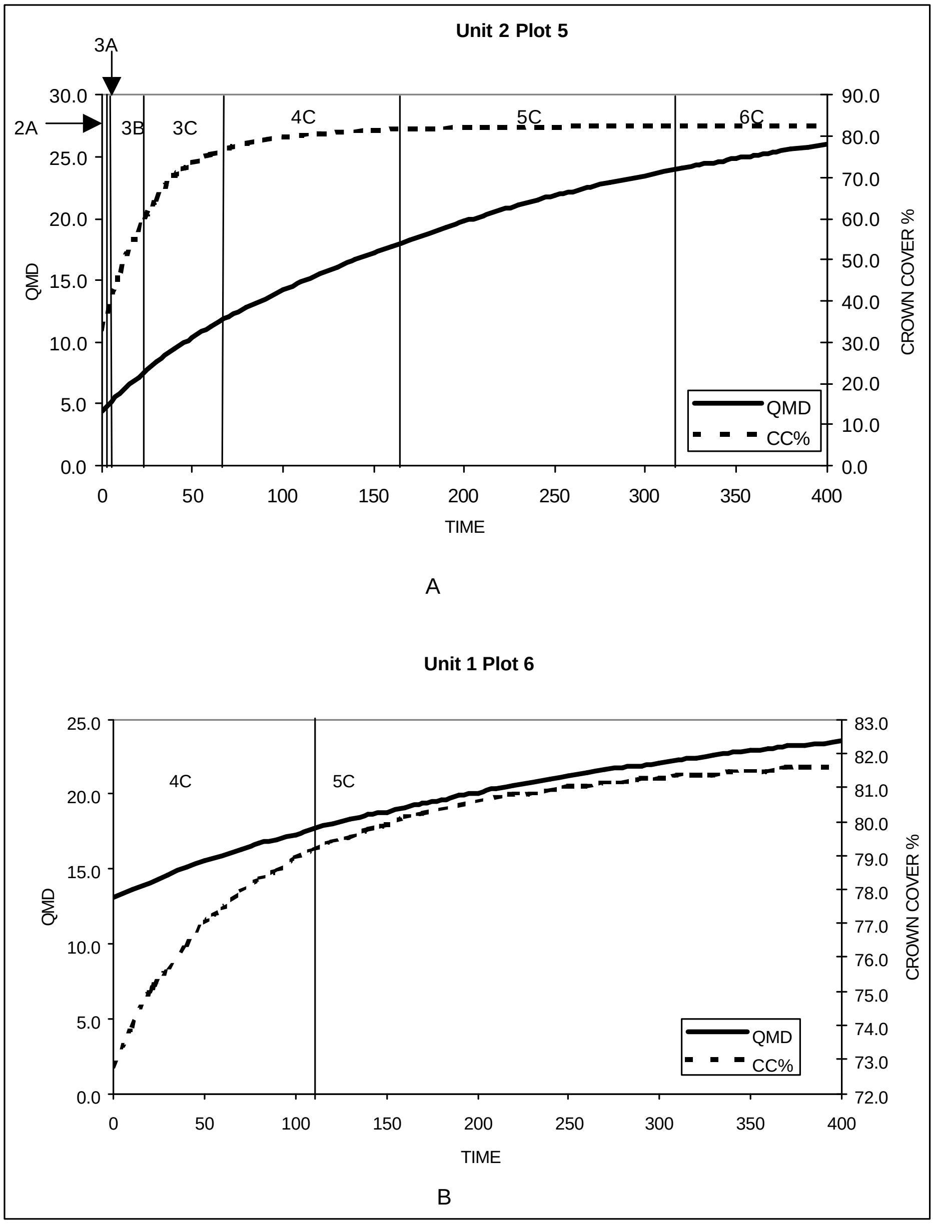

Figure 6–FVS projection of Quadratic Mean Diameter (QMD) and percent crown cover for: (**A**) a young sapling group; and (**B**) a densely stocked small sawlog group left unthinned. Vertical lines denote VSS boundaries.

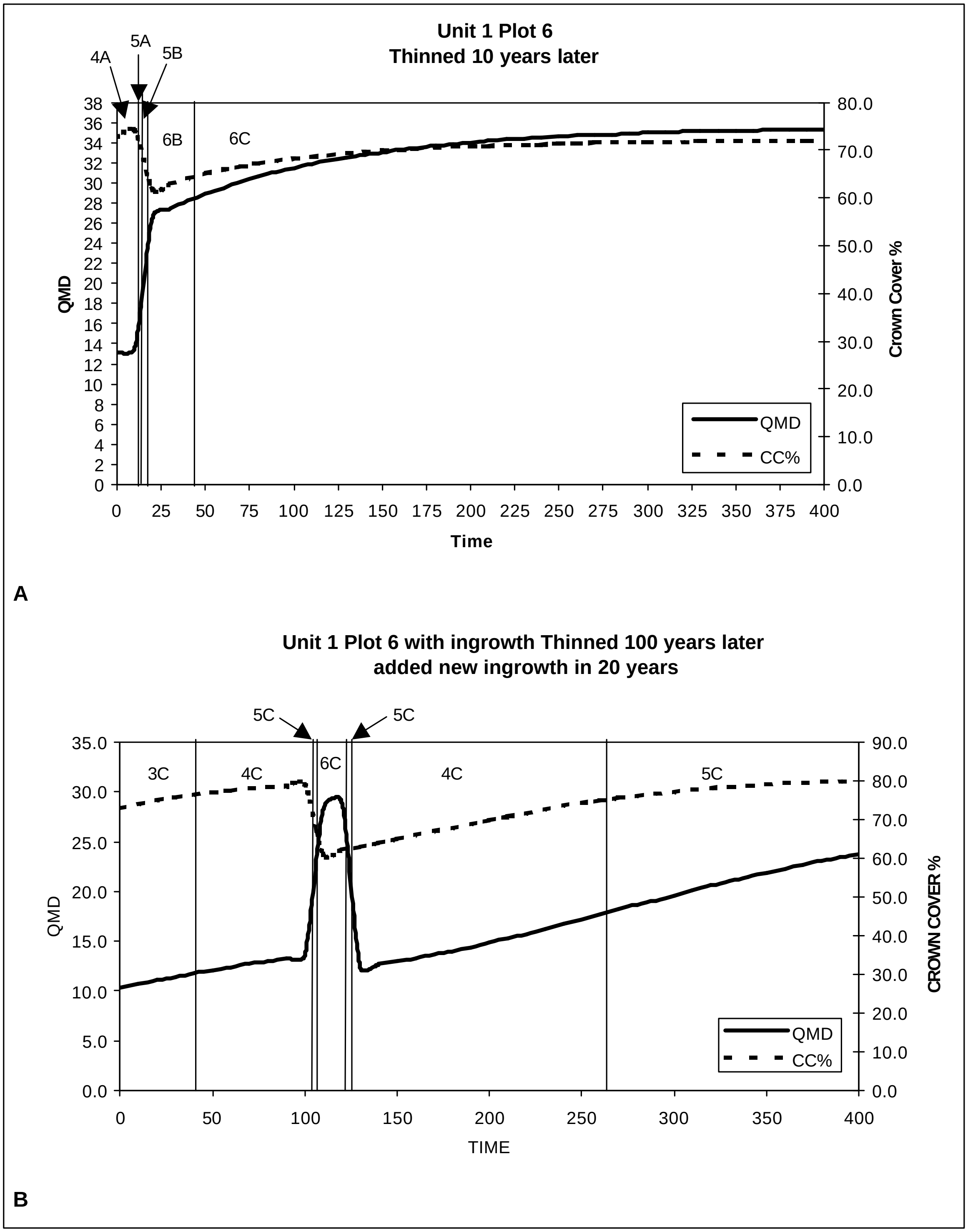

Figure 7–FVS projection of Quadratic Mean Diameter (QMD) and percent crown cover for a densely stocked small sawlog group thinned at 10 years (**A**), and thinned at 100 years with new seedling ingrowth at 120 years (**B**). Vertical lines denote VSS boundaries.

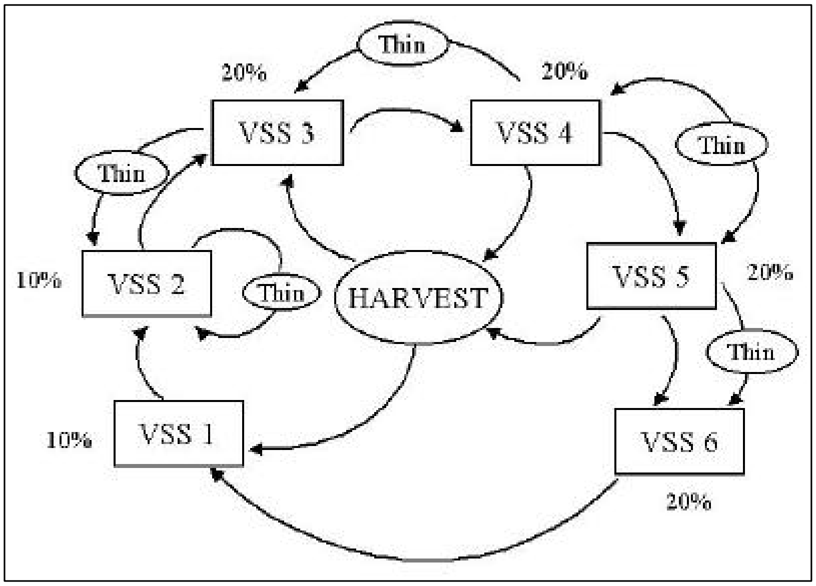

Figure 8–Conceptual model of silvicultural activities needed to maintain fine-scale structure in landscapes managed for northern goshawk. Scheduling of activities would depend on site productivity and other factors.

At the same time, some existing VSS5 groups will need thinning so they can grow into the critical VSS6, which again is currently lacking. If this weren't complicated enough, both commercial and non-commercial thinning and prescribed burning will need to be done simultaneously to some other VSS groups to maintain them in a condition beneficial to the goshawk. In short, as recommended in Reynolds et al. (1992), our study verifies that a lot of continuous silvicultural activity will be needed to establish and maintain the desired mix of VSS's for optimal northern goshawk habitat conditions.

Figure 8 presents our conceptualized model of how the process of managing goshawk habitat might work. We do not feel that this would be an impossible task, but rather one which will require intensive silviculture on a fine scale as opposed to the landscape-scale management schemes that have been previously proposed. Ignoring the growth dynamics that are operating at fine scales within irregularly structured forests will only decrease the chances of maintaining the mix of structural conditions that are needed at larger scales in northern goshawk habitats.

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Development and Maintenance of Northern Spotted Owl Habitat in the Gotchen Late-Successional Reserve of the Gifford Pinchot National Forest, Washington

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Abstract

Conservation of late-successional and old-growth forest ecosystems is a key objective of the Northwest Forest Plan (Plan). The Plan specifies a spatial array of Late Successional Reserves (LSRs) to help achieve this objective. Under the Plan, management options within LSRs are limited to the maintenance or development of spotted owl (*Strix occidentalis caurina*) habitat. Forests constituting spotted owl habitat on the east side of the Cascade Range in Washington and Oregon are more stressed for moisture than are forests in LSRs on the west side of the crest. The absence of disturbance, such as forest fire, has resulted in a greater proportion of late-successional forest stands. These stands have a greater proportion of shade-tolerant tree species, the majority of which is grand fir (*Abies grandis*). The grand fir in the Gotchen LSR is late-successional in nature and provides habitat for the northern spotted owl. Spotted owl habitat is at risk because of tree mortality. LSR function and legacy tree structure may also be at risk because of stand replacement crown fire. The legacy trees exceed 150 years in age. Nest sites in the Gotchen landscape are closely associated with this legacy structure. The trajectory of a substantial portion of the grand fir forest in the Gotchen LSR is continued tree mortality and increasing fuel loading. The purpose of this paper is to introduce a stand-scale treatment that will (1) maintain spotted owl foraging habitat, (2) increase the likelihood of stand recovery to late successional condition, (3) decrease the likelihood of crown fire, and (4) decrease spruce budworm (*Choristoneura occidentalis*) risk.

Keywords: Spotted owl habitat, grand fir forest, late-succesional reserves, Gotchen LSR, spruce budworm.

Issues

The 1994 Northwest Forest Plan (NWFP) was established with the intent of protecting and enhancing conditions of late-successional and old-growth ecosystems as habitat for northern spotted owls (a federally listed species) and other old-forest organisms. The NWFP, designated by U.S. Department of Agriculture, Forest Service (USDA FS) and U.S. Department of Interior, Bureau of Land Management (BLM), is a network of Late Successional Reserves (LSRs) across the range of the northern spotted owl on national forests and BLM lands. Gotchen is one of the LSRs in this network. It is located on the eastern flanks of the Cascade Range in the Gifford Pinchot National Forest of Washington. A substantial portion of the Gotchen LSR contains spotted owl habitat, which is in poor health and has a declining probability of persistence (USDA FS 2001). Tree stress is resulting from a drought of the last two to three decades (High 2001) and endemic forest pathogens (Obedzinski 2001, Forsberg 2000). Multi-century old legacy trees are at risk due to competition stress from the more abundant grand fir. Legacy trees are also at risk of loss via forest fire. The 1997 Forest Assessment (USDA FS 1997) expressed the concern for the Gotchen LSR that the combination of relatively dry environment, abundance of fire intolerant tree species, and increasing levels of forest pathogens would pose significant risk of catastrophic stand replacing fire. Under NWFP guidelines, forest silviculture and other forest management options within LSRs are limited to activities that would maintain or restore habitat for the northern spotted owl. A management expectation is that the Gotchen LSR continue to provide spotted owl habitat for at least the existing six pairs (Cox 2001).

This report explores active management of stand structure of foraging quality spotted owl habitat in the Gotchen LSR. This foraging quality habitat is decreasing canopy cover, canopy closure, and vertical diversity as tree mortality progresses. On the existing trajectory and within 5-10 years, these stands are expected to change spotted owl habitat type from the existing foraging quality to non-suitable. The primary management objective is the prevention of loss of spotted owl habitat. Secondary objectives are to (1) increase the likelihood of stand recovery to late-successional condition, (2) decrease the likelihood of crown fire, and (3) decrease spruce budworm risk. The management question is, "how much and what kind of change in stand structure can be implemented and still maintain spotted owl habitat?"

The Setting

The Gifford Pinchot National Forest (GPNF) covers 1.5 million acres in southwest Washington (fig.1) and is located within the Southwest Washington Cascades physiographic province. On the north flank of the GPNF, is the Western Washington Cascades province, and on the east flank is the Yakima province. Management direction for the GPNF is established by the Gifford Pinchot National Forest Land and Resource Management Plan, as amended by the NWFP (USDA FS 1994).

The NWFP established nine LSRs, which cover 447 thousand acres of the GPNF (fig. 2). Two of the LSRs on the GPNF, Peterson and Gotchen, occur on the east side of the Pacific Northwest Cascades crest. East side LSRs face a drier environment than on the west side of the crest and this results in different management issues. The Gotchen LSR, on the east side of the crest, is the driest of the GPNF LSR network.

The Gotchen LSR covers 15,169 acres and spans an elevation range of 2,375-5,525 feet. The most abundant 350 feet elevation class is the 3,775-4,125 feet class followed by the 4,125-4,475 feet class. The dominant aspect is southerly, and slopes are gentle (<10 percent) for most of the

Figure 1—Project area in southwest Washington.

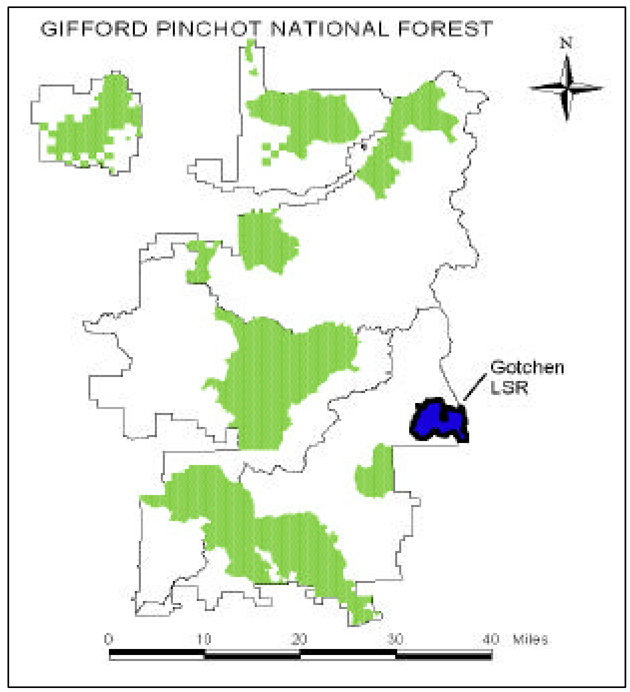

Figure 2—Gotchen Late-Successional Reserve in relation to the Gifford Pinchot National Forest LSR network.

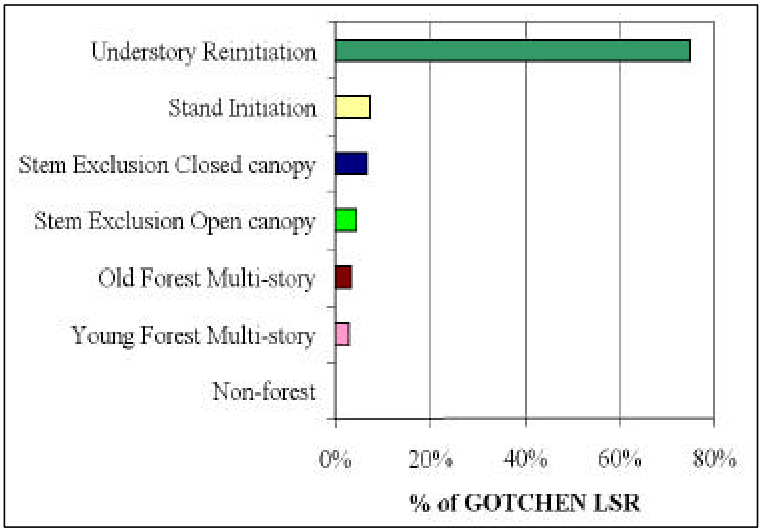

Figure 3—Forest structure stage distribution for the Gotchen LSR.

LSR. Stream courses drain to the south-southwest into the White Salmon River. A precipitation gradient exists in which an average of 90-100 inches occur in the northwest and 40-50 inches per year occur in the southeast. Soils, especially in the southern two-thirds of the LSR, have a high volcanic ash content and low soil moisture holding capacity.

The wildlife habitat type for the Gotchen LSR is the "Eastside Mixed Conifer Forest" (Chappell et al. 2001). Chappell et al. (2001) reports that this wildlife habitat type occupies about 4.6 million acres in the state of Washington and makes up most of the continuous montane forests of the inland Pacific Northwest. Three Forest Zones (Topik 1989) occur in the Gotchen LSR. The Grand Fir Zone occupies 86 percent of the LSR, and the remaining 14 percent in the higher elevations of the LSR is occupied by the Sub-Alpine and Mountain Hemlock forest zones. Grand fir forest within the Gotchen LSR is generally dense and closed multi-story stands, with ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) forming the legacy and over-story position of the canopy. Grand fir occupies the co-dominant, intermediate, and suppressed portions of the canopy. Other tree species present include western white pine (*Pinus monticola*), western larch (*Larix occidentalis*), lodgepole pine (*Pinus contorta*), quaking aspen (*Populus tremuloides*), and Oregon white oak (*Quercus garryana*). "Upland Aspen Forest" (Chappell et al. 2001) is scattered within the Gotchen LSR as small patches and is in decline as a function of senescence and or shading. Of the tree species in the Gotchen LSR, Oregon white oak is the least abundant and has a patchy (usually less than a dozen trees per patch) distribution.

As shown in figure 3, the Understory Reinitiation (UR) (Oliver and Larson 1996) structural stage occupies 75 percent of the Gotchen LSR (Hessburg 2001). The UR stage has a large tree (diameter at breast height, dbh >25") canopy cover of <30 percent, and seedling/sapling (<5" dbh) cover >10 percent, and pole-small-medium tree (dbh 5 to 25") cover >60 percent. The Stand Initiation (SI) stage exists when large tree cover is <30 percent, seedling/sapling cover >10 percent, and the pole-small-medium tree cover is <20 percent. The Stem Exclusion (SE) stages have a large tree cover of <30 percent and seedling/sapling cover of <10 percent. In the SE stage, a closed-canopy condition exists when canopy cover for the pole-small-medium tree component is >70 percent. Old forest stands have large tree cover >30 percent. The Young-forest Multi-story (YFMS) exists when large tree cover is <30 percent, seedling/sapling cover >10 percent, the pole-small-medium tree cover is >20 percent, and small (9-16" dbh) or medium (16-25" dbh) is >10 percent. Legacy trees (generally > 36" dbh and more than 150 years old) are a unique habitat element (O'Neil et al. 2001) present in low quantities and with wide distribution across the Gotchen landscape. Legacy trees became established prior to fire suppression efforts. Those legacy trees that exist today were excluded from extensive selective harvesting of large old-growth ponderosa pine and Douglas-fir during the 1940s through the 1970s.

Spotted owl habitat within the Gotchen LSR is not unlike habitat described in other places on the east side of the Pacific Northwest Cascades crest. The current condition and distribution of LSR spotted owl habitat reflects almost a century of fire suppression, timber harvest, and spruce budworm. Two to three tree cohorts are present with the majority being in the 60-90 year-old class. The second most common age class would be the 100-150 year olds, then the greater than 150. Grand fir is the most abundant species in the youngest cohort. Douglas-fir and ponderosa pine comprise the vast majority of the older age classes. Fifty-six percent, 8,553 acres, of the Gotchen LSR is typed as spotted owl habitat (fig. 4). Of that total spotted owl habitat, 82 percent is foraging quality, and the remaining 18 percent is of the nesting quality. Spotted owl surveys and systematic monitoring of nest sites in the Gotchen LSR have been conducted over the last 10 years. Six spotted owl nest sites are known of in the Gotchen LSR: Gotchen, Smith Butte, Big Tree, Buck Cr., Crof, and Ground. None of the known six spotted owl nest sites falls within nesting quality habitat. The nest site is defined as including the nest tree and an area of about 0.5 acres around the nest tree. That none of the nest sites fall within what is typed as nesting quality habitat likely reflects two aspects of habitat typing. First, the actual nest site is not necessarily representative of the stand in which the nest site is located (Everett et al. 1997). The nest site is often a coarse pocket within a stand. The coarseness is due to the presence of large trees and down logs, which are legacy structure carried over from the previous stand. Second, aerial photographs are used in typing forests using stand scale resolution. We do not actually know how and or why a spotted owl selects specific areas to use. Spotted owls appear to use at least a finer level of resolution in "typing" their habitat than we do in our stand measuring and typing.

Since 1992, the six spotted owl nest sites in the Gotchen LSR have been part of a demographics study focused on spotted owls on the east side of the Pacific Northwest Cascades. Monitoring includes yearly visits to each nest site during which a determination is made of which spotted owls are present, what they are doing, and how many young are being raised. Spotted owls at each of the sites have unique leg bands, which allow for field identification of individual owls. The sex of each owl, its

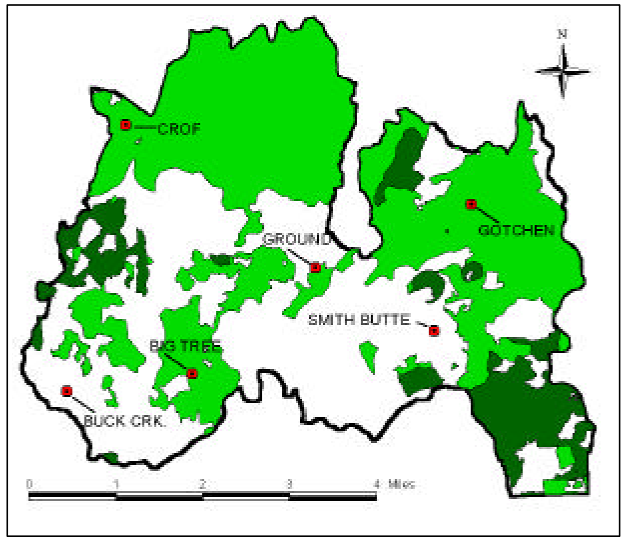

Figure 4—Spotted owl habitat (shaded) and nest site (red dots) distribution in the Gotchen LSR.

banding location, and when the owl was banded can be determined. This base data has been used to determine site productivity and owl movement. Emigration, immigration, and within LSR movement have been documented. The Gotchen is adding ("source") individual spotted owls to the population. Spotted owls have demonstrated strong site and pair fidelity though changes have been observed. The same stand and same individual tree are used for nesting and roosting each year. This remains even when there has been a change in the particular owl using a nest site. Pairs tend to stay together but occasionally one of the pairs moves to another site. There has also been the case of two males being present with one female at a reproductive site.

Tree disease and insects shape the Gotchen landscape. Over the last century, endemic root disease is suspected to have spread along with conifer (particularly grand fir) abundance and distribution. The greater amount of conifers in the Gotchen LSR increases the likelihood of root-to-root spread of root disease (Filip 1998). Compacted soils in the Gotchen LSR resulted from ground based logging systems of 60 years ago, and these compacted soils show limited levels of recovery (High 2000). Spruce budworm has been defoliating portions of the LSR since at least 1994 (Willhite 1999). The budworm outbreak extends beyond the limits of the LSR covering thousands of acres especially to the east on Yakima Indian Reservation land. Budworms effectively defoliate grand fir, the most abundant conifer species in the Gotchen landscape, although Douglas-fir has also been affected. Grand fir is the most abundant dead and dying species across the landscape. The distribution of this mortality varies from individual pockets of 6-12 trees to the majority of a stand being dead. Ground fuels are accumulating as dead tops and limbs fall to the forest floor. The thickets of small grand fir growing in the understory have undergone extensive defoliation from spruce budworm. The risk is increasing that under the right conditions, these thickets will serve as "ladder fuels" conducting a ground fire up into the crown. Once a fire starts in a densely stocked forest with widespread defoliated and dead trees, the potential for crown fire spread increases rapidly. East Cascades forest fires in 1994 altered forest habitat in LSRs for northern spotted owls by an average of 55 percent (Gaines et al.1995). Gaines et al. (1995) reported fewer spotted owls occupying and reproducing at these activity centers than in previous years.

Objectives

This report explores active management of foraging quality spotted owl habitat in the Gotchen LSR. As tree mortality progresses in foraging quality spotted owl habitat, canopy cover, canopy closure, and vertical diversity decline. On the existing trajectory and within 5-10 years, this foraging quality spotted owl habitat is expected to become unsuitable. The primary management objective of this investigation is the prevention of loss of spotted owl habitat. Secondary objectives are to (1) increase the likelihood of stand recovery to late successional condition, (2) decrease the likelihood of crown fire, and (3) decrease spruce budworm risk. The management question is, "how much and what kind of change in stand structure can be implemented and still maintain spotted owl habitat?"

Methods

I reviewed literature addressing spotted owl habitat on the east side of the Pacific crest in Washington. I located evidence of spotted owl use in the Gotchen LSR. The evidence was in the form of observed (audio and or visual) spotted owl activity including nesting, roosting, territorial displays, and foraging. I related spotted owl activity evidence to specific forest stands, then used Region 6 stand examination procedures (USDA FS 1989) to sample forest conditions at stands with spotted owl use. Stand structure and species composition were sampled via a regular grid of plots. Variable-radius plots were used with a BAF40 prism to quantify structure for trees >5" dbh. Hundredth-acre fixed radius plots were used to quantify structure for vegetation <5" dbh. Stand data were used to build tree-list files for analysis in Landscape Management System (Oliver 2001). To facilitate comparison to an existing spotted owl habitat study (Buchanan 1996), I grouped stand structure data into the same dbh classes used by Buchanan (1996). The proportion of basal area distribution within each diameter class reflects the average, plus or minus one standard deviation, of all stand examination data.

Results

Buchanan described forest structure at spotted owl nest sites from the east slope of the Cascade Range in Washington (Buchanan 1991), as well as southeastern Washington (Buchanan 1996). Buchanan noted that the spotted owls nested in relatively young (<100 years old) stands, many of which had a logging history. Buchanan's work yielded a total basal area of 236 square feet per acre with distributions in diameter classes as follows: one percent in the <4" dbh class, 23 percent in the 4-13" class, 28 percent in the 14-23" class, 40 percent in the 24-33" class, five percent in the 34-43" class, and two percent in the 44-53" class.

Everett et al. (1997) evaluated 48 nest stands, which had previously been reviewed by Buchanan (1996), though Everett focused only on reproductive nest sites. Seventy-nine percent of Everett's stands were in a grand fir series, whereas 86 percent of the stands were in the SE or UR stage of development. Everett reported that based on basal area (188-260 square feet per acre) or crown cover (83-94 percent), stands with active nesting were not discernible from non-nesting stands. It is possible that because of territoriality or food limitation, other stands though suitable could not be used at the same time as the successful stand. Everett reaffirmed that vertical diversity was an important aspect of spotted owl habitat quality. Everett's work yielded a total basal area of 236 square feet per acre, with distributions in diameter classes as follows: eight percent in the <4" dbh class, 27 percent in the 4-13" class, 14 percent in the 14-23" class, and 51 percent in the 24" and greater class.

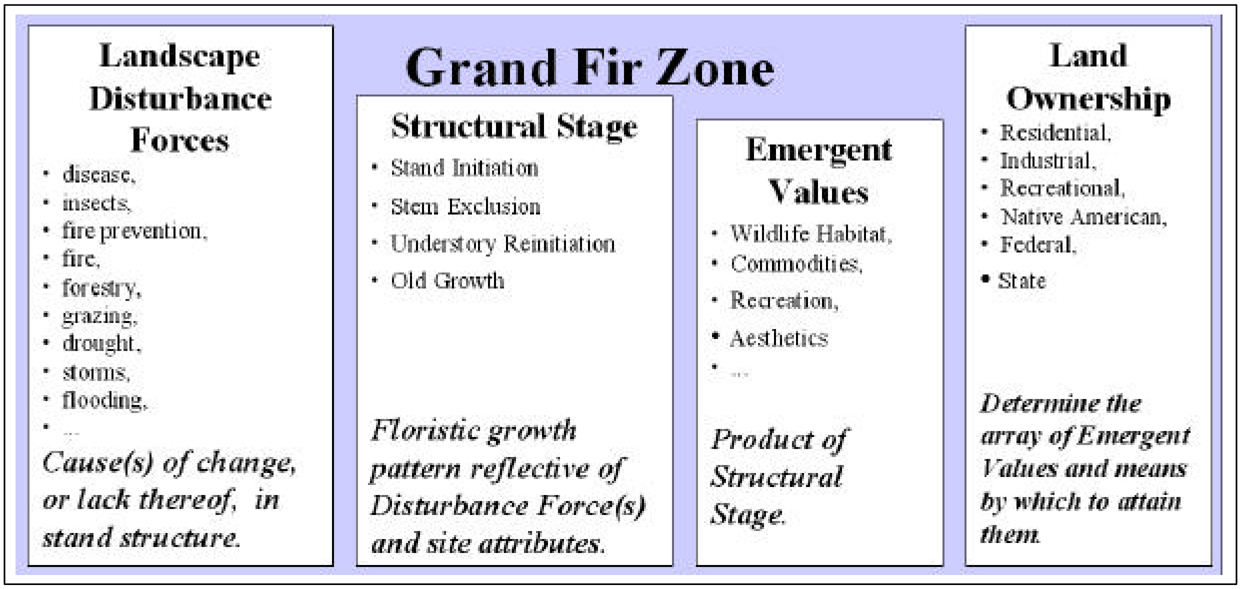

Figure 5—Hypothesis regarding relationship between habitat, forest structure, and goals.

Measures of forest structure at known spotted owl use sites in the Gotchen LSR yielded a total basal area (square feet per acre) range of 152-383 with an average of 260 (n=11, SE=23). Basal area was distributed across dbh classes as follows: 1-2 percent in the <4" dbh class, 23-30 percent in the 4-13" class, 38-44 percent in the 14-23" class, 17-22 percent in the 24-33" class, 5-9 percent in the 34-43" class, and 3-7 percent in the >43" class.

Discussion

Existing studies of spotted owl habitat use at nest sites on the east side of the Pacific Crest are observational rather than experimental. My work in the Gotchen LSR is also observational but includes habitat conditions in foraging areas. I used my findings of habitat use by spotted owl to establish a testable hypothesis, herein presented, on active management of spotted owl habitat. Spotted owl habitat definitions have stemmed from interpretation of nest site focused study.

My assumption is that emergent values, such as spotted owl habitat, are substantially influenced by, if not a direct result of, forest structure (fig. 5). It is furthermore assumed that spotted owl habitat quality can be estimated by measuring forest structure and that this structure can be actively managed to purposely affect spotted owl habitat quality. Of course, how wildlife perceives its environment versus how we as humans perceive and measure it, are not necessarily the same. My findings and proposal are from a limited data set and intended for preliminary use in the Gotchen LSR. This proposal needs to be tested with additional data from other spotted owl use sites on the east side of the Pacific crest then experimental field tests to assess selection by spotted owls.

Forest vegetation pattern and structural diversity on the eastern slope of the Pacific Northwest Cascades have changed during the past century (Everett et al.1997). Conversely, the area covered by stands in the young forest multi-story structural stage has decreased. The amount of old-forest multi-story stands is about the same, but its distribution is more contiguous than a century ago. The high stem density, particularly of grand fir, is closely associated with effective fire prevention and suppression over the past century. Late sere species such as grand fir, which are thin barked and more readily killed by fire, were typically "weeded out" by the periodic ground fires, and the open-grown, essentially single story stands were able to persist for hundreds of years. Though the specific amount and distribution remains uncertain, the pre-European forests were typically more open-grown and park-like than are today's stands. Periodic 6- to 45-year return interval, low intensity ground fires, maintained those open forest conditions (USDA FS 1997). Low-intensity ground fires were used in the Gotchen landscape by Native Americans and European settlers (Mack 2000). These ground fires increased the availability of nutrients while increasing growing space resulting in vegetation growth, which then served as forage for wild and domesticated ungulates. Dickinson (2000) reviewed Government Land Office records on forest conditions encountered in the Gotchen LSR by land surveyors during the late 1800s to early 1900s (1885-1917). Surveyor records indicate that during this period, the area below 3,800 feet in elevation (the southwestern third and the southern fourth of the LSR), had a tree density (TPA) of 17-27, with a basal area of 38-55 square feet per acre. Ponderosa pine, Douglas-fir, and lodgepole pine contributed the majority of the tree coverage reported, and most of the basal area was due to trees at least 30 inches dbh. The northern and eastern two-thirds of the LSR are reported to have had a lesser tree density and basal area per acre: 14-20 TPA, 30-72 square feet per acre. Douglas-fir and ponderosa pine, less than 28" dbh, accounted for the majority of the basal area. Though relatively stable, these pre-European stands were still subject to infrequent stand-replacing fires.

Habitat use by spotted owls for nesting, roosting, foraging, and dispersal varies across a landscape (Thomas et al. 1990, North 1993) and the suitability of an area for a particular use can be rated from poor to excellent. Recognizing this gradation in habitat quality, the GPNF stratified forest vegetation into nesting, foraging, dispersal, and non-habitat for spotted owls. On the GPNF, spotted owl habitat only includes nesting and foraging quality stands. Spotted owl habitat quality on the GPNF is estimated by querying the forest's vegetation database, GPVEG. Stand-scale variables such as elevation, ecoclass, overstory tree size class, dbh, canopy cover, crown layer, and major species are queried to identify spotted owl habitat. Generally, spotted owl habitat on the GPNF is at or below 5,000 feet in elevation, has a canopy cover of at least 40 percent, and is of a conifer ecoclass. Nesting quality habitat would have an average dbh of at least 21" and more than one canopy-story. Foraging quality habitat would have an average dbh of 16–20.9" and a single canopy. On the Mt. Hood National Forest in northern Oregon, for the purpose of "first screening" of potential late-successional forest as habitat for spotted owls, Huff et al. (2001) included forest patches of at least 40 acres below 5,000' in elevation, with >60 percent canopy closure, and with trees >21" dbh or a mix of trees >21 and 8-21" dbh. Neither the accuracy nor precision of Huff's methodology was reported, however.

The actual limits of home ranges for the spotted owls in the Gotchen LSR are unknown. For the purpose of habitat analysis and estimating landscape carrying capacity, a circle is used to approximate the home range. Successful spotted owls have a combination of nesting and foraging quality habitat in their home range. To be reproductively successful, spotted owl energy expenditures for resource gathering must be greater than expenditures. Total acres of spotted owl habitat within a home range are used on the GPNF as a gauge of likely success. On the GPNF, minimum spotted owl habitat thresholds are 2,663 acres and 500 acres at a 1.82 mile and 0.7 mile radius from the nest tree. The Gotchen LSR has numerous previously harvested stands and these stands are within the home range of at least one spotted owl pair. The use of partially harvested forest stands by spotted owls has been observed by the author and has been described by others including Everett et al. (1997).

Stand structure reports for spotted owl habitat on the east side of the Pacific Northwest Cascades crest have focused on structural conditions at nesting quality sites and or stands. This report addresses foraging quality habitat. A recommended starting point for teams challenged with managing for spotted owl habitat in the grand fir zone such as that in the Gotchen LSR, is a residual basal area of at least 150 square feet per acre distributed in diameter classes as shown in figure 6. Post-treatment conditions should fit the post-treatment stand and are expected to (1) fit the "Small Tree - Single Story - Moderate" forest structural stage, spotted owl foraging habitat (O'Neil et al. 2001), (2) have a higher likelihood of stand recovery to late successional condition, (3) have a lower likelihood of crown (Oliver et al.1994), and (4) have a lower spruce budworm risk.

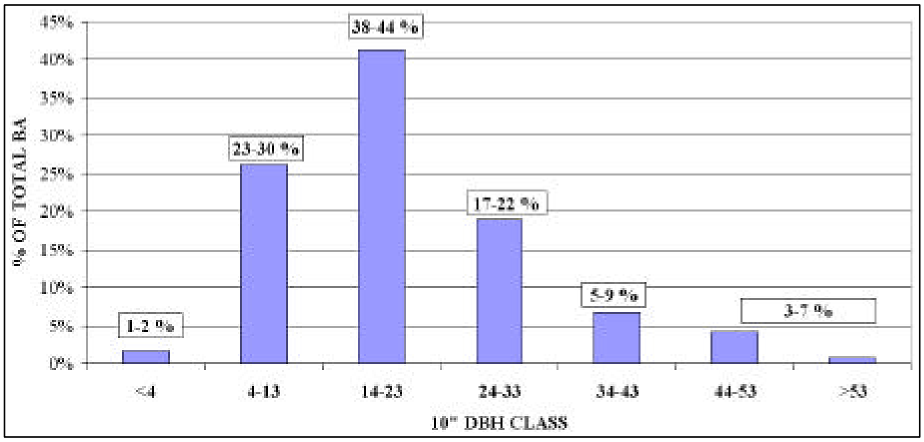

Figure 6—Proportional distribution of total basal area in 10" diameter classes. Foraging quality spotted owl habitat of the Gotchen LSR.

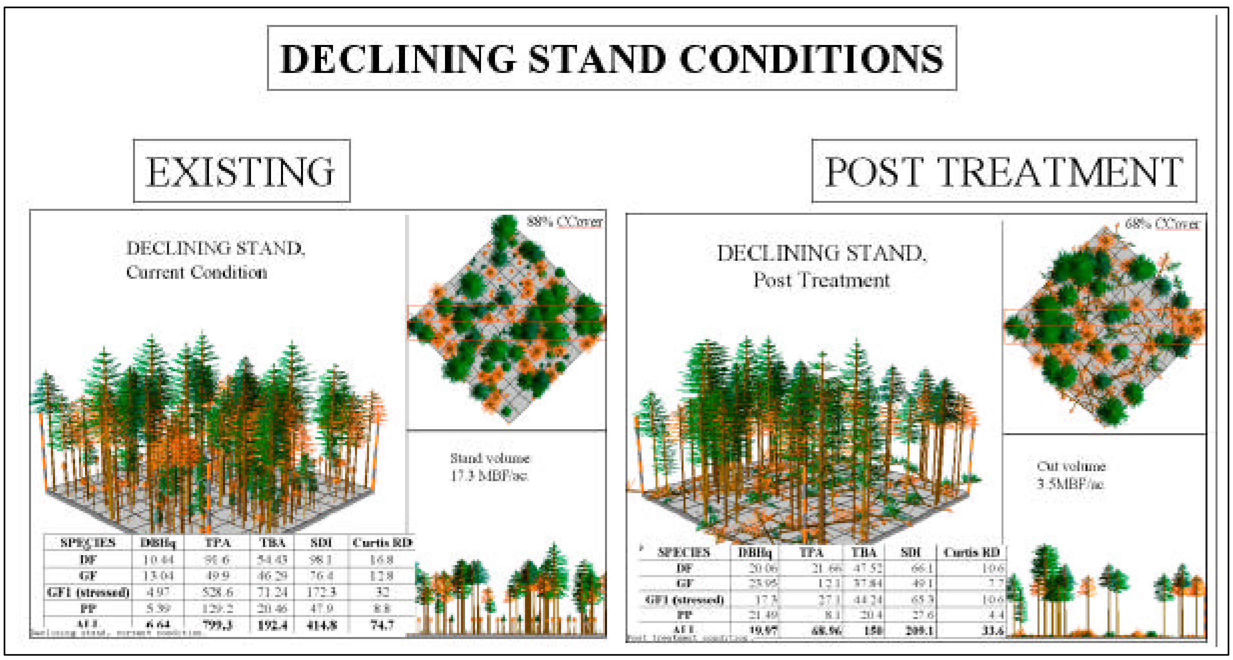

Figure 7—"Declining Stand" conditions pre and post treatment. Orange tinted trees represent stressed (via pathogens, drought etc.) trees.

In the Gotchen LSR, "Declining Stands" should be the primary focus for application of this thinning from below guideline. Early sere species should be favored for retention. Suppressed, understory, intermediate, and co-dominant trees most susceptible to spruce budworm defoliation and root disease would be preferentially selected for removal. Pre- and post-treatment stand structure conditions, using current stand structure data, are depicted in figure 7. The following changes occur: (1) basal area (square feet per acre) decreases from 192 to 150; (2) canopy cover decreases from 88 percent to 68 percent; (3) TPA decreases from about 800 to 70; (4) quadratic mean diameter (inches) increases from 6 to 19; (5) stand density index decreases from 415 to 209; and (6) Curtis relative density decreases from 75 to 35. For this stand, about 3.5M MBF per acre were removed, leaving about 14M MBF per acre. Recent timber harvest (East Timber Sale) in the planning area indicated a stump-to-truck cost of about $150 per MBF and a timber value of about $200 per MBF. Existing tree condition, small diameter, and current poor market conditions indicate that on this stand costs would likely exceed revenue.

Current forest conditions in the Gotchen LSR are (1) more suitable as spotted owl habitat, (2) more suitable for forest pathogens, (3) more conducive to drought related tree mortality, and (4) more susceptible to crown fires. The maintenance of spotted owl habitat in the Gotchen LSR may be better assured with active silvicultural management. Agee and Edmunds (1992) recommended active management that affords longer term protection of habitat instead of short-sighted attempts for total protection that would have been a viable strategy in 1910 but not today. The immediate need in the Gotchen LSR is for habitat areas that are on a trajectory towards function loss.

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Chapter 2

Vegetation

Application of Landscape Objectives to Stand-Level Silviculture: Blue River, Oregon

John H. Cissel, James H. Mayo, Steven L. Garman, and Frederick J. Swanson

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Abstract

Managers and scientists associated with the H.J. Andrews Experimental Forest and the Central Cascades Adaptive Management Area have worked together for the last decade to develop and refine approaches to landscape management based on interpretations of historical fire regimes. A large-scale effort is now underway in the Blue River watershed (western Cascade Range of Oregon) to implement, monitor and model this approach, and to apply the lessons learned through adaptive management. A landscape management plan for the watershed includes guidelines for the frequency, intensity and spatial pattern of timber harvest that approximate the frequency, severity, and spatial pattern of historical fire in the watershed. These guidelines provide broad parameters for stand-level prescriptions. Three silvicultural regimes were defined: a long rotation (260 years) even-aged management approach, a long rotation (180 years) two-aged management approach, and an uneven-aged management approach.

Simulation modeling and field experiments were used to develop stand-level prescriptions. Results from extensive stand growth modeling using the PNWGAP model, an ecological process-based gap model, were used to evaluate a wide range of intermediate treatments in terms of late-successional live and dead wood components and merchantable wood production. Selected prescriptions are in various stages of application to the ground. A network of permanent plots has been established in each of the three silvicultural regimes to monitor stand growth, mortality, composition, and structure. Nearby young stand field studies provide additional data concerning the effects of alternative thinning regimes. Practical experience developing and implementing prescriptions for the landscape management plan have resulted in adjustments to silvicultural prescriptions in an early phase of adaptive management.

Keywords: Late-successional habitat, landscape plan, disturbance regimes, adaptive management, silvicultural regimes, simulation modeling.

Introduction

A team of scientists and managers based on the H.J. Andrews Experimental Forest and the Blue River Ranger District of the Willamette National Forest has been working together for most of this decade to develop and test a landscape management approach based on natural disturbance regimes (Cissel et al. 1998, Cissel et al. 1999). The underlying assumption of this approach is that by approximating key aspects of native disturbance regimes in management regimes, risks posed to native species and ecological processes are reduced as compared to other historical and contemporary landscape management approaches (Swanson et al. 1994, Morgan et al. 1994, Landres et al. 1999). The Blue River Landscape Study is intended to use landscape objectives to set broad direction for stand-level management, and to evaluate the potential effects of implementing a landscape plan based on historical landscape dynamics.

The 23,900 hectare Blue River watershed study area is located within the McKenzie River watershed, a tributary of the Willamette River in western

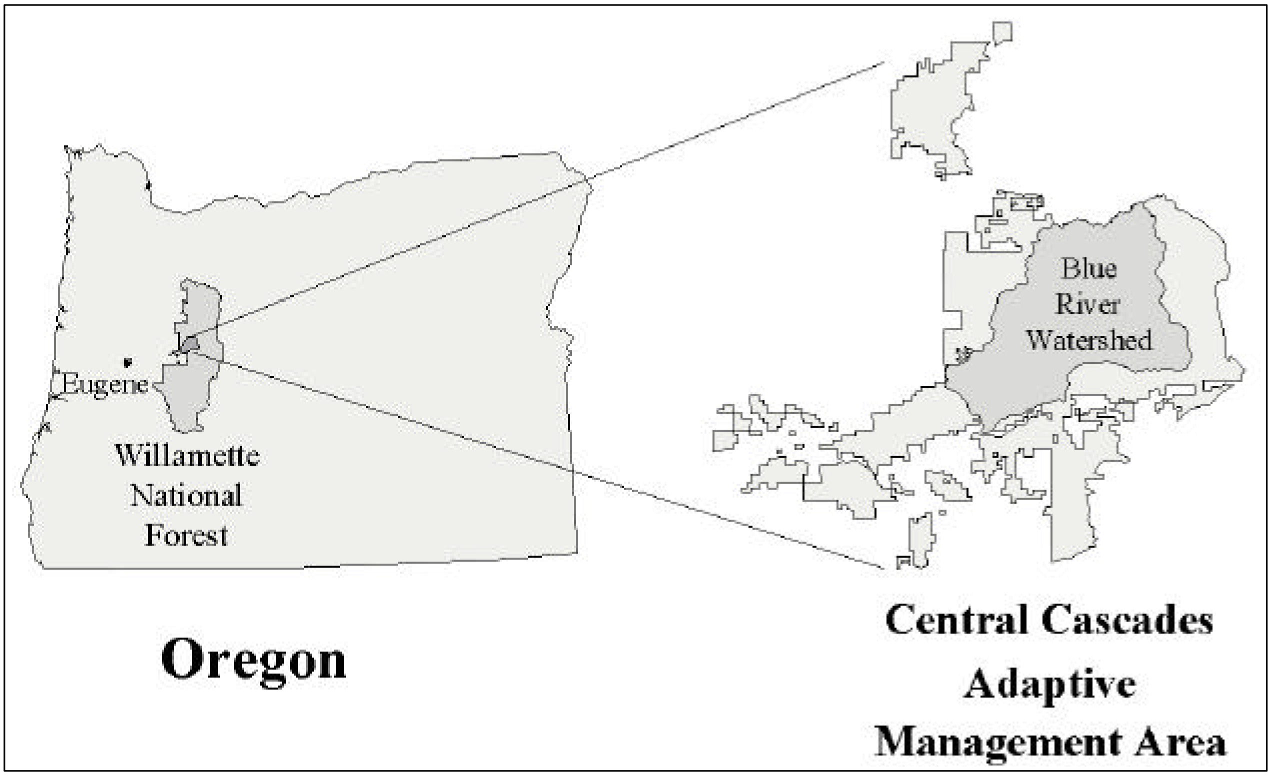

Figure 1—Location of the Blue River watershed and Central Cascades Adaptative Management Area.

Oregon (fig. 1). The Blue River area is part of the Willamette National Forest and includes the H.J. Andrews Experimental Forest, a source of extensive ecosystem information. The landscape is steep, highly dissected, volcanic terrain of the Cascade Range, covered largely by conifer forests dominated by Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and Pacific silver fir (*Abies amabalis*) of various ages (table 1). The Northwest Forest Plan sets land-use policy for portions of the region where spotted owls reside by defining systems of late-successional reserves intended to sustain old-growth forest ecosystems and associated species, riparian reserves, and stand management prescriptions for matrix lands between reserves. The study area lies within an alternative allocation, the Central Cascades Adaptive Management Area, one of 10 adaptive management areas established by the Northwest Forest Plan. Adaptive management areas are to test assumptions underlying the plan, and to develop and evaluate new approaches for meeting Northwest Forest Plan objectives.

Table 1— Area of existing stand types

Stand structure	Area (acres)
Shrub/sapling (1-20 years)	6,210
Closed pole (21-40 years)	8,550
Young (41-80 years)	2,039
Mature (81-200 years)	15,050
Old (>200 years)	21,130
Nonforest	3,099
Total	56,078

Objectives

The landscape management approach used in the study is intended to meet the same general objectives underlying the Northwest Forest Plan (USDA FS and USDI 1994): provide habitat to sustain species associated with late-successional forests, maintain and restore aquatic ecosystems, and provide a sustainable supply of timber. In addition, the Central Cascades Adaptive Management Area was directed to develop "approaches for integrating forest and stream management objectives and on implications of natural disturbance regimes" (USDA FS and USDI 1994). The Blue River Landscape Study incorporates and extends these objectives by organizing, planning, implementation, effectiveness monitoring, modeling, and associated research into an ongoing adaptive management process.

Adaptive Management Model

The adaptive management model followed in this study consists of three phases. In the first phase, new information is assessed to determine its potential relevance to the landscape management plan. Primary sources of new information include operational experience gained through project planning and implementation, field-based monitoring using permanent plots and sample points, and modeling assessments that evaluate the effects of plan implementation on a variety of species and ecological processes. Research conducted on the H.J. Andrews Experimental Forest also provides relevant new information through studies designed to help understand the interactions of landscape patterns and processes. Topics and issues identified in phase one are then evaluated to determine if changes should be made to the landscape management plan, or to implementation and monitoring procedures. Small teams of specialists consider the implications of new information, develop options for responding to new information, and make recommendations for change. Options and recommendations are further evaluated through discussions with interested parties during workshops and field tours and through feedback obtained directly from managers, policy-makers, and interest groups through personal interaction.

In the third phase, revisions to the landscape management plan, or to monitoring and implementation procedures, are considered if recommendations from phase two indicate a potential benefit to doing so. Forest Service managers with input from scientists responsible for conduct of the landscape study make the final decisions concerning changes to the study. Changes are documented in updates to the landscape management plan and in monitoring and research plans.

Landscape Plan

Fire History

Fire has been a prominent factor shaping landscape structure in the Blue River watershed for many centuries (Teensma 1987, Morrison and Swanson 1990, Weisberg 1998). Fire history data for the watershed were assembled and synthesized for 407 sample sites representing 44 fire episodes, and then integrated into a description of three generalized fire regimes representing a complex and highly varied fire history (Weisberg 1998, Cissel et al. 1999). Each regime was described by a characteristic fire frequency, fire severity, and mortality patch size as follows (fig. 2):

1) High Frequency (Mean Fire Return Interval (MFRI) range of 60-100 years, mean 79 years), small patches (predominantly <40 hectare), low severity (40-60 percent mortality).

2) Moderate Frequency (MFRI range of 100-200 years, mean 143 years), moderate sized patches (predominantly 40-80 hectare), moderate severity (60-80 percent mortality).

3) Low Frequency (MFRI range of 200-415 years, mean 231 years), large patches (predominantly >80 hectare), high severity (>80 percent mortality).

Landscape Management Strategy

The Landscape Plan contains two primary elements: reserves and landscape areas where varying vegetation management regimes are prescribed. Reserves were identified in two steps, both prior to and following definition of landscape areas.

"Special area reserves" were identified first (fig. 3, table 2). Objectives for these areas were to allow natural succession to occur. Special area reserves included late-successional reserves allocated in the Northwest Forest Plan, the H.J. Andrews Experimental Forest, and three geologically unique areas allocated as special interest areas in the Willamette National Forest Plan (USDA 1990).

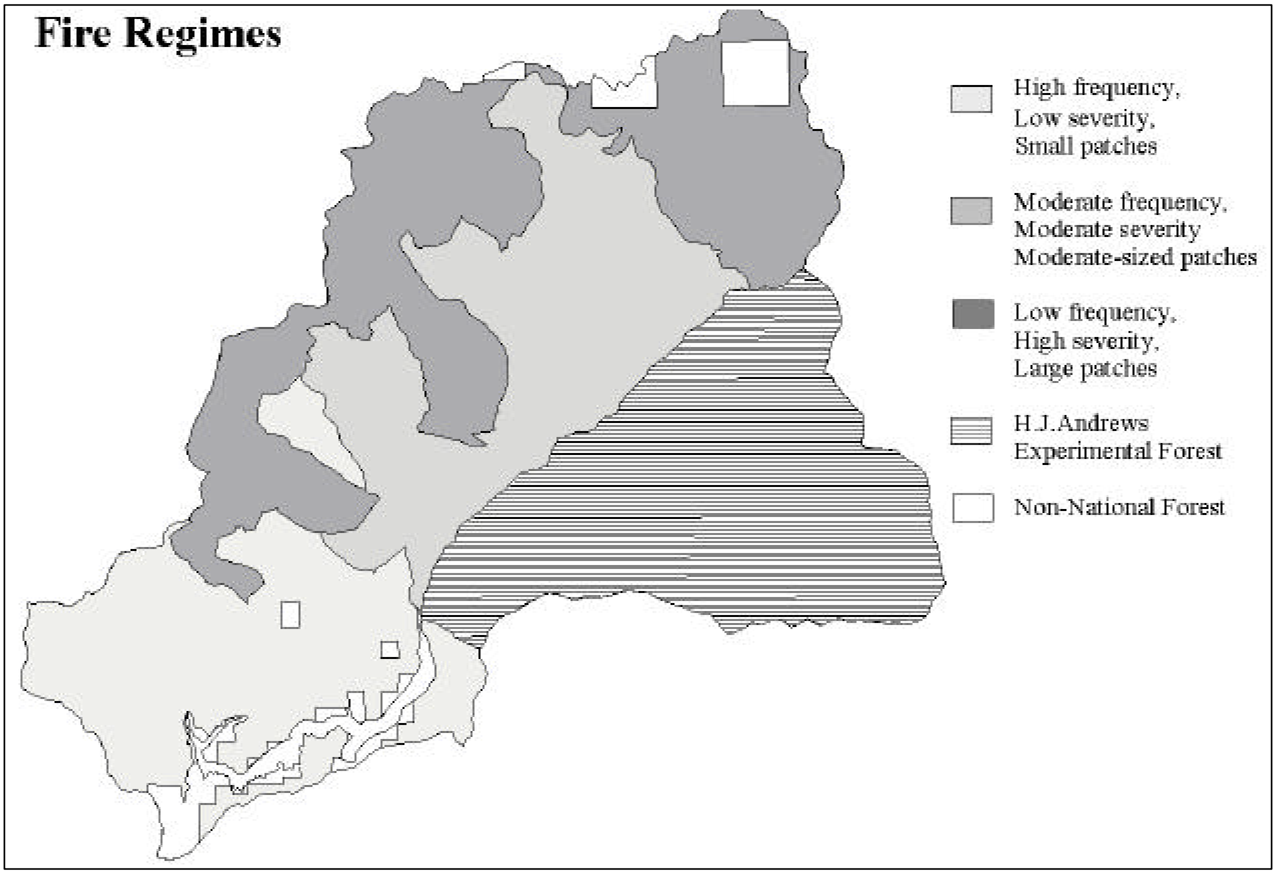

Figure 2—Generalized fire regimes for the Blue River watershed.

The remainder of the watershed was then subdivided into three noncontiguous zones of distinctive ecological conditions and disturbance regimes, termed “landscape areas” (fig. 3, table 2). Landscape area boundaries were based on and closely followed the interpreted fire regime mapping. Long-term vegetation management prescriptions were developed for each landscape area based on an interpreted range of historical conditions. General prescriptions for timber harvest frequency, intensity, and spatial pattern (table 3) were derived from corresponding parameters of historical fire regimes. Timber harvest frequency and rotation age (100 - 260 years) were based upon historical fire frequency, timber harvest intensity (15–50 percent overstory canopy cover retention) was based upon historical fire severity, and the spatial patterns of timber harvest were based upon the spatial patterns of historical fires. Implementation guidelines are intended to reflect natural disturbance patterns to the extent feasible while protecting ecological values.

An aquatic reserve system was also established to help meet the aquatic ecosystem objectives in the Northwest Forest Plan. These reserves are of two types: small-watershed reserves and corridor reserves. Small-watershed reserves are strategically located throughout the watershed to encompass areas of particular importance to aquatic ecosystems and spotted owls. In addition, corridor reserves are established on all fish-bearing streams (fig. 3, table 2). Figure 3 depicts a plan view of the landscape management plan (“Landscape Plan”), and, for comparison, a literal implementation of the standard matrix and riparian reserve system in the Northwest Forest Plan as if it were applied to the Blue River watershed (“Interim Plan”).

We next delineated management units, termed “landscape blocks,” representing the locations of future patches created through timber harvest, prescribed fire, and forest regeneration. Landscape blocks link the landscape plan to site-level project planning and are the units used to project future landscape conditions. Existing stand conditions

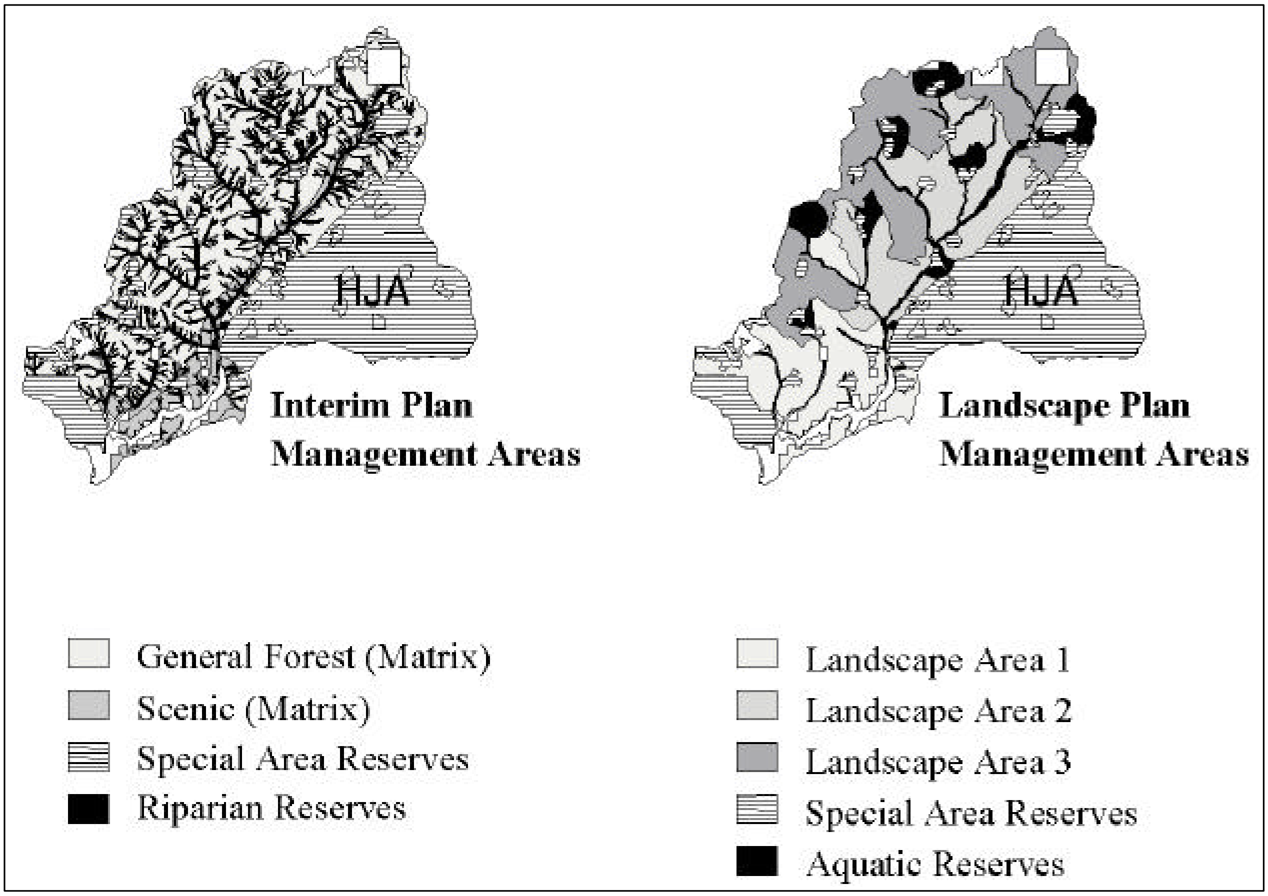

Figure 3—Management areas for the Blue River watershed (a) managed under matrix and riparian reserve designations in the Northwest Forest Plan (termed "Interim Plan"), and (b) for the Blue River landscape management strategy (termed "Landscape Plan"). Undesignated areas are nonfederal ownership.

Table 2—Area of Landscape Plan management areas. Management areas are listed in the order of precedence used to calculate area.

	Landscape Plan	
Management areas	**Area (acres)**	**Area (% of watershed)**
Blue River Reservoir	820	1.4
Non-National Forest	2,660	4.5
Special Area Reserves	21,007	35.5
Aquatic Reserves	5,824	9.9
Landscape Area 1	7,469	12.7
Landscape Area 2	9,574	16.2
Landscape Area 3	11,698	19.8
Total	59,052	100.0

may be quite variable within a block, ranging from very young plantations to old growth. Guidance for the Landscape Plan included specific objectives for landscape block size (table 3). Existing large patches and areas of similar landform were included within a block where feasible, and block boundaries were placed to avoid including entire watersheds in a single block. Streams, roads, and ridgelines generally formed block boundaries (fig. 4).

Evaluation

Future timber harvest and forest age-class structures were projected across the watershed for the next 200 years for both plans (fig. 5). Results show that the landscape plan will produce more late-successional habitat as compared to the interim plan (71 percent of the watershed versus 59 percent). Larger patches in the landscape plan create more interior habitat, thought to benefit some wildlife species such as the northern spotted owl. Relative to the Interim Plan, less edge between old and young forests in the landscape plan reduces edge effects such as altered microclimates and increased plant mortality, and may reduce habitat for certain species that favor edges, such as Rocky Mountain elk (*Cervus elaphus nelsoni*). More complex stand structures are present in the landscape plan due to generally higher overstory canopy cover retention levels. Retention of live and dead trees in young stands has been found to favor cyanolichens, certain fungi and invertebrates associated with older forests, amphibians with life histories requiring both stream/riparian and upland habitats, and to moderate understory environments. More late-successional habitat and more large-tree residual structure in young stands in the Landscape Plan may deliver more large wood and coarse sediment to streams when mass slope movements occur, mitigate potential harvest-induced changes to streamflows, and result in more carbon stored on the landscape. The Landscape Plan also maintains a substantial component of the mature forest age class (80-200 years old), whereas the interim plan nearly eliminates this age class over time. The absence of mature forest in the interim plan leaves few options for the future when mortality due to disturbance, climate change or senescence eliminates older Douglas-firs in reserves (Cissel et al. 1999).

Stand-Level Prescriptions

The landscape plan provides general guidance in terms of the rate, intensity and spatial pattern of timber harvest for each of the three landscape areas (table 3). These broad parameters shape the silvicultural system and prescription selected for each of the landscape blocks where vegetation management activities are planned and implemented. Stand modeling was used to further develop and evaluate prescriptions, including potential intermediate entries.

Model Description

We used the PNWGAP model to simulate thinning-treatment effects on stand dynamics (Urban 1993). PNWGAP simulates the annual establishment, diameter growth, and mortality of individual tree and shrub species, and the decay of snags and logs on a grid of small (0.1 acre) model plots. Diameter growth of individual stems is based on species' maximum potential rates, which are reduced as light conditions, soil moisture and fertility, and ambient temperature deviate from optimum levels. Light conditions on a model plot are determined by the leaf area of resident stems and the stature and leaf area of stems on surrounding model plots. Stochastic methods are used to simulate annual weather conditions by using means and standard deviations of monthly temperature and precipitation. Mortality is modeled as a probabilistic function of maximum age and number of years of suppressed growth due to resource limitations (i.e., shading, drought). When a tree succumbs to mortality, it has a probability of falling or remaining upright as a snag. Over time, each log and snag is advanced through the standard decay classes (Cline et al. 1980) using a probability function based on maximum residence time, which varies by decay resistance and stem size (Graham 1982). Natural inseeding of tree species on a model plot is determined by the density of sexually mature stems in a stand and plot-level attributes such as available growing space, light conditions, and soil moisture.

Analysis

Simulations representing a wide range of potential thinning densities were replicated eight times to derive an average trajectory of stand dynamics and to evaluate the effects on late-successional attributes and merchantable wood volume production

Table 3—Landscape area prescription elements

Prescription elements	Landscape Area 1	Landscape Area 2	Landscape Area 3
Rotation age (year/percent regeneration harvested annually)	100/1.0	180/0.56	260/0.38
Landscape block sizes (percent of area)			
<1000 acres	60	40	20
100-200 acres	20	40	40
200-400 acres	20	20	40
Retention level (percent overstory crown closure)	50	30	15

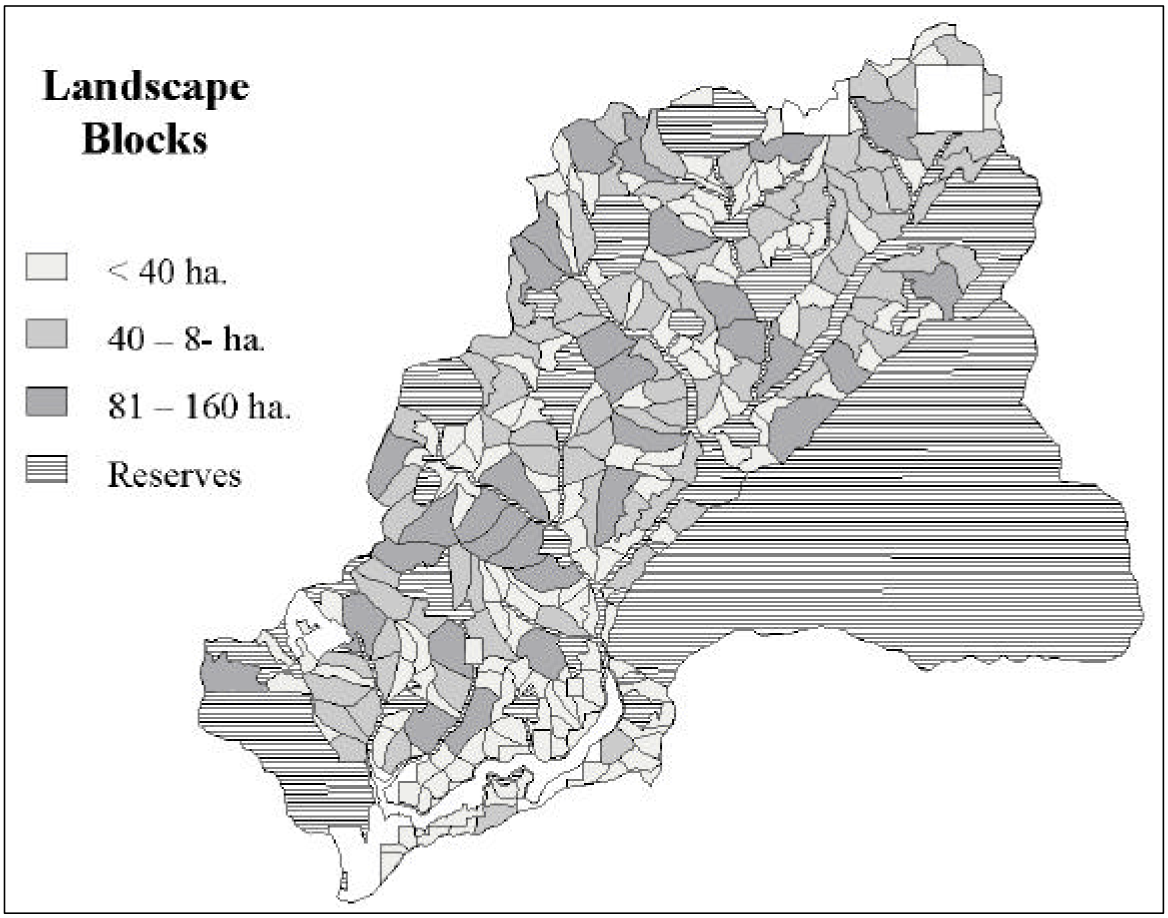

Figure 4—Landscape blocks for the Blue River Landscape Plan.

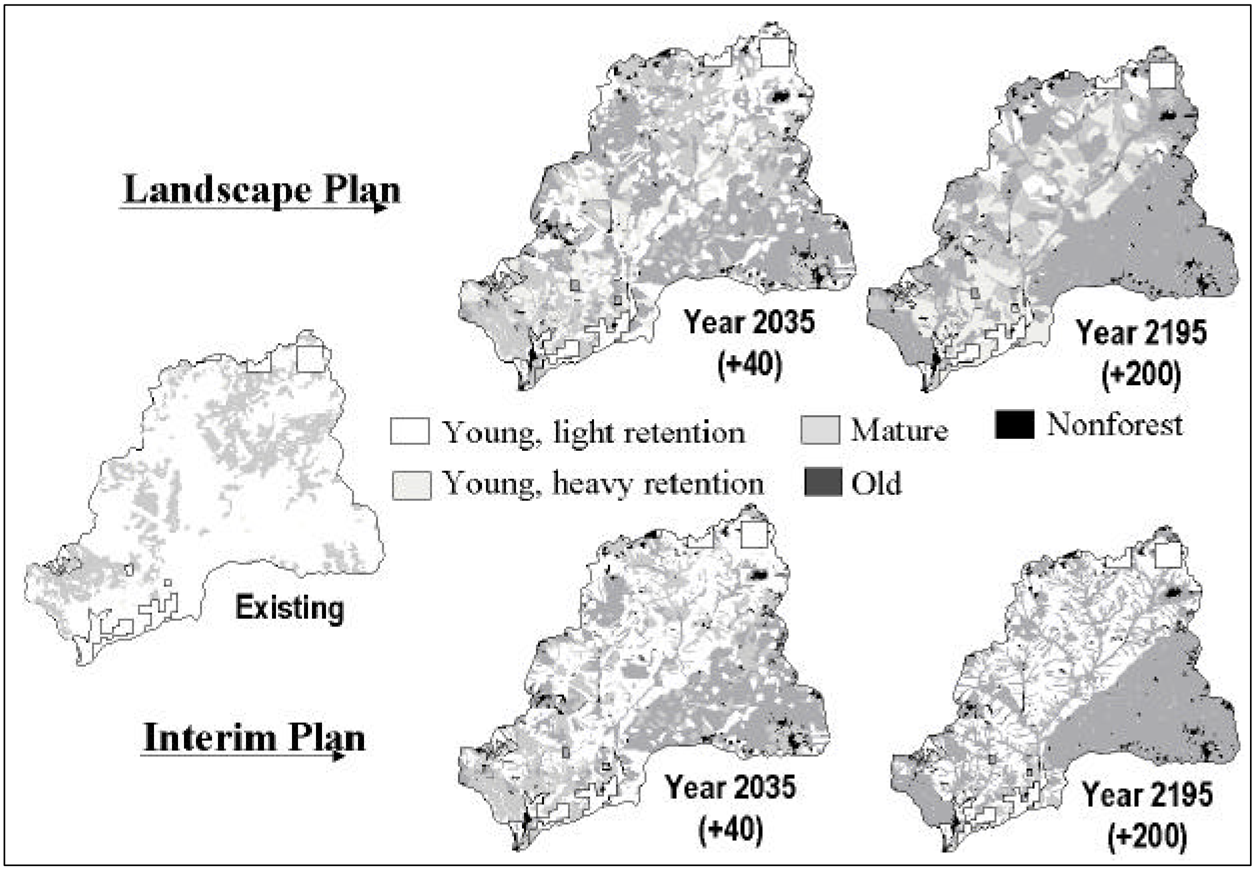

Figure 5—Projected future landscape structures for the Blue River landscape management strategy (termed “Landscape Plan”) and for the Blue River watershed managed under matrix and riparian reserve designations in the Northwest Forest Plan (termed “Interim Plan”). Undesignated areas are nonfederal ownerships.

(Garman et al., in press). Treatments evaluated by the model were selected to bracket a reasonable range of thinning options. Four thinning densities at ages 40, 60, and 80 years were evaluated for a total of 64 possible combinations. For each entry, a thinning density typical of prescriptions applied in this area over the last 10 years was selected, then densities with 50 percent fewer trees, 50 percent more trees, and a no-thinning treatment were defined (table 4). The first commercial thin was a thin-from-below approach; the other two entries thinned proportional to diameter for trees between 4 and 24 inches diameter at breast height (dbh). Each treatment combination was run for two rotations starting with a 40-year-old stand, for each of the three landscape areas.

Evaluation

Three general criteria were used to evaluate the simulated prescriptions: (1) time interval required to develop late-successional characteristics; (2) total wood volume production; and (3) risks associated with implementation.

Late-successional conditions of a simulated stand were evaluated on the basis of threshold values of characteristic attributes. Threshold levels for large live trees, shade-tolerant trees, and large snags and logs were from recommendations by Franklin and Spies (1991) and the USDA Forest Service Region 6 Interim Old-Growth Definitions for the western hemlock series, site class 3 (USDA FS 1993). Vertical heterogeneity is an important characteristic of late-successional stands, but exact methods for measuring this attribute are lacking in federal guidelines. As a measure of multi-layer condition, the Canopy Height Diversity Index (CHDI) developed by Spies and Cohen (1992) was used. This index considers the relative volume of space occupied by tree crowns in five different 50-foot height classes and has been shown to be sensitive to vertical development in natural Douglas-fir stands ranging in age from 30 to 999 years. The

Table 4—Simulated thinning densities

Stand Age	Thinning Intensity TPA remaining)
40	all, 165, 110, 55
60	all, 120, 80, 40
80	all, 75, 50, 25

CHDI criterion of 8.0 corresponds to conditions of 200-year-old, naturally regenerated Douglas-fir stands.

Species, age, and dbh of harvested stems were recorded, and total extracted merchantable volume was derived by using a modified version of the Harvest model (Harmon et al. 1996). The Harvest model calculated merchantable volume based on timber utilization standards, species-specific rot tendencies, and breakage rates during harvest. Current harvest standards of a 7-inch minimum dbh, a 4-inch top, and a stump height of 18 inches were used in calculating total merchantable volume. Volume production was evaluated for feasibility at each of the intermediate entries as well as the final harvest. A minimum volume considered to be economically viable was 700 cubic feet per acre. Changing market conditions could affect what is considered a commercial entry.

Relative risk of windthrow, snow and ice damage, and loss of Douglas-fir was evaluated for each prescription. Heavy thins generally have a higher risk of windthrow than light thins, especially when the stand is densely stocked. This risk can be mitigated by locating heavy thins on lower slopes and valley bottoms with less wind exposure. There is a higher risk of snow and ice damage in dense, unthinned stands where height/diameter ratios are approaching 100 or more, especially on higher-elevation sites. Relatively heavy canopy retention levels risk loss of relatively shade-intolerant stems (e.g. Douglas-fir and western white pine).

Results

Several general trends surfaced from inspection of simulation results. Within each landscape area there were significant differences in the rate at which late-successional characteristics appeared. We focused on live attributes, since snags and logs can be created when needed. Prescriptions with heavier thins tended to accelerate development of late-successional characteristics. In some cases, CHDI or shade tolerant stems were the limiting factor, and lighter thins or not thinning at some stand ages proved to be a better management tool. In some cases, the combination of treatments that most rapidly attained threshold values of late-successional characteristics resulted in lower levels of late-successional characteristics in the long term. Wood volume production tended to be inversely related to late-successional characteristics. Heavy-thin prescriptions produced less volume overall than light-thin or no-thin prescriptions. Light thins keep the site fully occupied, maximizing cubic volume. Wood quality may be higher with fewer, larger boles. More extreme prescriptions generally have higher risks, although risks can be mitigated somewhat by choosing prescriptions that fit the terrain and overstory conditions.

The prescription for landscape area requires close attention to understory density due to the relatively heavy overstory (50 percent canopy cover; Zenner 1995, Rose and Muir 1997). The modeled treatment employing two moderate-density thins at ages 40 and 60 years produced late-successional habitat at 64 years, and 7.4 mcf per acre over the 100 year cutting cycle. Heavier thins delayed achieving threshold values for CHDI and shade tolerant stems, while lighter thins are not economically viable. Not thinning at all produced up to 10 percent more volume, but tended to reduce Douglas-fir presence and would likely render the stand more susceptible to snow and ice damage.

The general prescription for landscape area two has an intermediate retention level (30 percent canopy cover), allowing the understory to develop for a longer period of time before high densities significantly reduce the rate of diameter growth. The simulated prescription of only one moderate thin at age 60 produced the best balance among late-successional attributes, volume production, and implementation risks. This treatment yields late-successional habitat at 83 years and about 8.8 mcf per acre over the 180-year rotation length. Earlier and heavier thins delayed development of shade tolerant stems and produced less volume, while lighter thins are not considered economical. Not thinning until age 80, while producing about six percent more volume, would risk significant snow and ice damage. Overstory trees help mitigate the risk of blowdown when the understory is thinned.

Landscape area three has the longest rotation length (260 years) and the lightest retention level (15 percent canopy cover). Two moderate thins at ages 40 and 60 years, followed by a heavy thin at age 80 produced late-successional habitat in about 150 years with a total volume of 12.7 mcf per acre over the 260-year rotation. Heavier thins accelerated development of late-successional habitat, but produced about 10 percent less volume and a higher risk of blowdown. Lighter thins were not economical, and not thinning, while producing slightly more volume (four percent) has a higher risk of snow and ice damage.

Monitoring

Permanent plots have been installed in each of the landscape areas to monitor the effects of these prescriptions on vegetation in both upslope and riparian environments. Pre-treatment measurements have been taken, and post-treatment measurements are scheduled following planned and ongoing harvest, prescribed fire, and reforestation activities. Plot measurements include species and abundance for all tree, shrub and herb species, tree diameter, crown closure, crown width, sapwood and bark thickness, tree height, snags, coarse woody debris, and environmental variables (slope, aspect, topographic position, and surface characteristics). Results from monitoring will be evaluated on a regular basis to determine if there is a need to adjust plans or practices.

Conclusions

Landscape structures resulting from both the landscape management plan in this study and from the interim plan are historically unprecedented. For that reason we feel it is critical that an adaptive management approach be followed for both plans. Novel aspects of the Landscape Plan include the extensive use of information on historical landscape dynamics, use of landscape objectives to direct stand-level silviculture, and the use of very long rotations and multi-cohort prescriptions on federal lands in this forest type. The PNWGAP model allowed further analysis of stand dynamics and intermediate treatment options for long-rotation and multi-cohort prescriptions. We are pressing ahead with implementation, monitoring, modeling, and research to better define and evaluate this approach. We hope these concepts can be tested in other provinces in the region and that the matrix and riparian reserve approach of the interim plan can also be similarly tested.

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We thank the many people who contributed time and ideas to the Blue River Landscape Study, and especially Tere Turner for her production of high-quality GIS analyses and products.

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Historical Stand Reconstruction in Ponderosa Pine Forests to Guide Silvicultural Prescription

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Abstract

We reconstructed the historical stand structure and spatial patterning of fire-maintained ponderosa pine forests in the eastern Cascades of Washington to develop and design silvicultural prescriptions to restore historical structure and composition. The structure of the dominant overstory was inferred from the size and spatial patterning of stumps, logs, snags, and live trees ($\geq$140 years of age) within 48 0.5-hectare plots. Size class distributions, basal area, and spatial distribution of historical trees were compared among plant association groups representing a range of environmental conditions. Using spatial point pattern analysis, we found significant clumping at the small scale (0-15 meters) existed historically. Spatial patterning of present day and historical trees of four comparable plots suggests that while strong clumping exists in present day stands, the largest trees today exhibit less clumping than did large historical trees. Historical stand density index (260) for dominant overstories was nearly the same as threshold for serious beetle mortality (263) for ponderosa pine. Cut-tree marking was carried out within 15-meter-radius circles, as guided by the spatial patterning analysis and using a sliding scale of trees per circle by quadratic mean diameter.

Keywords: Stand reconstruction, ponderosa pine, forest restoration, ecosystem management.

Restoring the Longleaf Pine Ecosystem: The Role of Fire

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Abstract

Longleaf pine (*Pinus palustris* Mill.) ecosystems once occupied 90 million acres in the southern United States coastal plain. These fire-dependent ecosystems dominated a wide range of coastal plain sites, including dry uplands and low, wet flatlands. Today, less than 4 million acres remain, but these ecosystems represent significant components of the region's cultural heritage, ecological diversity, timber resources, and present essential habitat for many animal and plant communities. This ecosystem is also the favorite habitat for endangered species like the red-cockaded woodpecker and the gopher tortoise. Fire was an essential component of the original longleaf pine ecosystems. The landscapes were characterized by open stands of mature longleaf pine with a savanna-like understory that was biologically diverse. Recent improvements in the technology to artificially regenerate longleaf pine have stimulated interest in restoring longleaf pine on many sites. Long-term studies show that the frequent use of fire hastens initiation of height growth, reduces undesirable competing vegetation, and stimulates growth and development of the rich understory. Fire is, therefore, an important element in establishing the species and is critical to achieve and maintain the biologically diverse conditions that are characteristic of the ecosystem.

Keywords: *Pinus palustris*, regeneration, biological diversity, plantation establishment.

Introduction

Currently, there is considerable discussion about restoring ecosystems to some previous condition, but there is little consensus on the means to achieve restoration; what are the target landscapes; what methodologies should be used; and how is success measured? The present condition of available sites, the legacies from the past land use, along with available technology and methods constrain restoration goals. Restoration of the longleaf pine (*Pinus palustris* Mill.) ecosystem in the southern United States is now receiving a great deal of attention (Landers et al. 1995, Noss 1989). The use of fire plays an important role in the restoration of this fire-dependent system.

Longleaf pine ecosystems once occupied over 90 million acres in the southern United States coastal plain from southern Virginia to central Florida and west to eastern Texas (Frost 1993). These fire-dependent ecosystems dominated a wide array of sites within the region. Today, less than 4 million acres remain (Kelly and Bechtold 1990), with much of this in an unhealthy state. Longleaf pine ecosystems represent significant components of the region's cultural heritage, ecological diversity, timber resources, and present essential habitat for many animal and plant communities. This once extensive ecosystem has nearly vanished. The objectives of this paper are to describe the longleaf pine ecosystem and its ecological and economic values and explore possibilities for restoring the ecosystem to an important part of the southern landscape.

The Longleaf Pine Ecosystem

The natural range of longleaf pine covers most of the Atlantic and Gulf Coastal Plains with extensions into the Piedmont and mountains of north Alabama and northwest Georgia. The species occurs on a wide variety of sites, from wet, poorly drained flatwoods near the coast to dry, rocky mountain ridges (Boyer 1990). It is a long-lived tree, potentially reaching an age of several hundred years; however, longleaf pine forests are often exposed to catastrophic hazards such as tropical storms or fire, and to continuing attrition from lightning, which shortens possible rotation ages (Landers et al. 1995).

Longleaf pine is a very intolerant pioneer species and the seedlings go through a stemless grass stage. If competition is severe, they may remain in this grass stage for years. The ecosystem is distinguished by open, park-like "pine barrens," which are composed of even-aged and multi-aged mosaics of forests, woodlands, and savannas, with a diverse groundcover dominated by bunch grasses and usually free of understory hardwoods and brush (Landers et al. 1995). The diversity of understory plants per unit of area places longleaf pine ecosystems among the most species-rich plant communities outside the tropics (Peet and Allard 1993). Although the pine barrens are known for persistence and diversity, they occur on infertile soils. The ecological persistence of these areas is a product of long-term interactions among climate, fire, and traits of the key plants.

The Historical Role of Fire

Fire was an essential component of the original longleaf pine ecosystems. Longleaf pine and bunch grasses (e.g., wiregrass and certain bluestems) possess traits that facilitate the ignition and spread of fire during the humid growing seasons (Landers 1991). Frequent fire was largely responsible for the competitive success of longleaf pine and its associated grasses. These keystone species exhibit pronounced fire tolerance, longevity, and nutrient-water retention that reinforce their dominance and restrict the scale of vegetation change following disturbance. Fires that were ignited by Native Americans or that resulted from thunderstorms with frequent lightning prevailed over the region, a complex of quick-drying sites that are exposed to natural and anthropogenic disturbances. Many of these fires occurred during the growing season and largely prevented species native to other habitats from encroaching into the pine barrens. The chronic fire regime also maintained the soil structure and nutrient dynamics to which longleaf pine is adapted (McKee 1982). These fire effects tended to make longleaf pine sites more favorable to resident species than those indigenous to more nutrient-rich habitats.

Decline of the Longleaf Pine Ecosystem

The depletion of the longleaf ecosystem resulted from its many desirable attributes that have caused it to be exploited since the settlement of the Nation by Europeans (Croker 1979). However, it was the event of railroad harvesting in the late 1800s and early 1900s that provided access to and depleted the vast remaining longleaf timberland. Cutting proceeded from the Atlantic states west through the Gulf Coast Region with increasing intensity of use with time. Longleaf pine logging reached a peak in 1907, when an estimated 13 billion board feet were cut (Wahlenberg 1946). The longleaf pine ecosystem now occupies only a small part (less than 5 percent) of its original area. This habitat reduction is the reason for the precarious state of at least 191 taxa of vascular plants (Hardin and White 1989, Walker 1993) and key wildlife species such as the red-cockaded woodpecker, gopher tortoise, and southern fox squirrel (Landers et al. 1995).

Regeneration of longleaf pine was limited because of a combination of circumstances. The completeness of the harvest left little seed source for natural regeneration, and much of the harvested land was cleared for cropland or pasture. Longleaf pine does not successfully invade open land in competition with more aggressive pine or grass species. Regeneration sometimes succeeded the removed old-growth when periodic fires provided a seedbed and controlled woody competition and when wild hogs did not reach a density high enough to destroy established seedlings (Wahlenberg 1948). The disruption of natural fire regimes, resulting in part from forest fire protection policies implemented during the 1920s, allowed invasion of longleaf sites by hardwoods and more aggressive pine species. Longleaf pine and its associated species cannot compete under these conditions. Regeneration, both natural and artificial, is more difficult than for any other southern pine due to the delay in stem elongation (the grass stage), which is a genetic trait of the species. Also, survival of planted bareroot nursery stock is generally poor and established seedlings in the grass stage are very sensitive to competition.

Restoring the Longleaf Pine Ecosystem

A key to restoration of the longleaf pine ecosystem is to ensure that its recovery benefits society. Without economic benefits, long-term conservation projects usually do not succeed (Oliver 1992). Longleaf pine forests have high economic value due to the quality of solid-wood products produced. Harvesting or forest management need not be eliminated or even moderately restricted to restore and maintain longleaf pine ecosystems, as evidenced by the fact that logging at the turn of the

20th century apparently had little effect on groundcover diversity (Noss 1989). Restrictions on harvest would be a disincentive to many landowners and could result in the elimination of much of the remaining longleaf pine on private lands.

Restoration of the longleaf pine ecosystem is achievable since pockets of longleaf pine occur in much of its former range. It should be feasible to gradually expand longleaf pine acreage through education, research, and commitment on the part of resource managers. Restoration is now a goal on much of the public lands in the southern United States, where longleaf pine remains as a component of the forest. In fact, much of the current acreage of the ecosystem occurs on public lands.

A number of interacting factors will determine whether the restoration of the longleaf pine ecosystem can be achieved. These include the capability to successfully regenerate longleaf pine on its native sites, to use fire to enhance establishment and management of both the overstory and understory species, to educate the public and resource managers on the value and technology of restoration, and to evaluate restoration success.

Reforestation Technology

Utilization of the trees in the original forest was so complete that inadequate numbers of seed trees remained to naturally regenerate many of the harvested stands. Therefore, artificial regeneration must be used to restore longleaf pine on many of the appropriate sites where it originally grew. Until recently, regeneration success from planting was generally unacceptable due to problems related to severe competing vegetation, delayed stem elongation, and poor storability of bareroot seedlings. We now have the knowledge and technology to reestablish longleaf pine by planting bareroot stock. The keys to successful establishment are: well-prepared, competition-free sites; healthy, top-quality, fresh planting stock; meticulous care of stock from lifting to planting; precision planting; and proper post-planting care (Barnett 1992). Attention must be given to all of these factors to obtain acceptable seedling establishment, so success of planting bareroot stock remains elusive.

Planting container stock is now accepted as the most successful method of regenerating longleaf pine (Barnett and McGilvray 1997). Production of longleaf container seedlings has increased from about 15 million to 85 million annually in the last five years. This improved survival and growth is generally attributed to root systems that remain intact during lifting while roots of bareroot plants are severely damaged. Thus, container seedlings experience a significantly shorter period of transplant shock or adjustment than bareroot stock. However, using container stock does not eliminate the critical need for controlling competition during the first growing season after planting.

Role of Fire

Fire is an essential component of the restoration and management of the longleaf pine ecosystem. Long-term studies show that the frequent use of fire hastens initiation of height growth by reducing undesirable competing vegetation and foliage that is infected with brown-spot needle blight (Siggers 1934). Longleaf pine seedlings that are in grass stage are resistant to injury because the buds are protected by a rosette of needles (Walker and Wiatt 1966). Prescribed fire also stimulates growth and development of species that are an essential component of the understory. Seasonal burning studies show that late spring burns are much more effective in the restoration process than the typical winter burns that are usually favored for other pine species because they are hotter and more effective in reducing competing woody vegetation (Grelan 1978). Fire is an important element in establishing the species and is a critical component for achieving and maintaining the biologically diverse understory that is characteristic of the ecosystem.

Education and Commitment

Educating the public on the current status of the longleaf pine ecosystem, its potential economic value, its outstanding biodiversity, and the role of fire in maintaining the system is an initial step in securing support for restoration (Landers et al. 1995). A primary need in this process is to promote the use of fire as an ecological force necessary for maintenance of this fire-dependent ecosystem. Frequent prescribed burning, including use of growing-season fires where appropriate, promotes the diversity and stability of these communities (Noss 1989). Many private landowners are concerned about the environment and will support restoration, if through the process they generate income from their land. Longleaf pine can be managed in an ecologically sensitive manner that generates income satisfactory to interest a landowner in restoration (Landers et al. 1990).

Determination of Success

One way to measure the success of the restoration process is to determine through periodic forest surveys if the area in longleaf pine plantations increases. Another method is to determine if the production of longleaf pine nursery stock increases in relation to the other southern pines. Some would question whether an increase in area of longleaf pine plantations equates to an increase in ecosystem restoration. Certainly it takes more than planting trees to restore the ecosystem, but it is the critical first step. Recent research indicates that the productivity of an ecosystem is controlled to an overwhelming extent by the functional characteristics of the dominant plants (Grime 1997). So, with reestablishment and appropriate management, including the appropriate use of fire, restoration processes that include development of the typical diverse understory vegetation will begin.

Conclusions

Fire was an important component of the original longleaf pine ecosystem. Landscapes were characterized by open stands of mature pine with a savanna-like understory. This very biologically rich understory was typical of the ecosystem. Recent improvement in reforestation of longleaf pine has increased interest in restoring the ecosystem on many sites where it originally grew. It is recognized that fire must play an important role in the restoration process. Frequent use of fire hastens initiation of height growth, reduces undesirable competing vegetation, and stimulates growth and development of species that are a component of the understory. Fire is an important element in establishing the species and is a critical component of achieving and maintaining the biologically diverse understory that is characteristic of the ecosystem.

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Silvicultural Options for Multipurpose Management of West-Side Pacific Northwest Forests

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Abstract

The Westside Silvicultural Options Team of the Pacific Northwest Research Station has established an array of long-term research studies to develop and assess a wide range of silvicultural options. In this paper, we review three large-scale studies that focus on three major stages in the life of managed stands—early development (precommercial thinning), midrotation (commercial thinning), and regeneration harvest. These studies will provide information about stand development that will be useful in managing for wood production, wildlife habitat, and other forest resource values in large portions of the Pacific Northwest west-side forests. All three studies measure the response of both overstory trees and understory plant species. Additionally, several other aspects of concern to forest managers, such as coarse woody debris, residual stand damage, soil disturbance, economics, and public acceptance of treatments, are investigated.

Keywords: Silviculture, multiple use, silvicultural systems, forest management, precommercial thinning, variable density thinning.

Introduction

The forest landscape in the Pacific Northwest (PNW) has changed dramatically over the last century. This is particularly evident in the Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) region west of the Cascade Divide where forests have been heavily logged and replaced with young-growth stands, agriculture, or development. During the last three decades, this change in forest cover became a national focus for the efforts of the environmental movement to preserve old-growth forests and galvanized the public's displeasure with clearcutting as the primary harvest method in the west-side PNW forests. During this same period, several plant and animal species in the region that are dependent on older forest structures have been identified as threatened or endangered under the Endangered Species Act of 1973 and the National Forest Management Act of 1976 (USDA FS 1993). These listings, coupled with legal actions by concerned groups and the public's dislike for clearcutting, have forced reevaluation of forest management strategies and practices, particularly on public lands. Many alternative silvicultural strategies and practices for managing young-growth forests for multiple objectives are being proposed and implemented. In many cases, they are intended to maintain or accelerate development of forest structural components that are common to older forests and needed as habitat for species dependent on older forest types. In addition, options for harvesting and regenerating young-growth stands are being implemented with the intent that they will produce a significant volume of wood products while minimizing visual effect and impact on other values that are often disturbed by the traditional clearcut system.

Past Research and Management Experience in the Douglas-Fir Region

Past research and management practices in the Douglas-fir region generally have focused on clearcutting followed by establishment and management of even-aged plantations. This traditional approach has emphasized managing one (or a few) primary tree species in uniform stands. Early management practices were designed to reduce competition from nontimber vegetation and enhance growth of crop trees. In addition, relatively short rotation lengths were chosen (in relation to the biological limits for most northwestern tree species). The intent was to maximize the volume and value of merchantable wood products with little attention given to species associated with older forest structures. Curtis and others (1998) review the historical development of silvicultural regimes in the PNW and point out how practices can be modified and used to maintain and produce wildlife habitat, diverse stand structures (including those associated with older forests), and scenic values while also producing wood products.

There is little research or operational experience, however, to validate successful outcomes of new silvicultural approaches being proposed and implemented for managing young-growth stands. These new approaches generally are intended to mimic observed characteristics in older stands that developed after natural disturbance. It has been assumed that it is desirable to increase both species diversity and structural heterogeneity within stands. No young-growth stands, however, have been managed for an extended period under these proposed alternative regimes. Thus, estimates of relative costs and benefits are based on major extrapolations from limited data. In addition, no experimentation has focused on how various factors (i.e., understory and overstory species composition, vertical and horizontal spatial distribution of trees, snags, and coarse woody debris (CWD) within a stand, and age-size distribution of trees) independently affect plant and animal populations, or how altering these factors will impact tree growth, stand differentiation, habitat functions, or the production of forest products. Most of the existing work with alternatives to even-age management in the Douglas-fir region was done in old-growth stands and has little relevance to management of young-growth stands (Curtis 1998).

Silvicultural Options Studies in the West-Side Pacific Northwest Region

The Westside Silvicultural Options Team of the PNW Research Station is conducting several large-scale studies of silvicultural options for young-growth stands. These studies will evaluate the results of management options intended to produce multiple resource outputs and habitat values. Three such studies are summarized in this paper. Each study examines options for managing young-growth stands in one of three major stages in the life of managed stands—early development (precommercial thinning), mid-rotation (commercial thinning), and regeneration harvest.

Early Development Options—Alternative Silviculture in Young Douglas-fir Plantations

In recent years, the Forest Service in the PNW region has increased emphasis on young stand management, including ways to have some stands develop old-growth structural characteristics. One study is investigating silvicultural options to create diverse stand structures by treating young, even-aged plantations. The study area is in the Upper Clearwater Creek valley of the Mount St. Helens National Volcanic Monument in the Gifford Pinchot National Forest. The forests in the area were completely destroyed by the 1980 eruption of Mount St. Helens. After salvage logging, the area was planted in the mid-1980s. Young, vigorous, uniform Douglas-fir plantations resulted from this reforestation effort. Given the timber production goal for these plantations, the area was scheduled for precommercial thinning in the mid-1990s as the plantations approached canopy closure. The Westside Silvicultural Options Team and the Gifford Pinchot National Forest staff took this opportunity to design an experiment to investigate how silvicultural activities, undertaken during the early development of stands, can influence vegetation structure and thereby habitat.

Study goals—The study goals are to:

1. Test how silviculturally induced variation in tree species composition and stand structure affect plant and animal populations.
2. Quantify the effects of different silvicultural regimes on tree and stand characteristics and the production of forest products.

Study design—Five treatments were designed and replicated five times in the study area, resulting in a total of 25 plots. The main aspects of each treatment are summarized below.


A

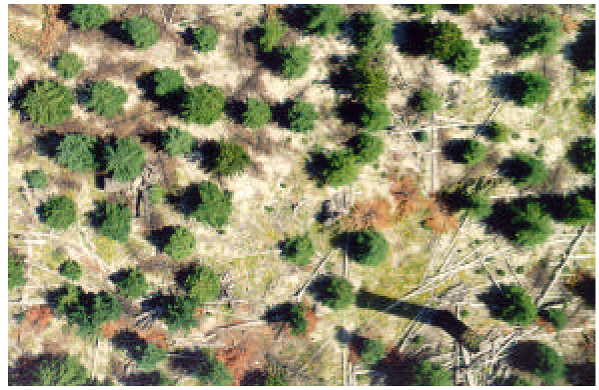
B

Figure 1—Aerial view of uniform (a) and irregular (b) thinning in the Clearwater Valley. The plantation was 12 years old at time of thinning, the same year these photos were taken.

A. Control plots with no treatments planned for several decades. Plots were not thinned. These plots have stands that are uniform with one primary species (Douglas-fir), a fairly dense spacing of 680 trees per acre, and simple stand structure (one canopy layer and little understory vegetation).

B. Thinning (fig. 1a) to emphasize uniformity of species composition and stand structure. Plots were evenly thinned to about half their original density by removing alternate diagonal rows of trees. Stand treatments were not intended to alter species composition. Subsequent commercial thinnings will be applied as stand and economic conditions allow. In these future thinnings, the largest, most vigorous Douglas-fir, followed by other coniferous species, will be left. Tree spacing will be kept relatively uniform.

C. Uniform thinning with supplemental plantings in small, uniform openings to increase tree species diversity. Plots were first evenly thinned as in treatment B. Immediately after the initial uniform thinning, an additional 100 Douglas-fir trees per acre were removed to form small, evenly spaced openings (about 40 by 40 ft). A mixture of red alder (*Alnus rubra* Bong.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western redcedar (*Thuja plicata* Donn ex D. Don) seedlings were then planted in these openings. Subsequent commercial thinnings will be applied as stand and economic conditions allow; however, they will emphasize increasing tree species diversity rather than maintaining stand uniformity.

D. Irregular thinning with variable-sized openings to increase structural heterogeneity (fig. 1b). Plots were thinned to increase horizontal and vertical diversity (spatial heterogeneity) in the stand. Plots were first evenly thinned as in treatment B. Immediately after following the initial thinning, an additional 100 Douglas-fir trees per acre were removed in unevenly spaced clumps that created openings of three sizes: 30 by 30 ft, 40 by 40 ft, and 50 by 50 ft. No additional species were planted in these openings. Subsequent commercial thinnings will be applied as stand and economic conditions allow; however, increasing heterogeneity and tree species diversity will be emphasized by only allowing harvest of Douglas-fir and expanding or creating new openings in these thinnings.

E. Irregular thinning with variable-sized openings and supplemental plantings to increase structural heterogeneity. This treatment is similar to treatment D; however, openings were planted with a mixture of red alder, western hemlock, and western redcedar seedlings. In addition, 30 large, vigorous trees per acre are to be selected for growth enhancement via fertilization. Twenty of these large trees will be kept in an open grown condition to maximize growth. Some of these selected trees will be topped or killed in several decades to provide early snag recruitment. The primary objective of subsequent commercial thinnings is to accelerate the development of multi-layered, uneven-aged, mixed-species stands.

Each treatment plot is 836 by 836 ft (16 acres) including a 90-ft treatment buffer. Within each plot, two or three 130- by 200-ft measurement subplots were located after initial treatments were applied in 1994 or 1995. In these subplots, all trees were tagged and measured. In addition, understory and ground vegetation was surveyed via small area plots and line transects. Subplots will be periodically remeasured for several decades. Study response variables emphasize understory development (abundance and diversity of plants), horizontal and vertical vegetation structure, and tree response to thinning (density, spacing, and growth).

Current status—All subplot trees were measured immediately after initial treatments were applied. Three years after initial treatment, a subsample of trees in the subplots was remeasured, then at 5 years, all subplot trees were remeasured. Understory and ground vegetation surveys were conducted 2 and 5 years after initial treatments.

All plots were juxtaposed over a large, highly homogeneous area with regard to climate, aspect, topography, soil, and current vegetation. This resulted in a high degree of similarity among and within treatment plots before manipulation, thereby increasing the probability that real differences among the treatments will be detected as vegetation develops. In addition, the relatively low density and limited variety of plant species present in the area at the time of initial treatments made it relatively easy to manipulate species composition by planting and seeding. Although no associated wildlife studies have yet been initiated, one might expect that wildlife responses would differ between treatments as stand structure differentiates over time.

Midrotation Options—Olympic Habitat Development Study

In the Douglas-fir region, well-stocked stands with closed canopies often have limited understory vegetation and consequently limited habitat for small forest-floor mammals. In the absence of active management (or a natural disturbance), the understories of these stands can remain impoverished for many decades. However, retrospective studies have shown that the presence of well-developed understory and midstory vegetation, cavity trees, and CWD can allow young, managed stands to function as late-seral forest for many wildlife communities (Carey and Johnson 1995). In 1994, the U.S. Congress directed the Forest Service to establish ecosystem restoration demonstrations in Washington and Oregon. The Westside Silvicultural Options and the Ecological Foundations of Biodiversity Teams from the Olympia Forestry Sciences Laboratory used this opportunity to collaborate with Olympic National Forest staff to design and implement the Olympic Habitat Development Study (OHDS), a large-scale study of silvicultural management options for midrotation stands on the Olympic Peninsula.

Study goals—The study goals are to:

1. Test the efficacy of specific management practices for their ability to accelerate development of stand structures and plant and animal communities associated with late-successional forests.
2. Test if accelerating the development of structures that are often missing in closed-canopy midrotation stands will increase the function of the ecosystem as habitat for terrestrial amphibians and small mammals that dwell on the forest floor.
3. Develop and test in an operational manner prescriptions that allow wood production consistent with sustainable ecosystems.

Study design—The OHDS was designed as a randomized block experiment with eight blocks distributed around the Olympic Peninsula. Each block has four or five treatment plots that are 15 to 25 acres. Study stands are 30- to 70-year-old young-growth stands of Douglas-fir, western hemlock, and Sitka spruce (*Picea sitchensis* (Bong.) Carr.). The core treatment is a novel variable-density thinning referred to as “thinning with skips and gaps.” It consists of 10 percent of the area in no-cut patches to protect existing snags and portions of the forest floor, 15 percent in small (65 by 65 ft) gaps to allow increased light to reach the understory without undermining stand wind resistance, and 75 percent lightly thinned from below (removal of 30 percent of the basal area) to increase wind firmness and to promote understory reinitiation and development. Minor tree species and trees with long crowns are retained. In addition to thinning, CWD treatments are a major feature of the study. The following five treatments are being applied:

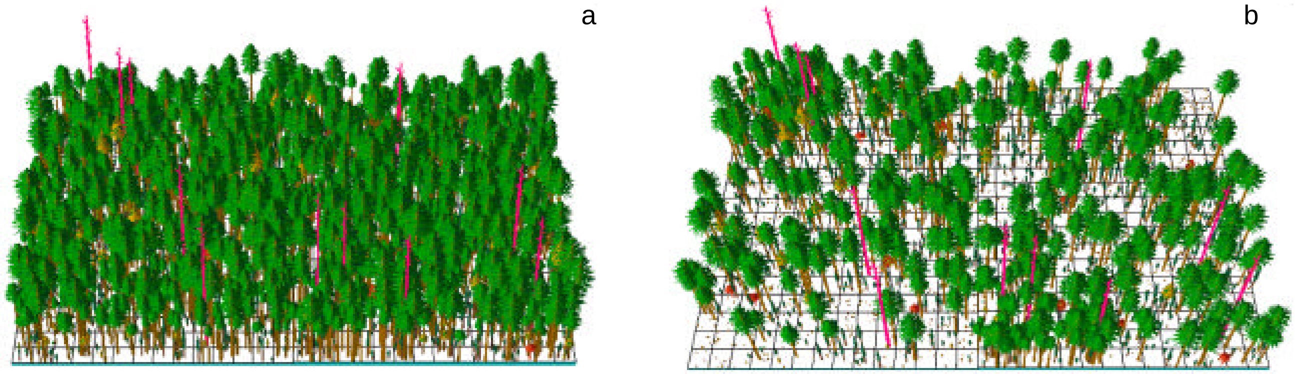

Figure 2—Visualization images of a portion (8 acres) of one of the stands in the Olympic Habitat Development Study before (a) and after (b) application of the variable thinning treatment. Height of snags is exaggerated to increase their visibility. Note that uncut patches were located to preserve snags.

A. Untreated control.

B. Variable-density thinning with scattered slash and scattered logs. Additional trees felled to supplement CWD levels.

C. Variable-density thinning with scattered slash and clumped logs. Additional trees felled to supplement CWD levels.

D. Variable-density thinning with slash piled and logs clumped and supplemental planting of desired species in gaps. Additional trees felled to supplement CWD levels.

E. Variable-density thinning with slash left scattered and no supplemental CWD treatment.

The treatments with CWD enhancement (B, C, and D) were to be evaluated after two winters. If windthrow and nonmerchantable logs were not sufficient to meet CWD targets, additional trees would be felled and left as CWD. The CWD clumping treatments also were to be implemented after two winters.

Study response variables emphasize CWD function (response of small mammals and amphibians), understory development (abundance and diversity of plants, response of small mammals), and tree response to thinning (density, spacing, and growth).

Current status—Pretreatment baseline data on small mammal and amphibian populations were collected from 1995 through 1998 on all eight blocks. Pretreatment data describing the presence and amount of cover of shrubs, ferns, herbs, mosses, and lichens were collected, as well as amount of CWD, on all blocks. Tree species, size, and age data were measured on prism plots in every treatment plot. One subplot in each block was stem-mapped (fig. 2). Some blocks also were used to study forest floor and soil seed banks, understory species root characteristics, and invertebrates associated with CWD.

Thinning treatments are being implemented through the timber-sale program of the Olympic National Forest. Four blocks were thinned during the period 1997-99. The completion date for an additional block originally scheduled for 2000 has been extended to 2006. Unfortunately, treatment of the remaining three blocks has been delayed owing to the requirement to first complete surveys for mollusks and fungi on the regional list of species to be surveyed and managed under the Northwest Forest Plan (Tuchmann and others 1996).

Post-treatment surveys of wind-thrown trees and residual stand damage have been completed on the four thinned blocks. Two blocks have had some of the CWD treatments and supplemental plantings implemented after thinning and have had post-harvest vegetation surveys.

Carey and Harrington (in press) completed a retrospective analysis of the influence of residual CWD and vegetation on forest small mammals. The OHDS is a major part of the adaptive management area program of the Olympic National Forest.

Regeneration Harvest Options—Silvicultural Options for Harvesting Young-Growth Forests

The wood-producing roles of state, industrial, and private forests have become increasingly important as harvests from national forests have declined. The Washington State Department of Natural Resources (DNR) is one of the largest nonfederal forest owners in the Northwest and has a legally defined management objective to generate income from timberlands in perpetuity for trust beneficiaries (educational and other state and county institutions). Expanding population, social changes, and related pressures and conflicts affect the DNR, as they do other managers of production forests.

Visual effects of harvesting activities are major considerations in management decisions, especially along major travel routes, in areas with heavy recreational use, and in the urban-forest interface. Desire to retain public support and reduce conflicts have stimulated interest in, and limited application of, various alternative harvest practices aimed at reducing visual impacts when young-growth stands are harvested. Obligations to DNR trust beneficiaries require that forest managers consider financial trade-offs and effects on long-term forest productivity when implementing alternative harvesting strategies. Unfortunately, little or no management experience or research exists for these alternative strategies. The Westside Silvicultural Options Team collaborated with DNR staff to design and implement a joint study aimed at evaluating young-growth harvest practices and silvicultural options that can be used in a landscape management context to reduce the visual impacts of harvest operations while at the same time maintaining a high level of timber production.

Study goals—The study goals are to:

1. Evaluate the biological, economic, and visual effects associated with alternative timber harvest patterns and management regimes for young-growth forests.
2. Provide experience and demonstrations of contrasting silvicultural systems that are biologically feasible for management of young-growth forests in the Douglas-fir region.

Study design—The study is a stand-level experiment that also provides components for various assessments at the landscape level. It compares six treatments in a randomized block design with a planned minimum of three replications. All blocks are on DNR Capital Forest, a highly productive young-growth forest southwest of Olympia, Washington. Treatments are being installed as part of the normal DNR timber sale program and are designed to create highly contrasting stand conditions. They will provide comparative data on biological responses and economic aspects. They also will permit evaluation of foreground and landscape-level visual effects. Treatments are applied in harvest units of 25 to 75 acres each. The initial treatments are (fig. 3):

A. Clearcut—A conventional even-aged system widely used in the Northwest and elsewhere. All merchantable and nonmerchantable trees will be cut with nearly 100 percent removal.

B. Retained overstory—A two-aged system that resembles a shelterwood, but with the residual trees carried through the next rotation to provide some large, high-quality trees. This is a heavy cut with 15 evenly spaced trees per acre left as the residual stand.

C. Small patch cutting—An even-aged system in which small openings (1.5 to 5 acres in size) are cut over 20 percent of the unit area. A concurrent thinning may be applied throughout the residual stand for density control purposes.

D. Group selection—An uneven-aged system in which evenly spaced small openings (up to 1.5 acres in size) are created by removing groups of trees over 20 percent of the unit area. A concurrent thinning may be applied throughout the residual stand for density control purposes.

E. Extended rotation with commercial thinning—Regular thinning from below in which about 30 percent of the basal area is removed throughout the stand. This treatment takes advantage of the capacity of thinned Douglas-fir to maintain high growth rates for extended periods. It defers regeneration harvest, which would eventually be accomplished with any of the above systems.

F. Unthinned control—No tree removal with regeneration deferred an additional 50 to 75 years.

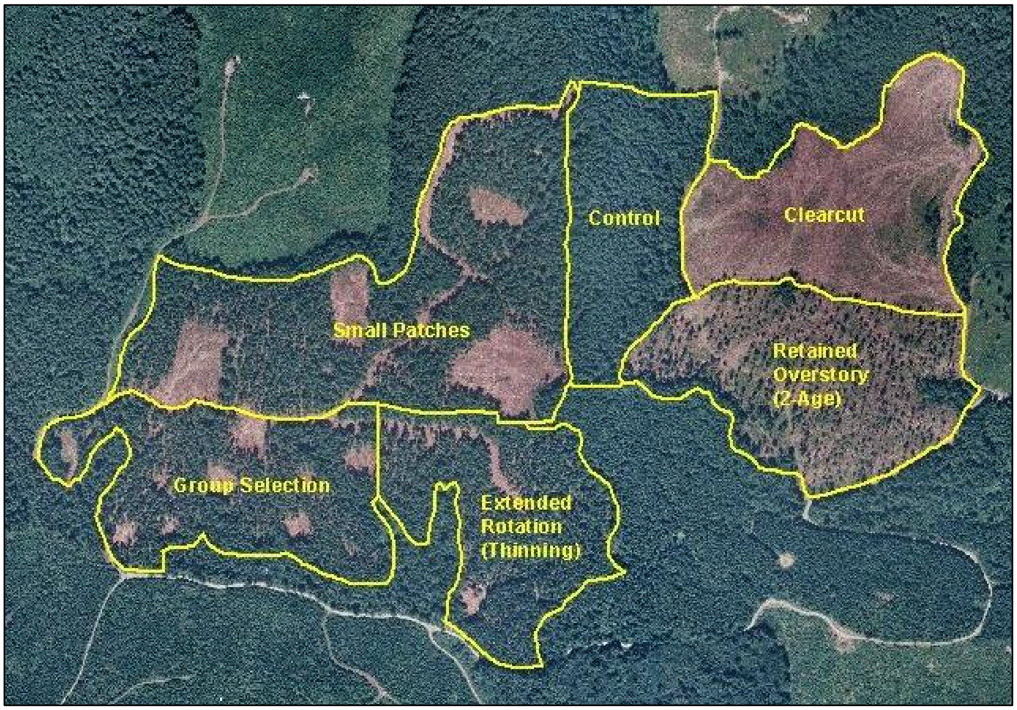

Figure 3—1999 aerial photograph of the Blue Ridge study site showing initial treatment units (yellow).

Regeneration in treatments A-D will be achieved primarily by planting in openings that are larger than 0.1 acre, with some supplementary natural regeneration. No planting is prescribed for treatments E and F. It is planned that plots that initially receive treatment A will be managed similar to traditional even-aged PNW stands over the next 60 to 75 years, with precommercial and commercial thinnings conducted as relative stand densities exceed desired targets. Treatment B plots will be managed similar to the clearcut plots, except that the residual overstory (15 trees per acre) will be retained for several decades. Plots that initially receive treatments C-E will be retreated (by using the same guidelines that were used during initial treatment) approximately every 15 to 20 years when relative stand densities exceed target ranges.

Permanent, circular, fixed-area plots (0.2 acre) were installed and measured before treatment. Plots were located on a regular grid within each plot. Regeneration and shrub cover were measured on small, fixed-area plots.

Harvesting production, cost data, log grades, and volumes will be collected to allow economic comparisons of treatments. Pre- and post-treatment photographs will be taken within the treatments and from landscape perspectives, where feasible, to allow evaluation of visual impacts and public perceptions of each treatment. Such photos will likely be taken at regular intervals for several decades so visual changes over time can be evaluated.

Current status—The first block (Blue Ridge) was harvested in 1998 and replanted in 1999. Pre- and post-harvest tree and vegetation measurements have been completed on the first block, as have measurements for residual stand damage and soil disturbance levels. Logging production, cost information, and wood products yields were collected. Pre- and post-harvest photographs of each treatment have been taken and a survey of public preferences of treatments has been conducted by University of Washington cooperators. The Ecological Foundations of Biodiversity Team has completed a post-treatment survey of song birds.

The second block (Copper Ridge) has been designed, pre-harvest plot measurements have been completed, and the block is scheduled for harvest in 2002. The third block (Rusty Ridge) has been identified and is tentatively scheduled for harvest in 2004. In addition to these three replications, the British Columbia Ministry of Forests plans to install a replication of the study in British Columbia.

Basic comparisons that will be made between treatments include tree growth and stand development, public response to visual impacts, harvest operation productivity and economic assessments, levels of soil disturbance, and song bird usage. The relatively large size of treatment units should provide opportunities for future research on wildlife and ecological questions, in addition to the primary focus on reconciling wood production, economic returns, and aesthetic values.

Discussion and Conclusions

Although the studies described in this paper address different stand development stages, their design and implementation have many similarities:

- Studies are in the Douglas-fir region in young-growth stands.
- Studies are long term and are intended to run for several decades.
- Multiple forest values and outputs are being examined.
- Studies involve collaboration with public land management partners.
- Studies were designed to use adaptive management approaches that allow future treatments to be modified as conditions and objectives change.
- Study treatments have been implemented as part of ongoing forest management activities by the land managers.
- Treatments are intended to stimulate the development of various stand structures.
- Studies were designed with replication and randomization of treatments.
- Large treatment areas and plot sizes were implemented, providing sufficient area for related wildlife research.
- Study sites are valuable as both research and demonstration sites.
- Undertaking and implementing these studies required a major effort involving scientists, professionals, and support staff from all involved partners.
- Studies of this scale usually require supplemental funding from special programs or research initiatives.

Although direct study of wildlife species is not the primary goal of these silvicultural studies, each study is generating valuable information about how vegetation structure and diversity is modified via management activities over the life of young-growth forests in the Douglas-fir region. Such vegetation response data should be of great use to wildlife biologists as they work to restore or maintain habitat in young-growth forests. When treatment differences in vegetation become established, these installations will provide outstanding opportunities for direct study of some wildlife species.

The network of studies described in this paper establish an accessible show-case of silvicultural options that address all phases in the management of young-growth forests in the Douglas-fir region. As the forests in these studies develop, they will provide examples of the environments that can be created by different management approaches. With time, the studies also will provide opportunities for public education and professional training on the advantages and disadvantages associated with each silvicultural option.

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The authors thank the many people who have assisted with the development, implementation, and ongoing monitoring of these studies.

Metric Equivalents

1 acre = 0.4047 hectare (ha)

1 foot (ft) = 0.3048 meter (m)

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Snag Frequencies 50 Years After Partially Cutting Interior Ponderosa Pine Stands

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Abstract

Snags, or standing dead trees, are important nesting and foraging substrates for many species of wildlife, especially birds. The importance of this resource to wildlife has prompted forest managers to set snag frequency goals in the forest stands that they manage. Although a body of information links wildlife use to snags and in some cases minimum snag frequencies, research on the frequencies of snags that should be expected in late-seral interior ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) habitats is scarce. Snag frequencies were determined in unharvested stands and in stands harvested to varying intensities after 50 years and 43 years after widespread snag felling at the Blacks Mountain Experimental Forest in northeastern California. Recent data show that only unharvested and lightly harvested stands (15 percent of the merchantable volume removed) met the USDA Forest Service's recent goal of three snags per acre larger than 15 inches in diameter. Thus, the capacity of interior ponderosa pine stands to meet this goal is questioned.

Keywords: Ponderosa pine, snag frequency, harvested stands, late seral forests, northeastern California.

Introduction

Snags, or standing dead trees, are important nesting and foraging substrates for many species of wildlife, especially birds. Snags, when they fall, shelter small mammals and recycle nutrients leading to soil improvement. Dead tops of live trees also provide foraging and nesting substrates for some species. The importance of this resource to wildlife has prompted forest managers to set specific snag frequency goals in the forest stands that they manage.

Historically, snags were regarded as an undesirable component of managed interior ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) forests. Before the early 1970s the management objective was to eliminate snags and dying trees that were destined to become snags. Snags sometimes constitute a fire hazard because they can serve as lightning rods, increase the risk of wildfire, and once ignited, increase its spread by wind-blown embers. Snags also constitute a human safety hazard because of the risk of falling limbs or boles. Dying trees serve as reservoirs for tree-damaging insects. And finally, many recently dead trees retain economic value. Consequently, timber sales generally required removal of all snags in the sale area and many salvage sales were conducted.

In the 1970s, managers began to realize the importance of snags to wildlife and snag management became somewhat passive. Although snags no longer were felled throughout timber sale areas, neither were they actively recruited. Nevertheless, snags, especially those of large diameter, continued to decline in number as a result of continued salvage sales and fuelwood harvest.

In the early 1980s planning regulations promulgated in response to the National Forest Management Act (1976) established minimum management requirements for snags to enhance diversity of plant and animal communities. Since then, individual National Forest plans have specified various snag frequency, condition, location, and species goals. The Lassen National Forest Land and Resource Management Plan (USDA Forest Service 1993) requires at least:

- 1.2 snags per acre between 15-24 inches in diameter at breast height (dbh) and greater than 20 feet high;
- 0.3 snags per acre greater than 24 inches dbh and greater than 20 feet high;
- dispersion of one group per 5-15 acres or less with 5-15+ snags

More snags are required around pileated woodpecker (*Drycopus pileatus*) nest trees, and green culls can be substituted for all but one snag per acre. The recently released Sierra Nevada Forest Plan Amendment (USDA FS 2001) further requires snag retention of the largest three snags per acre, evaluated on a 10-acre basis, when conducting fuel treatments. However, this study was conducted on the Blacks Mountain Experimental Forest (BMEF) that is exempt from these requirements.

How achievable are these standards for the interior ponderosa pine forest type? The literature on snag frequencies for late seral stands in northern California has increased (Keen 1929, 1955; Landram et al. in press; Morrison et al. 1986; Raphael and Morrison 1987). However, observation periods are often short and none of the literature relates frequencies to past harvesting practices or to the capability of the forest to support the number of snags needed to meet guidelines.

I had the opportunity to determine the snag frequencies in unharvested, late seral stands, and in stands harvested to varying intensities 50 years ago at the BMEF. This paper discusses a comparison of the snag frequencies at BMEF with snag size and frequency standards providing insight into how realistic the standards are for interior ponderosa pine forests.

The Study Area

The BMEF is located 35 miles northwest of Susanville, Lassen County, California (lat. 40° 40' N., long. 121°10' W.) within the interior ponderosa pine forest type (SAF 237) (Eyre 1980). It is an extensive forest type that stretches from southern British Columbia, Canada, to northern Baja California in Mexico and from northeastern California to the Plains States. In northeastern California, ponderosa pine is the principal species mixed with small numbers of Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.*),* incense-cedar (*Lebocedrus decurrens* Torr.), and white fir (*Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.), becoming prevalent at higher elevations. Typical of vast areas of this forest type, BMEF has two major age classes that originated after wild fire exclusion: a scattered overstory of 300-to 500-year-old pines and a dense understory of pines and white fir. An intermediate age class of 150-to 200-year-old trees is largely absent.

Methods

Between 1938 and 1947 unharvested late-seral stands were cut to various intensities in a Methods-of-Cutting Study (MOC) (Dolph et al. 1995). Treatments were described by the proportion of sawtimber volume removed and included—zero percent (no removal), 15 percent (a sanitation/salvage cut), 55 percent, 85 percent, and 100 percent removal of the sawtimber overstory greater than 11.6 inches dbh. Each year for the 10-year period, treatments were performed on a new group of four or five 20-acre plots surrounded by a 100-foot buffer similarly treated. All trees 11.6 inches dbh within the 20-acre plots were measured for dbh and tagged before the next growing season after treatment. Re-measurements were conducted at 5, 10, and 20 years after treatment. Trees that had grown to the 11.6-inch minimum size were measured and tagged at each re-measurement. In 1947 snags were felled throughout BMEF to reduce the perceived fire hazard.

In 1990 and 1991, 42 or 43 years after snag removal and 43 to 53 years after partial cutting, all standing dead trees were tallied on the MOC plots by plot number, species, and by two dbh classes: 15 to 24 inches and larger than 24 inches. The total number of acres inventoried for snags by intensity of harvest is shown in table 1.

Because snags were not measured for dbh in the 1990-1991 inventory, ingrowth into the size classes had to be estimated. The dbh at time of death was estimated by adding half the growth for that species and size class since the re-measurement when the tree was last living. Most growth estimates consisted of white fir into the 15- to 24-inch size class in the 100 percent overstory removal treatment. The few Jeffrey pine and incense-cedar snags recorded were combined with ponderosa pine in this analysis. Snag counts in each MOC plot were expressed as numbers per acre, and differences among treatments were analyzed by one-way Analysis of Variance. Differences between

Table 1—Total number of acres inventoried for snags by intensity of harvest

Harvest intensity	Pine	Pine/fir
Percent removal	– – – – *acres* – – – –	
0	80	120
15	40	40
55	80	120
85	80	120
100	20	40

species and size classes across treatments were analyzed by "t" tests. Also, snag numbers in MOC plots in almost pure pine stands at lower elevations were analyzed by "t" test separately from mixed pine and white fir stands at higher elevations at BMEF. Significance at the 90 percent probability level was estimated by the Bonferroni procedure.

Results

In 1990 and 1991, the number of snags in both ponderosa pine and mixed ponderosa pine and white fir stands was similar for unharvested stands and stands with only 15 percent removal ($p<0.1$). On a per acre basis, ponderosa pine stands averaged 0.5 small snags, 15 to 24 inches dbh, and 1.7 large snags, larger in dbh than 24 inches (table 2). Snag frequencies were significantly higher in mixed stands of ponderosa pine and white fir than in nearly pure pine stands ($p<0.1$), averaging 1.1 small snags and 2.8 large snags per acre, due to higher mortality in small white firs and large pines. Numbers of snags in all categories generally declined when intensity of harvest increased. At 100 percent removal, there were few snags except in mixed stands where 2.0 small white fir snags per acre were recorded.

Discussion

Only the unharvested and lightly harvested stands, removing 15 percent of the merchantable volume, produced a sufficient number of snags in the 43 years since the snag felling in 1947. This treatment met the minimum goal of 1.5 snags per acre required for this area in the Lassen National Forest Land and Resources Management Plan (USDA Forest Service 1993) and the updated requirement of three snags per acre (USDA FS 2001). Stands harvested more intensively, removing more than 50 percent of the merchantable volume 50 years ago, produced fewer than 1.5 snags per acre over the past 43 years.

The requirement of 1.5 snags per acre, and certainly three snags per acre, is unlikely to be met at present by most managed stands of interior ponderosa pine because the stands and partial harvesting practices at BMEF were common throughout the region. Until about 10 years ago, a typical cutting practice by the USDA Forest Service (USFS) was to partially cut stands to 55 percent of the basal area shown in normal yield tables (Meyer 1938) for the appropriate site quality. The average stand chosen for cutting had a Site Index of 75 (Meyer 1938) and a stand density of about 80 percent of the normal yield table value or about 140 ft^2 per acre of basal area. Because the MOC plots had a similar Site Index and stand density before treatment, it is likely that extensive areas of the interior ponderosa pine type fail to meet the USFS snag frequency goals. Forest inventory data for the interior ponderosa pine type in California provides evidence of this, showing an average of only 0.6 snags per acre larger in dbh than 20 inches (personal communication, Michael Landram, Regional Silviculturist, Region 5, USFS).

The failure of the intensively harvested stands at BMEF to meet snag frequency goals is surprising because precipitation was below normal for seven of the eight years before the snag inventory. This prolonged drought was associated with an abundance of bark beetle-killed trees throughout northeastern California. At BMEF, bark-beetle-induced mortality has subsequently declined with a return to normal precipitation levels (personal communication, P. J. Shea, Research Entomologist, Pacific Southwest Research Station).

Ponderosa pine snags are surprisingly short lived. In southern Oregon and northeastern California, only 40 percent of bark-beetle-killed ponderosa pines were still standing after 10 years and only 25 percent was still standing after 14 years (Keen 1955). In central Oregon, comparative longevities for fire-killed trees were 47 percent and 35 percent (Dahms 1949). In Colorado, bark beetle-killed ponderosa pines fell at a faster rate than did Engelmann spruce (*Picea engelmannii*) (Schmid et al. 1985). A fast rate of fall is probably enhanced by rapid decomposition of the roots. Ponderosa pine roots were found to decompose more rapidly than

Table 2—Snag frequencies in two species types within interior ponderosa pine forests unharvested and harvested to remove varying proportions of sawtimber trees 50 years ago at Blacks Mountain Experimental Forest, California (all snags subsequently felled 43 years ago).

	Number of snags per acre by size class and percent timber harvest									
	15-24 inch dbh size class					>24 inch dbh size class				
Species	**0%**	**15%**	**55%**	**85%**	**100%**	**0%**	**15%**	**55%**	**85%**	**100%**
					Ponderosa pine stands					
Pine	0.6	0.4	0.3	0.1	0.0	1.9	1.5	0.6	0.3	0.0
White fir	0.0	<0.1	<0.1	<0.1	0.0	0.0	0.0	0.0	<0.1	0.0
Both species	0.6	0.4	0.3	0.2	0.0	1.9	1.5	0.6	0.3	0.0
					Ponderosa pine-white fir stands					
Pine	0.7	0.8	0.2	0.1	0.0	2.2	2.3	0.4	0.3	<0.1
White fir	1.0	1.9	0.7	1.1	2.0	0.4	0.7	0.2	0.2	<0.1
Both species	1.7	2.6	0.9	1.2	2.0	2.6	3.0	0.7	0.4	<0.1

other common coniferous trees in the Pacific Northwest (Chen et al. 2001). Ponderosa pine snags at BMEF seem to have similarly short life spans. For example, the inventories reported here covered more than 740 acres, and yet only 10 snags predating the previous inventory of 30 years ago were discovered. Most of these old snags were propped up by falling into live trees.

Currently, interest is high in creating stands with age, size, and spatial structures that mimic pre-European settlement forests. Little or no information exists on historical snag frequencies. The stands inventoried in this paper are one estimate of these historical frequencies. Although these data are the result of only 43 years of snag production, it could be argued that this estimate may be high because historical stands were subject to periodic fire that kept stand frequencies low, eliminating one major cause of the present mortality of the large old trees. Because these unharvested and lightly harvested stands, with abundant large old trees, fail to meet snag frequency standards, the Forest Service's current minimum management requirements for snags appear to be higher than interior ponderosa pine stands managed for timber production can achieve.

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Damage to Residual Trees from a Commercial Thinning of Small-Diameter Mixed-Conifer Stands in Northeastern Washington

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Abstract

Dense stands of small-diameter timber are common in the inland West and present unique challenges for land managers. Managing stands to reduce susceptibility to insects, diseases, and catastrophic fires is constrained by low economic values of many small-diameter stands and, on public lands, internal and external restrictions on regeneration harvesting. In 1996, the U.S. Congress, recognizing a need to address forest health issues and stimulate local resource-based economies in northeastern Washington, provided funds for "implementation and evaluation of controlled silvicultural treatment in designated, fire-generated, overstocked, small-diameter stands" (U.S. Congress House Report 104-625). As part of this Congressionally mandated research effort, eight harvest units in two different stands were commercially thinned to a 20-foot spacing with different harvesting systems. Comparisons were made among the systems tested to assess damage to residual trees. While some systems performed better than others, no single system was clearly superior. Systems producing fewer or less severe wounds were often more costly to implement. In some cases, wounding may have been exacerbated by factors other than equipment, including the silvicultural prescription and unusual weather conditions during harvest.

Keywords: Silviculture, harvesting, thinning, wounding.

Introduction

Forested landscapes characterized by dense stands of small-diameter trees present considerable challenges to land managers in the Intermountain West. As these stands age they become increasingly susceptible to insects, pathogens, and catastrophic wildfires (Oliver and Larson 1996, Hessburg et al. 1994, Lehmkuhl et al. 1994, Lotan et al. 1988). With opportunities for harvesting older stands and larger trees increasingly limited, land managers are re-thinking management options for overstocked, small-diameter stands, although these options are constrained by economics and, on National Forest lands, public sentiment against regeneration harvesting. Increasingly, management opportunities for small-diameter stands will involve partial harvesting to achieve multiple objectives of reducing risk of catastrophic disturbances, accelerating stand development trajectories toward late-successional conditions for wildlife, and providing needed jobs and revenues for resource-dependent rural communities.

During the 1920s and 1930s, forests in northeastern Washington experienced a series of catastrophic wildfires, many deliberately ignited. In the aftermath of these fires, dense stands of lodgepole pine (*Pinus contorta* var. *latifolia*), western larch (*Larix occidentalis*), Douglas-fir (*Pseudotsuga menziesii*), and several other conifer species established. Trees in some lodgepole pine-dominated stands are now approaching sizes where the initiation and sustained outbreak of mountain pine beetle (*Dendroctonus ponderosae*) could occur (McGregor et al. 1981, Amman and Cole 1983). Managers express concern that mountain pine beetle outbreaks could result in widespread mortality of lodgepole pine over large areas, setting the stage for a repetition of the catastrophic fires that burned earlier in the century.

Forest health concerns are matched by concerns about the region's economic health. Per-capita incomes in northeastern Washington counties are some of the lowest in the state. Recognizing an opportunity for simultaneously addressing forest health issues and stimulating local rural economies, the U.S. Congress (House Report 104-625) provided National Forest Systems with funding and legislative language for "implementation and evaluation of controlled silvicultural treatment in designated fire-generated, overstocked, small-diameter" stands on the Colville National Forest. This research program is frequently referred to by the acronym CReating OPportunities (CROP).

The first activity included case studies comparing operational costs of different harvesting systems used to commercially thin two stands. Four different harvesting technologies were compared within each stand. One stand was on a steep slope ($\geq$35 percent), the other on more gentle terrain. Treatment effects on residual trees and other stand attributes were measured and are being analyzed and documented. This paper summarizes each set of harvesting technologies with respect to the amount and severity of damage to designated retention trees and to the non-merchantable trees left on site after harvest.

Methods

Study Site

The case studies were conducted as part of the Fritz and Fritz Demo I timber sales on the Kettle Falls Ranger District of the Colville National Forest in Ferry County, WA. Sale units were in the Sherman Creek drainage, over 50,000 acres of which burned in the1929 Dollar Fire. A few ponderosa pine (*Pinus ponderosa*), western larch, and Douglas-fir survived the fire, providing a source of seed for regenerating stands. Serotinous cones of lodgepole pine provided an additional and abundant seed source. Nearly all relic trees died or were selectively harvested in the first few decades following the fire.

Two stands, one that established in the aftermath of the Dollar fire and another that established following a smaller fire that burned a decade or so earlier, were selected. Four experimental harvesting units were installed in each stand. The steep stand was on a west-facing slope with aspects between 228 and 300°; average aspect was 256°. Elevations ranged from 4,440 to 4,700 feet and slopes were between 23 and 53 percent with an average slope of 35 percent. Plant associations within the stand included PICO/SHCA (lodgepole pine/buffaloberry [*Shepherdia canadensis*]), PSME/CARU (Douglas-fir/elk sedge [*Calamagrostis rubescens*]), and PSME/VAME (Douglas-fir/big huckleberry [*Vaccinium membranaceum*]) as described by Williams et al. (1995). The flat stand was on gently rolling terrain with predominantly SE aspects averaging 150°. Elevations ranged from 3,900 to 4,500 feet; slopes were between 2 and 25 percent, with an average slope of 11 percent. Plant associations included ABLA2/CARU (subalpine fir (*Abies lasiocarpa*)/pinegrass (*Calamagrostis rubescens*), ABLA2/VAME (subalpine fir/big huckleberry (*Vaccinium membranaceum*), ABLA2/LIBOL (subalpine fir/ twinflower (*Linnaea borealis*), ABLA2/CLUN (subalpine fir/queencup beadlilly (*Clintonia uniflora*), and PSME/VAME (Douglas-fir/big huckleberry). In each stand, variability of plant associations, trees/acre (tpa), basal area/acre (ba), and other plot metrics were as great or greater within units as among units, reflecting some heterogeneity in initial stand conditions. Harvest unit size ranged from 8 to 27 acres.

Pre-harvest metrics for each stand are shown in table 1. Both stands were predominantly a mixture of lodgepole pine and western larch. Expressed as tpa lodgepole pine comprised 43 percent of the steep stand and 45 percent of the flat stand, with western larch being 34 and 29 percent, respectively. Associated species in the steep stand included Douglas-fir (18 percent), ponderosa pine (2 percent), and Scoler's willow (*Salix scouleriana*) (2 percent), while in the flat stand, subalpine fir (13 percent), Engelmann spruce (*Picea engelmannii*) (7 percent), and Douglas-fir (6 percent) were included.

The silvicultural prescription consisted of thinning to a 20-feet spacing between reserve trees, with the objective of retaining approximately 100 tpa. Retention trees were clearly marked at diameter at breast height (dbh) with orange paint. Thinning was generally from below, removing smaller merchantable trees and favoring retention of western larch, Douglas-fir, and ponderosa pine. Lodgepole pine was targeted for removal because of its susceptibility to attack from mountain pine beetles. The spacing constraint and a desire for retaining the aesthetically-desirable western larch (because of its fall foliage and visibility from a designated scenic highway) occasionally superceded thinning from below. Harvest operations in the steep units began in late July and finished in September 1998.

Table 1—Pre-harvest stand conditions

	Steep		Flat	
Trees/acre (TPA)	589		1,022	
Quadratic mean diameter in inches (Qmd)	6.6		5.7	
Basal area in ft^2 / ac (BA)	140		180	
Percent species composition	BA	TPA	BA	TPA
Lodgepole pine (LP)	43	47	42	45
Western larch (WL)	34	34	42	29
Douglas-fir (DF)	18	17	4	6
Ponderosa pine (PP)	2	2	—	—
Subalpine fir (SF)	—	—	8	13
Englemann spruce (ES)	—	—	4	7

Flat units were harvested during the summer of 1999. Unmerchantable trees were left on site and not deliberately killed or destroyed.

Harvesting Equipment and Methods

Harvesting systems and the units in which they were implemented are shown in table 2. Equipment operation was by professional loggers with experience using the machinery. In the cut-to-length (CTL) units, a tracked Valmet Model 500T single grip harvester with tilting cab felled and processed trees. Forwarding was accomplished with a 1993 Valmet Model 892 with a 14-ton load capacity. Whole tree felling was done by hand with a chainsaw in one unit and with a tracked Timbco Model 445 B feller-buncher with a 20-inch capacity Quadco head in the other units. Cable yarding operations incorporated a Skagit Model 333, originally designed as a two-drum yarder, but adapted with a third drum normally used as a strawline. In downhill yarding, the strawline was used as the mainline and the regular mainline was used as the haulback line. The system included a Christy haulback carriage with a radio-controlled skyline clamp. Power was provided to the skyline stop by a hydraulic accumulator in the carriage. A mobile tailhold was located on an upper road to provide lift to the skyline. It was mounted on a crawler tractor and could travel off haul roads to provide lift. Settings for the downhill yarding were configured with the haulback line routed over several corridors, up the hill, and back to the yarding corridor. No intermediate supports were used as all settings had adequate skyline deflection.

Data Collection

Ten permanent plots were established within each unit prior to harvesting. Plots were located systematically with random starting points. Plot centers were marked with a 24-inch rebar stake driven completely into the soil. An aluminum tag was affixed to the closest tree marked for retention and engraved with the distance and azimuth to plot center to facilitate relocating the plots following harvest. Prior to harvest, $\geq$ 7 inch dbh were sampled on 0.1-acre circular plots and all trees $\geq$ 1 and < 7 inch dbh were sampled on 1/50th-acre plots nested within the larger plots. The following information was recorded for each tree: species, dbh, height, height to live crown, crown class, and damage from insects, diseases, or other disturbance agents. None of the trees in the pre-harvest sample exhibited wounds that could be mistaken for any wounding that might occur during harvest.

Following harvest, all remaining trees were inventoried for harvest-related damage on the 0.1-acre permanent plots and on 10 additional 0.1-acre plots, installed systematically between permanent plots. Han and Kellogg (2000a) reported that systematic plot sampling provided estimates of damage similar to 100-percent surveys. Wound severity was classified by type of tissue affected. Scraped bark with some cambial tissue exposed but no penetration into the cambium was considered a minor wound. Penetration or removal of cambial tissue was considered moderate wounding. Penetration through the cambial tissue and into the sapwood was considered severe wounding.

Table 2—Harvesting systems and the units in which they were implemented

Unit and abbreviation		Felling and Processing		Forwarding / Yarding			
				Ground-based		Cable	
		Method	Equipment	Equipment	Trail spacing	Method	Corridor width
					Feet		*Feet*
Steep stand							
8	CTLUS	CTL	CTL Harvester[a]		40	Uphill	80
9	CTLF	CTL	CTL Harvester	Forwarder[b]	40	—	—
16	WTFB	Whole Tree	Feller-buncher[c]		40	Downhill	40
17	CTLDS	CTL	CTL Harvester		40	Downhill	80
Flat stand							
2	HF	Hand	CTL Harvester	Forwarder	130	—	—
3	CTLF	CTL	CTL Harvester	Forwarder	40	—	—
4	WTFB	Whole Tree	Feller-buncher	Skidder[d]	130	—	—
19	CTLFB	Whole Tree	Feller-buncher + CTL Harvester	Forwarder	130	—	—

[a] Tracked Kabelco 200 single-grip harvester with Kato 500 saw head

[b] Rubber-tired Valemt 892 forwarder (14-ton capacity)

[c] Tracked Timbco 445 feller-buncher with Quadco Hot-Saw felling head

[d] Rubber-tired Caterpillar 518 skidder with swinging grapples

Results

Damage to Trees Specifically Marked for Retention

Following harvest, density of designated retention trees in the eight experimental units varied from 66 to 99 tpa (table 3). Lower residual amounts than the 100 tpa specified in the prescription reflect the relatively small size of the harvest units and some necessary removal of retention trees to accommodate skyline corridors and forwarder trails. In addition to designated retention trees, between 71 and 638 unmerchantable trees/acre were left on the site.

Mean percentages of designated retention trees by wound severity are shown in tables 4 and 5. In the steep stand, the least moderate-to-severe wounding occurred with the CTL and downhill skyline system. The CTL and forwarder system had the greatest combined cambial and sapwood damage, although this system resulted in the greatest percentage of undamaged trees and was the least costly system to implement. In the flat stand, the smallest percentage of moderate-to-severe wounding occurred in the unit in which whole trees were harvested with the feller-buncher while the greatest amount of moderate to severe wounding occurred with the CTL and feller-buncher system.

Discussion

Trees sustain wounds when cambial tissue is exposed through breaks in the bark. Wounds can result in stain, decay and stem deformity, impacting stand development and the ability of a stand to provide commodity and amenity values. From a timber perspective, wounds reduce future value of the stand, especially when wounds are large, numerous, and prone to decay (Han et al. 2000b). Factors predisposing a tree to wounding include its species and the season when harvesting occurs. Silvicultural prescriptions that are difficult to implement may also contribute to residual stand damage.

The silvicultural prescription for these case studies stipulated that western larch and Douglas-fir be preferentially retained over lodgepole pine to create stands less at risk to catastrophic fires and

Table 3—Post-harvest retention levels of designated and unmerchantable trees

Unit number and abbreviation		Designated retention trees/acre	Unmerchantable trees/acre
Steep			
8	CTLUS	87	244
9	CTLF	66	79
16	WTFB	88	164
17	CTLDS	66	224
Flat			
2	HF	80	638
3	CTLF	71	430
4	WTFB	74	525
19	CTLFB	99	313

Table 4—Steep stand wounding expressed as the percentage of designated retention trees

Harvest system	Relative Cost	No damage	Minor damage (bark)	Moderate damage (cambial)	Severe damage (sapwood)
CTLUS	$$	9	45	23	23
CTLF	$	26	26	27	21
CTLDS	$$$	12	50	24	14
WTDS	$$$$	15	39	17	30

Table 5—Flat stand wounding expressed as the percentage of designated retention trees

Harvest system	Relative Cost	No damage	Minor damage (bark)	Moderate damage (cambial)	Severe damage (sapwood)
HF	$$$$	17	42	25	16
CTLF	$	10	44	34	12
WTFB	$$$	46	29	14	11
CTLFB	$$	8	40	26	26

outbreaks of mountain pine beetle. Unfortunately, the desired post-treatment conditions were not met because of the large number of unmerchantable trees left on site. While some of these trees may die from windthrow, snow and ice breakage, or competition with larger trees, others are likely to persist. Furthermore, some research suggests that species conversion through silvicultural thinning could replace one set of forest health problems with others. Many residual trees sustained wounds penetrating the cambium and sapwood. In a survey of mixed stands of lodgepole pine and western larch, Allen and White (1997) noted that 88 percent of the larch but only 8 percent of the lodgepole pine had decay associated with past wounds. Filip et al. (1995) also reported an absence of decay in wounded lodgepole pine three years after a commercial thinning operation.

Retaining trees on a 20-foot grid may have constrained equipment. Sizes and species of trees likely exacerbated wounding levels and compounded problems associated with narrow spacing of residuals. Many designated retention trees were small and had thin bark, increasing the likelihood that wounds would penetrate into cambial or sapwood tissues. In the flat units, the density of very small trees made it extremely difficult to manually fell trees and operate equipment. It would have perhaps been more efficient to retain trees in clumps interspersed with open areas rather than attempt to create a uniform spacing between designated retention trees.

Weather probably played a role in the amount of damage to retained trees in the steep stand. Harvesting began in late July, following an unseasonably long, wet spring. Typical hot dry summer weather did not occur until the middle of August. Research comparing production and cost of the harvesting systems indicated that bark on 33 percent of the harvested trees was so loose as to require two or more passes over a felled tree for the processor to accurately measure log lengths (Johnson 1999). This suggested active cambial growth and higher susceptibility to damage (Wilcox et al. 1954, Hennessey et al. 1989, Smith et al. 1997).

Conclusion

Because these are unreplicated case studies, it is difficult to draw firm conclusions regarding the best system(s) to use to reduce wounding incidence and severity. Cost of implementation may reduce the incentive for using a system that reduces the incidence of wounding, especially in stands that are already marginally economic.

Wounding to residual trees in the experimental harvest units occurred because of several factors, only one of which was the harvesting technology utilized. Overall wounding could probably be reduced with silvicultural prescriptions calling for wider spacing between residuals and less uniform distribution of retention trees to mitigate problems associated with height/diameter ratios. When specific numbers of trees/ac are required, wider spacing could be achieved through some clumping of residuals rather than leaving all trees in a grid configuration (Smith et al. 1997). More research on how different silvicultural prescriptions alter wounding metrics and operational costs in dense, small-diameter stands would be beneficial.

Han and Kellogg (2000) recommend designating skid trails and skyline corridors prior to marking leave (crop) trees. Doing so might have resulted in more closely meeting the objective of retaining 100 crop trees/acre. Management objectives determine acceptable levels of decay in living trees. Management toward providing late-successional habitat will be more tolerant of wounds at risk to decay than management toward providing large trees for timber. However, management goals generally change more rapidly than the ability of stand development processes to achieve the conditions required to fulfill new objectives. Reduction of wound-induced decay in residual stands might be achieved through silvicultural prescriptions allowing for more lodgepole pine in the residual stand. The amount of pine retained may need to be balanced against the risk of creating optimal habitat for mountain pine beetles.

Season of harvest likely played a role in the damage sustained by residual trees in the steep stand units. It is likely that had harvesting occurred in late fall or winter after cambial development ceased, wounds would have been smaller or less severe. In particular, it would be of interest to compare size and severity of wounds incurred with the CTLF system during different seasons. While this system did not perform well with respect to percentage of residual trees sustaining moderate and severe wounds, it did result in the highest percentage of residual trees that had no damage whatsoever.

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Lake States Aspen Productivity Following Soil Compaction and Organic Matter Removal

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Abstract

Aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.) provides wood products, watershed protection, and wildlife habitat for numerous game and non-game species across the northern Great Lakes region. Sustaining the productivity of these ecosystems requires maintaining soil productivity. Management activities that decrease soil porosity or remove organic matter can reduce productivity. We determined effects of three levels of soil compaction and organic matter removal (OMR) on aspen regeneration and growth following winter harvest of aspen-dominated stands in northern Minnesota, western Upper Michigan, and northern lower Michigan. Compaction treatments were applied to increase surface soil bulk density by either zero, 15, or 30 percent. The OMR treatments were merchantable bole harvest (MBH); total tree harvest (TTH); and total woody vegetation, plus forest floor removal (FFR). Soil compaction tended to increase mean sucker diameter and height on the sand and decrease them on the fine textured soils. Compaction greatly reduced sucker density and growth on the most productive silt-loam soil, primarily due to late spring treatment. These results apply to planning of operational harvest of aspen-dominated stands throughout the northern Great Lakes region. Sucker density increased with level of OMR on all three sites. On the sand site, mean diameter, height, and biomass were greatest with MBH and decreased significantly with increasing OMR, indicating a potential decline in productivity with repeated total tree harvesting on sand soils.

Keywords: Sustaining productivity, harvest intensity, organic matter removal, soil compaction.

Introduction

Sustaining forest productivity requires maintaining soil productivity. Management activities that decrease soil porosity and/or remove organic matter have been associated with declines in site productivity (Agren 1986, Greacen and Sands 1980, Grier et al. 1989, Standish et al. 1988). As part of an international network of cooperative studies on long-term soil productivity (LTSP) (Powers et al. 1990, Tiarks et al. 1993), we are evaluating effects of soil compaction and organic matter removal (OMR) in the aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.) forest type across the northern Lake States region and in northeastern British Columbia (Kabzems 1996, Stone and Elioff 1998, Stone et al. 1999). The research is designed to determine how changes in soil porosity and organic matter content affect soil processes controlling forest productivity and sustainability, and to compare responses among major forest types and soil groups across the United States and Canada.

The rationale for these studies is: (1) harvesting equipment and practices affect soil properties; (2) soil properties control soil processes; (3) soil processes affect plant community composition and growth; and (4) these determine net primary production, ecosystem functions, and forest sustainability. The objectives are to monitor changes in soil properties following forest harvesting and the soil compaction and OMR treatments, and to measure responses by the forest regeneration and herbaceous vegetation. Fifth-year results from a pilot study with four treatments and two replications (Stone and Elioff 1998) and 4^{th}-year results of the complete study with nine treatments and three replications on sand soils were reported earlier (Stone et al. 1999). This paper summarizes aspen development after five growing seasons on sites in northern Minnesota, western Upper Michigan, and northeastern lower Michigan.

Table 1—General characteristics of the aspen Long-Term Soil Productivity (LTSP) sites in the Lake States

Installation Date	National Forest	Relative Productivity	General Soil Description	Approximate Site Index[a] (m)	(ft.)
1991	Marcell	Medium	Loamy sand/clay loam till at 110 cm; well drained	21	70
1992	Ottawa	Low	Deep, calcareous clay; moderately well drained	17-18	55-60
1993	Chippewa	High	Silt loam cap/clay loam till at 30 to 40 cm; well drained	23	75
1994	Huron	Medium to low	Deep, acid sands; excessively drained	19	62

[a] Aspen, age 50

Methods

Stand and Site Conditions

Four sites were selected to represent a range of soil conditions and aspen productivity across the northern Lake States region (table 1). The overstory of each stand was dominated by aspen but included a codominant component, or a subcanopy of more tolerant conifer and northern hardwood species. The pilot study is on the Marcell Experimental Forest (part of the Chippewa NF), and represents our medium site (Stone and Elioff 1998). The surface soils are loamy sand over clay loam till at about 110 cm; site index (age 50) for aspen is about 21 m (70 ft). The least productive site is on the Ottawa National Forest (NF) in western Upper Michigan. The study is on a glacial lake plain and the soils are moderately well-drained, calcareous, lacustrine clay; site index for aspen is 17 to 18 m (55 to 60 ft). White spruce (*Picea glauca* (Moench) Voss), balsam fir (*Abies balsamea* (L.) Mill.), and red maple made up about 35 percent of the preharvest basal area. The most productive site is on the Chippewa NF in north-central Minnesota. The study is located on the Guthrie till plain; the surface soils are silt loam, formed from a loess cap 30 to 40 cm deep, over clay loam till. Site index is about 23 m (75 ft); the associated species were predominantly red maple (*Acer rubrum* L.), basswood (*Tilia americana* L.), sugar maple (*A. saccharum* Marsh.), and eastern white pine (*Pinus strobus* L.). Our medium-to-low-quality site is on an outwash plain on the Huron NF in northeastern lower Michigan; the soils are deep, acid sands with a site index of about 19 m (62 ft). Both trembling and bigtooth aspen occur on this site. The predominant associated species were red maple, red oak, black cherry (*Prunus serotina* Ehrh.), and white pine.

Design and Treatment

Three levels of harvest intensity and OMR, and three levels of soil compaction were applied to 50×50 m (0.25 ha, 0.62 ac) plots in a complete 3×3 factorial design with three replications. The compaction treatments were designed to provide: (1) no additional compaction above that due to harvesting; (2) light, to increase bulk density of the surface 10 to 20 cm of soil by 15 percent; and (3) heavy, to increase bulk density of the surface soil by 30 percent. The levels of OMR were: (1) merchantable bole harvest (MBH) to a 10 cm (4 in.) top diameter; (2) total aboveground tree harvest (TTH); and (3) total woody vegetation harvest plus forest floor removal (FFR). The FFR treatment was included to represent those areas in skid trails and landings where most, or all of the forest floor materials, are removed during harvest. It also could provide an indication of productivity trends following repeated rotations of total tree harvesting. Tops from the MBH+compaction treatments were piled adjacent to the plots and replaced after the compaction treatments were completed. Four non-cut control plots were installed in the adjacent stands, for a total of 10 treatment combinations on each site. Prior to harvest, the plots were established to minimize variation in soil properties and all trees =10 cm (4 in.) diameter at breast height were measured and their location mapped.

Ottawa—The stand was harvested between January 13 and February 3, 1992. During logging, snow depths averaged 76 to 91 cm (30 to 36 in.) and the soils were not frozen. All merchantable stems were cut by using a Caterpillar model FB-227 feller-buncher and placed in bunches between the plots. The bunches were skidded to a landing with John Deere 648D, 740A, and Timberjack 450B grapple skidders. All skidder traffic was restricted to the areas between plots. The FFR treatment consisted of manually removing all coarse woody material and then removing the forest floor materials between April 21 and May 21 by prison work crews using fire rakes; the materials were piled outside of a 5- to 10-m-wide buffer zone surrounding each treatment plot. The compaction treatments were applied between May 6 and 21 by traversing the plots with a 20.9-Mg (23-ton) Hough model H-100 front-end loader, advancing one tire width each pass. Two passes at right angles provided the light treatment, and two passes with the bucket empty and two passes with the bucket filled with soil provided the heavy compaction.

Chippewa—The stands were harvested during January and February 1993. During November and December 1992, snowfall was somewhat greater than normal and mean monthly air temperatures were slightly above average. Thus, soil frost was discontinuous initially, and ranged from 5 to 10 cm (2 to 4 inches) when logging was completed. Snow depth increased from about 30 cm (12 in.) initially to 46 cm (18 in.) during the logging operation. On the non-compacted plots, the trees were felled with chainsaws and winched off the plots with a cable skidder. On all other plots, the stems were cut with a Case-Drott model 40 feller-buncher and placed outside the plot boundaries; skidders did not enter any of the plots. The FFR treatment consisted of manually removing all coarse woody material and then windrowing the forest floor materials by using a power-driven sidewalk sweeper with a revolving wire brush head; the materials were piled outside of the 5- to 10-m-wide buffer zone surrounding the treatment plots. The light compaction treatment consisted of a double pass, at right angles, across the plots with a model D-7 Caterpillar tractor, advancing one track width each pass. The heavy compaction treatment included the light treatment followed by a double pass with a Michigan model 75C front-end loader, advancing one tire width each pass.

Huron—The stands were harvested in late January 1994; the winter was colder than normal, with several days below -30°C (-22°F). During harvest, the surface 20 to 25 cm (8 to 10 in.) of soil was frozen and covered by 35 to 40 cm (14 to 16 in.) of snow. All merchantable stems were cut with a tracked Bobcat shear or a Hydro-Ax feller-buncher, and skidded using Caterpillar 518, and Timberjack 380B grapple skidders. In mid-April, the coarse woody debris and forest floor materials were removed by using the same methods as on the Chippewa, and piled outside the 5- to 10-m-wide buffer zone around each treatment plot. In late April, when the soil was at field capacity, the compaction treatments were applied by using a 9.5-Mg (10.5-ton) Hough model 60 front-end loader, advancing one tire width each pass. The light compaction treatment was accomplished with a single pass of the loader with a tire pressure of 172 kPa (25 psi). The heavy compaction treatment included the light treatment plus a second pass of the loader, at right angles, with the bucket filled with sand and tire pressures of 276 kPa (40 psi). This provided a total machine weight of about 12.7 Mg (14 tons).

Measurements and Analyses

On each site, all measurements and sampling were made within the interior 40×40-m area of each treatment plot. In late July to early August, the 5th-year aboveground herbaceous vegetation was collected from four 1.0-m^2 subplots per plot, dried at 75°C, and weighed. In September, after five growing seasons, the basal diameter of all woody stems (>15 cm height) was measured and recorded by 2-mm diameter classes on eight 5.0-m^2 subplots per plot. Mean height of aspen suckers in each diameter class was recorded to the nearest 5-cm class. Aboveground biomass was estimated by using allometric equations developed by Perala and Alban (1994).

For each site, all subplot data were composited and treatment effects were evaluated by analysis of variance of the plot-level means. First, the overall effects of compaction level, OMR, and compaction-OMR interactions were evaluated. Few of the

Table 2—Mean 5th- year sucker density (k ha^{-1}) by level of compaction

Compaction Level	National Forest Ottawa	Chippewa	Huron
None	19.7[a]	33.2c	20.5
Light	28.9	12.6b	26.8
Heavy	28.6	4.4a	25.4
ANOVA *p*	0.092	0.000	0.123

[a] Treatment means followed by the same letter, or without letters, do not differ significantly at the $p = 0.05$ level.

interactions were significant, so the effects of compaction were evaluated across OMR levels, and the effects of OMR were evaluated across compaction levels. Comparisons among means were made with the Least Significant Difference procedure at the 95 percent confidence level (Analytical Software 1998).

Results and Discussion

Soil Compaction

The objective of the compaction treatments was to increase bulk density of the surface soil by either 15 percent or 30 percent without damaging the root systems by rutting. This was accomplished successfully on the Marcell, Ottawa, and Huron sites. However, spring and early summer rainfall was higher than normal in 1993 and delayed study installation on the Chippewa. The frequent rainfall, and the desire to avoid rutting, caused numerous delays in application of the treatments. Thus, the suckers had begun to emerge by the time the soil had drained sufficiently to complete the compaction treatments, and many were broken by the machine traffic.

Stand density—Soil compaction increased mean sucker density on the clay and sand sites; however, the differences were not significant on the sand and only marginally significant ($p = 0.092$) on the clay (table 2). The compaction treatments also tended to increase first-year sucker density in the British Columbia study, but by the 4th year the differences by level of compaction were no longer significant (Kabzems 2000a). Presumably, these initial increases were due to minor root injury during compaction. Disturbance of aspen root systems and increased soil temperatures are known to stimulate sucker production (Peterson and Peterson 1992, Schier et al*.* 1985). Soil compaction significantly decreased sucker density on the Chippewa installation, primarily because of the late spring treatment. On this site, effects of the compaction treatments on reducing sucker density were dramatic and not unlike many operational logging jobs in the northern Great Lakes region (Bates et al*.* 1990, 1993).

Diameter—Soil compaction tended to decrease mean diameter of suckers on the fine-textured soils, but the differences were significant only on the Chippewa (table 3). The decreased growth on these sites most likely is due to a combination of direct and indirect effects (Greenway 1999). Sucker growth could be reduced directly by reduced soil aeration, and indirectly by the increased sucker density. In contrast, the compaction treatments tended to increase mean basal diameter on the Huron sands, despite the substantially greater stand density (table 2). On coarse-textured soils, low to moderate levels of compaction will convert a portion of the macropore space to micropores, thereby increasing the water-holding capacity of the soil, thus decreasing water stress in the regeneration (Powers and Fiddler 1997, Powers 1999). We emphasize that these experimental levels of compaction are well below those encountered on major skid trails and landings found on conventionally harvested sites (Stone et al*.* 1999). On those areas, we have measured substantial reductions in both sucker density and growth. Moreover, the effects are likely to persist for decades (Grigal 2000), a century (Sharrett 1998), or possibly longer (Curran 1999).

Height—As with diameter, the compaction treatments tended to decrease mean height of suckers on the fine-textured soils, but the differences were significant only on the Chippewa (table 4). Likewise, the decrease can be attributed to the combination of reduced soil aeration and increased sucker density. On the Huron sands, increased water-holding capacity of the soil and decreased water stress in the suckers would account for the small but consistent increases in sucker height with level of compaction. Both trembling and bigtooth occur on this site, but the differences in diameter and height were not significant, so they were analyzed together.

Table 3—Mean 5th-year sucker diameter (at 15 cm) by level of compaction

Compaction Level	National Forest Ottawa	Chippewa	Huron
None	11.1[a]	21.6 c	15.9
Light	9.5	13.7 b	16.7
Heavy	9.2	10.9 a	17.0
ANOVA *p*	0.168	0.000	0.519

[a] Treatment means followed by the same letter, or without letters, do not differ significantly at the p = 0.05 level.

Table 4—Mean 5th-year sucker height (cm) by level of compaction

Compaction Level	National Forest Ottawa	Chippewa	Huron
None	134[a]	301c	218
Light	112	171b	223
Heavy	103	123a	238
ANOVA *p*	0.111	0.000	0.427

[a] Treatment means followed by the same letter, or without letters, do not differ significantly at the p = 0.05 level.

Biomass—The compaction treatments produced little difference in dry weight of aspen on the clay soil, but dramatic differences on the silt loam, primarily due to the delayed application of the treatments (table 5). On these clay sites, rutting has been more detrimental to aspen regeneration and growth than has compaction (Stone and Elioff 2000). On the sand site, compaction resulted in slight, but non-significant increases in aspen biomass. Again, the differences among sites were far greater than those of the compaction treatments. Comparison of the non-compacted plots, for example, illustrates a 10-fold difference in potential aspen productivity between the least productive clay soil and the most productive silt loam. Likewise, despite the relatively small (<5 feet) difference in aspen site index, 5th-year aspen biomass on the sand was four times that on the clay site.

Table 5—Mean 5th-year sucker dry weight (kg ha^{-1}) by level of compaction

Compaction Level	National Forest Ottawa	Chippewa	Huron
None	1,380[a]	13,260 b	4,630
Light	1,410	2,290 a	5,490
Heavy	1,260	330 a	5,870
ANOVA *p*	0.941	0.000	0.267

[a] Treatment means followed by the same letter, or without letters, do not differ significantly at the p = 0.05 level.

Table 6—Mean 5th -year sucker density (k ha^{-1}) by level of organic matter removal

	National Forest		
Treatment[a]	Ottawa	Chippewa	Huron
MBH	20.2[b]	10.0 a	21.9
TTH	22.7	17.3 ab	24.9
FFR	30.8	22.9 b	25.9
ANOVA *p*	0.102	0.007	0.425

[a] MBH, merchantable bole harvest (10 cm top); TTH, total tree harvest; FFR, total vegetation plus forest floor removal.

[b] Treatment means followed by the same letter, or without letters, do not differ significantly at the p = 0.05 level.

Organic Matter Removal

Stand density—Winter harvesting by MBH produced abundant aspen regeneration on all three sites. After five growing seasons, sucker density ranged from 10,000 (10 k) to 22 k ha^{-1} (table 6). For perspective, with uniform distribution, the 10 k stems ha^{-1} on the Chippewa is equal to a 5-year-old sucker on every m^2 of the site. The TTH and FFR treatments further increased sucker density, frequently at the expense of the associated commercial species. The differences were marginally significant (p = 0.102) on the clay soils on the Ottawa, highly significant on the silt loam on the Chippewa, and non-significant on the sand soils on the Huron. Graham et al. (1963) considered a 1st-year sucker density of 15 k ha^{-1} (6 k ac^{-1}) as minimal stocking and 30 k ha^{-1} (12 k ac^{-1}) as optimal. The FFR treatment resulted in a 1st-year sucker density of >260 k ha^{-1} on the loamy sand site in

Table 7—Mean 5th-year sucker diameter (at 15 cm) by level of organic matter removal

	National Forest		
Treatment[a]	Ottawa	Chippewa	Huron
MBH	10.0 b[b]	15.5 b	19.1 b
TTH	11.5 b	17.9 c	15.4 a
FFR	8.5 a	12.8 a	15.0 a
ANOVA *p*	0.017	0.000	0.001

[a] MBH, merchantable bole harvest (10 cm top); TTH, total tree harvest; FFR, total vegetation plus forest floor removal.

[b] Treatment means followed by the same letter, or without letters, do not differ significantly at the $p = 0.05$ level.

Table 8—Mean 5th-year sucker height (cm) by level of organic matter removal

	National Forest		
Treatment[a]	Ottawa	Chippewa	Huron
MBH	104 a[b]	195 a	263 b
TTH	138 b	234 b	214 a
FFR	105 a	167 a	201 a
ANOVA *p*	0.036	0.001	0.002

[a] MBH, merchantable bole harvest (10 cm top); TTH, total tree harvest; FFR, total vegetation plus forest floor removal.

[b] Treatment means followed by the same letter, or without letters, do not differ significantly at the $p = 0.05$ level.

northern Minnesota (Alban et al*.* 1994), and about 220 k ha^{-1} in British Columbia (Kabzems 1996), most likely due to increased soil temperatures and removal of competing vegetation (Kabzems 2000b). By the 4th year, sucker density had declined to about 55 k ha^{-1} in British Columbia (Kabzems 2000a), and by the 5th year, to about 40 k ha^{-1} in Minnesota (Stone and Elioff 1998).

Diameter—Mean basal diameter (at 15 cm) tended to be greater with TTH on the fine-textured soils, although the difference between MBH and TTH was not significant on the Ottawa clay (table 7). The aspen on the Huron sands responded differently than those on the other sites. Mean diameter was significantly greater with the MBH treatment and declined with increasing level of OMR, as indicated by the 4th-year data (Stone et al. 1999). In fact, the smallest mean diameters occurred with the FFR treatment on all sites, indicating a potential problem of sustaining productivity with repeated total tree harvesting, particularly on sand soils.

Table 9—Mean 5th -year sucker dry weight (kg ha^{-1}) by level of organic matter removal

	National Forest		
Treatment[a]	Ottawa	Chippewa	Huron
MBH	980[b]	4,950	6,200 b
TTH	1,610	6,710	5,140 ab
FFR	1,300	4,220	4,650 a
ANOVA *p*	0.376	0.230	0.082

[a] MBH, merchantable bole harvest (10 cm top); TTH, total tree harvest; FFR, total vegetation plus forest floor removal.

[b] Treatment means followed by the same letter, or without letters, do not differ significantly at the $p = 0.05$ level.

Height—On the fine-textured soils, mean sucker height on the TTH plots was significantly greater than the MBH plots (table 8). As with diameter, mean sucker height on the sand site was significantly greater in the MBH treatment and declined with increasing level of OMR. This raises the question of whether the additional biomass removed by total tree harvesting is worth the cost in soil resources—nutrients, organic matter, and water-holding capacity (Stone et al. 1999). On both the Chippewa and Huron sites, the lowest mean height was in the FFR treatment, partially due to high sucker densities and the resulting intra-clonal competition. Stone et al. (2001) found that retaining 18 to 38 dominant aspen ha^{-1} (7 to 15 ac^{-1}) reduced first-year sucker density by about 40 percent and increased their basal diameter and height growth by about 30 percent.

Biomass—Dry weight production per unit area integrates sucker density, diameter, and height in a single value. On the fine-textured soils, aspen dry weight was non-significantly greater with TTH (table 9). On these sites, the TTH treatment produced intermediate sucker densities with greater mean diameter, height, and dry weight, while total woody vegetation plus FFR produced greater numbers of suckers, but with lower mean diameter, height, and dry weight. On the sand site, MBH produced the lowest number of suckers with significantly greater mean diameter and height and dry weight. The differences among sites were much greater than the treatment effects within sites. For example, mean (all treatments) 5th-year aspen dry weight on both the sand, and the silt loam site was greater than four times that of the clay.

Summary and Management Implications

Soil Compaction

Responses to soil compaction differed greatly among sites. Compaction prior to sucker emergence tended to increase sucker density, but after they had emerged, machine traffic drastically reduced sucker density, diameter and height growth, and biomass production; the differences were highly significant after five years. Compaction on the clay site produced small, but non-significant reductions in sucker diameter and height. On these kinds of soils, rutting has shown much greater impacts on aspen regeneration and growth than has compaction. In contrast, the levels of compaction applied on the sand site produced small, but non-significant increases in sucker diameter, height, and biomass. However, the more severe compaction that routinely occurs on major skid trails and landings, severely reduces both sucker density and growth. Moreover, the effects are likely to persist for decades to a century or longer. Thorough pre-harvest planning is required to designate these areas—and to minimize the area affected—in order to sustain the future productivity of these sites.

Organic Matter Removal

Harvest intensity and OMR significantly affected one or more of the regeneration parameters on each site, and the responses differed greatly by site. These 5th-year data illustrate much larger differences in productivity between sites than might be expected from site index data. Increasing levels of OMR increased sucker density on all sites. On the fine-textured soils, 5th-year sucker diameter and height were greater in the TTH treatment. On the sand soil, both the TTH and FFR treatments significantly reduced mean diameter and height. In fact, the FFR treatment generally showed the smallest diameter and height on all three sites. Treatment differences in 5th-year aspen biomass were not significant on the fine-textured soils, but declined significantly with increasing level of organic matter removal on the sand. This raises the question of whether the additional biomass gained by total tree harvesting is worth the cost in soil resources—nutrients, organic matter, and water-holding capacity. The question also needs to be addressed in other forest types on sand soils, such as jack pine (*Pinus banksiana* Lamb.) in the upper Great Lakes region.

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Reserve Tree Method Produces Abundant Aspen Regeneration and Increases Early Growth

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Abstract

A reserve tree method (RTM) of harvesting was installed in six 65- to 75-year-old aspen-dominated stands to determine if retaining 10 to 15 dominant aspen/acre would decrease sucker density to facilitate restoration of a conifer component. After the first full growing season following harvest, 96 percent of the harvested areas were stocked; sucker density averaged 27,000 (27 k)/acre vs. 38.2 k/acre on a clearcut control, 41 percent less. Basal diameter of dominant suckers averaged 0.45 in., 28 percent greater than the control, and mean height was 60 in., 33 percent greater. The control site had 3.1 k stems/acre of associated commercial species vs. 5.8 k on the RTM sites, an 87 percent difference. Four of the six stands have been planted; first-year survival ranged from 88 percent to near 100 percent. The RTM shows promise for reducing sucker density, increasing their early growth, maintaining species diversity, and providing abundant regeneration of commercial species on a high proportion of the areas harvested. Early results indicate that the RTM can facilitate restoring a component of native conifer species in these ecosystems.

Keywords: Partial cutting, aspen management, conifer establishment, ecosystem restoration, silviculture.

Introduction

Throughout the northern Great Lakes region, most of the forest types are far different from those of a century ago. Depending on location, the pre-settlement species growing on well-drained, medium- to fine-textured soils of northern Minnesota, Wisconsin, and Michigan were predominantly shade-tolerant conifers including white pine (see Appendix for scientific names), eastern hemlock, and northern white-cedar; and tolerant hardwoods dominated by sugar maple, red maple, yellow birch, and basswood (Albert 1995, Coffman et al. 1983, Kotar et al. 1988). White spruce, balsam fir, white ash, and American elm were common associates. Without stand-replacing disturbances (primarily fires), the aspens (trembling and bigtooth) occurred as minor associates (Braun 1950).

During the late 19th century, exploitative logging, initially of conifer species, created conditions for slash-fueled wildfires that swept over large areas of the region, destroyed advance regeneration of the former species, and resulted in “brushlands” comprising predominantly aspen suckers and stump sprouts of associated hardwood species (Graham et al. 1963). Effective fire control beginning in the 1920s permitted these stands to develop into the present-day second-growth forests dominated by aspen.

Throughout much of the region, the abundance of aspen reduces the landscape diversity associated with more natural, conifer- and northern hardwood-dominated landscapes. Resource managers are seeking silvicultural alternatives to conventional clearcutting, and ecologically sound and cost-effective means to reestablish a component of native conifer species on some of these sites. Reestablishing a component of native conifers in these ecosystems is viewed as a step toward ecosystem restoration, so that stand-level species composition is somewhat closer to that prior to the logging and wildfires of a century ago. We report data on aspen regeneration the first full growing season after harvesting six stands using a reserve tree method (RTM) on the Superior National Forest in northern Minnesota.

Traditional Management

The aspens are shade-intolerant, rapidly growing, short-lived species that regenerate by root suckers following removal of the parent stand (Perala and Russell 1983). Suckers exhibit more rapid early height growth than seedlings or sprouts of associated species, so they typically form the dominant overstory during the early and mid-stages of stand development. On medium- and fine-textured soils, pure aspen stands are rare; most include a component of the more tolerant, longer-lived conifer and northern hardwood species typical of these sites in the absence of disturbance. On most commercial forest lands in the Lake States, aspen is managed for wood products or for a combination of fiber and wildlife habitat. Where wood production is a primary objective, the stands normally are harvested by a silvicultural (complete) clearcut of all species and the aspen is regenerated from root suckers. Presumably, the procedure can be repeated and the aspen maintained indefinitely (Perala and Russell 1983), provided the root systems are not damaged by severe soil disturbance during logging (Bates et al*.* 1989, Stone and Elioff 2000).

Thus, in the Great Lakes region, aspen management has been viewed rather simplistically—clearcut a mature stand, let suckers regenerate the site, wait, and then clearcut again when the stand matures—no site preparation, no cleaning, no thinning, no pest control, little thinking (Cleland et al. 2001). However, clearcutting at frequent (40- to 60-year) intervals to maintain single species stands in an early successional state counters several of the objectives of ecosystem management (e.g., Irland 1994) by interrupting natural processes and "resetting the successional clock" (Mladenoff and Pastor 1993). Many stakeholders object to clearcutting and to single species management because of visual quality and aesthetic values. Extensive loss of the conifer component from much of the forest area of the Lake States region has caused concerns about ecosystem structure and function and the diversity and quality of wildlife habitat (Green 1995, Mladenoff and Pastor 1993). Ruark (1990) proposed a reserve shelterwood system to convert 30- to 35-year-old, even-aged aspen stands to two-aged stands, and to allocate limited site resources (sunlight, nutrients, water, and growing space) to fewer stems per unit area. The method had not been tested or validated, but offers several potential advantages at different spatial scales (Stone and Strand 1997).

A major objective of ecosystem management is maintenance or enhancement of species diversity (Hunter 1990, Kaufmann et al. 1994). Many resource managers in the northern Great Lakes region are seeking ways to reestablish a component of native conifer species. Establishing these species on suitable sites would be a first step toward restoring stand-level species diversity. Moreover, total yields of mixed-species stands may well exceed those of aspen alone (Man and Lieffers 1999, Navratil et al. 1994, Perala 1977). Natural regeneration of most conifers on these sites usually is limited by lack of available seed sources. Development of planted seedlings frequently is hampered by competition from dense stands of aspen suckers, shade-tolerant shrubs such as beaked hazel and mountain maple, and herbaceous species.

As an alternative to conventional clearcutting, and to facilitate reestablishing a component of native conifer species on the Mighty Duck timber sale, the LaCroix District on the Superior National Forest decided to take an "adaptive management" approach and try an RTM to reduce the density of aspen suckers, and thus, increase survival and growth of planted conifers. The aspen was 65 to 75 years old, mature or overmature, and the stands were losing net volume from mortality due to stem decay. The residual aspen overstory will not be salvaged.

Methods

In each stand, 7 to 15 dominant or codominant aspen stems per acre were selected at a uniform spacing of 50 to 80 feet and marked with paint spots at the stump and at 6 to 8 ft. on the stem. Prior to harvest, we established transects at 1.5 chain intervals across each stand, marked sample points every 1.0 chain along each line, measured the diameter of all living trees >4 in. density at breast height (dbh) with a 10-factor prism, and recorded all saplings and shrubs >6 in. height on a circular 5-m^2 (54 ft.^{2}) plot at each sample point. Stand 9 included an intermittent drainage that separated the RTM portion from a control portion

Table 1—Characteristics of reserve trees on the Mighty Duck sale

Site	DBH Number	Height	BA	Density	
		Inches	*feet*	*square feet/acre*	*number/acre*
1[a]	100	15.0	88	9.4	7.3
7[a]	150	11.5	66	12.2	15.0
9	108	13.5	80	10.7	10.0
11	150	10.6	56	10.5	15.3
13	129	12.2	67	11.8	12.8
17	171	15.2	93	12.2	9.3
Mean	135	13.0	75	11.1	11.6

[a] Summer logged

that received a silvicultural clearcut. Stands 1 and 7 were harvested during the summer (July 1997 and August 1998) and the other four during the winter. During September, after the first full growing season following harvest, we recorded the dbh and height of each reserve tree within 1.0 chain west or south of the transect lines. On each 5-m^2 regeneration plot, we recorded the number of stems of all commercial species >6 in. height, the basal diameter (at 6 inches), and height of the dominant aspen sucker on each. Each regeneration plot was considered stocked if it included one (800/acre) or more stems of aspen or other commercial species. The data were summarized and means calculated for each site.

Results and Discussion

The density of reserve trees ranged from 7.3 to 15.3/acre and averaged 11.6/acre on the six sites (table 1). Site 1 was the first stand marked and fell below the desired 10 to 15 trees/acre. However, as the markers gained experience, their judgement of spacing distance improved, and density on the other five sites was close to the objective. Except for the first stand, the residual basal area was consistently between 10.5 and 12.2 ft^2/acre, indicating that markers can produce uniform results with relatively little training and experience. Except for site 11, the dbh and height data indicate better-than-average site quality. However, the regeneration data (table 2) suggest that this stand may have been younger than the others.

After the first full growing season following harvest, sucker density ranged from 18,300 (18.3 k)/acre to 33.4 k/acre and averaged 27.0 k/acre on the six RTM sites (table 2). Interestingly, the highest density occurred on a summer-logged site (1), and the lowest on a winter-logged site (13). However, the relatively low sucker density on site 13 most likely is because 40 percent of the initial basal area consisted of associated species, predominantly paper birch and red maple. Thus, in these areas there would be few, if any, aspen roots present to produce suckers.

During the public comment period on the environmental assessment of the timber sale, there were concerns that the RTM might severely reduce sucker density and growth. These data indicate clearly that this is not a problem. Graham et al. (1963) considered a first-year sucker density of 6 k/acre as minimum stocking and 12 k well-distributed suckers/acre as optimal; using these criteria, all six of the sites are more than fully stocked. A mean basal diameter of 0.45 inches and height of 60 inches is excellent first-year growth. Moreover, the greater diameter and height of suckers on the RTM sites suggest that carbohydrate and nutrient reserves in the parent root systems are, indeed, channeled to fewer suckers, thereby increasing their early growth as postulated by Ruark (1990). Site 1 was logged during July 1997 and planted with container-grown white pine in May 1998; first-year survival was near 100 percent.

Table 2—First-year regeneration on the Mighty Duck sale.

Site	No. Plots	Aspen Diam.	Aspen Ht.	Aspen Density	ACS[a] Density	Total Density	Percent Stocked
		– – – Inches – – –		*– – Ten thousands per acre – –*			*Percent*
1[b]	138	—[c]	59	33.4	5.0	38.4	99.3
7[b]	101	0.38	46	21.8	5.5	27.3	90.1
9	109	0.40	49	31.4	5.0	36.4	95.4
11	98	0.56	76	29.7	7.5	37.2	99.0
13	102	0.37	50	18.3	7.4	25.7	95.1
17	187	0.58	80	27.4	4.4	31.8	95.7
Mean	122	0.45	60	27.0	5.8	32.8	95.8
Control	43	0.35	45	38.2	3.1	41.3	97.7

[a] Associated commercial species

[b] Summer logged

[c] Not measured

An objective of ecosystem management is conservation or enhancement of species diversity (Hunter 1990, Kaufmann et al. 1994). Dense stands of aspen suckers and their rapid early height growth place the seedlings and sprouts of associated species at a competitive disadvantage. The nearly twofold difference in density of associated species on the RTM sites (table 2) suggests that reserving a portion of the overstory contributes, either directly or indirectly, e.g., less machine traffic, to maintaining stand-level species diversity. While this is a limited sample size, we have noted similar trends in other studies (unpublished data on file).

Each of these stands was commercially harvested using conventional logging equipment, i.e., mechanical fellers and grapple skidders. Except for the second summer-logged site (7), >95 percent of the regeneration plots were stocked with one or more stems of aspen or associated commercial species (table 2). In related studies designed to monitor harvesting effects on site disturbance and regeneration, 11 percent to 38 percent of sites were occupied by roads, skid trails, landings, or other heavily disturbed areas that remain nonstocked for several years following harvest (Stone and Elioff 2000). A significant difference between the contract for the Mighty Duck sale and other typical national forest timber sales was the inclusion of a clause specifying a $75 penalty for damage to each reserve tree. The damage clause was highly effective; except for an occasional broken live limb, we noted little logging damage to reserve trees. Operator awareness is critical to protecting advance regeneration (Navratil et al. 1994). Enhanced operator awareness also may have contributed to the relatively low amount of rutting and other severe soil disturbance, and in turn, to the high proportion of the areas stocked with commercial species. Use of reserve tree, or other contract modifications, to increase operator awareness of site disturbance and silvicultural objectives merits serious consideration.

Summary and Management Implications

Reserving 7 to 15 dominant aspen/acre in six commercially harvested stands resulted in: (1) little logging damage to the reserve trees; (2) regeneration of aspen and associated commercial species on 96 percent of the area; (3) first-year sucker density of 27.0 k/acre on the RTM sites vs. 38.2 k/acre on the clearcut control; (4) mean sucker diameter of 0.45 inches and height of 60 inches; and (5) 5.8 k stems/acre of associated commercial species vs. 3.1 k on the control site. Of the four stands that have been planted, first-year survival ranged from 88 percent to near 100 percent. The RTM shows promise for reducing sucker density, increasing their early growth, maintaining species diversity, and providing abundant regeneration of commercial species on a high proportion of the areas harvested. These early results indicate that the RTM can provide stand conditions that are favorable for restoring a component of native conifer species in these ecosystems.

Application

From a landscape perspective, two-storied stands comprising a mixture of species are aesthetically more appealing to many people than clearcuts and single species management. Maintaining partial stocking of the site can be less disruptive to normal hydrologic (evapotranspiration) and nutrient cycling processes; this is a critical factor on some sites (Stone and Elioff 2000). Two-storied, mixed-species stands provide structural diversity that benefits several wildlife species. The portion of the timber volume retained will reduce the sale volume per unit area, so the Allowable Sale Quantity can be distributed over a larger area. This will accelerate development of a more balanced age class distribution and reduce the eminent breakup of overmature stands. From a silvicultural and forest health viewpoint, this is especially important to those districts that are losing net volume from mortality due to stem decay.

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Appendix

Common and Scientific Names of Trees and Shrubs

Balsam fir (*Abies balsamea* (L.) Mill.)

Red maple (*Acer rubrum* L.)

Sugar maple (*Acer saccharum* Marsh.)

Yellow birch (*Betula alleghaniensis* Britt.)

Paper birch (*Betula papyrifera* Marsh.)

White ash (*Fraxinus americana* L.)

Black ash (*Fraxinus nigra* Marsh.)

White spruce (*Picea glauca* (Moench) Voss)

Eastern white pine (*Pinus strobus* L.)

Bigtooth aspen (*Populus grandidentata* Michx.)

Trembling aspen (*Populus tremuloides* Michx.)

Northern white-cedar (*Thuja occidentalis* L.)

Basswood (*Tilia americana* L.)

Eastern hemlock (*Tsuga canadensis* (L.) Carr.)

American elm (*Ulmus americana* L.)

Mountain maple (*Acer spicatum* Lam.)

Beaked hazel (*Corylus cornuta* Marsh.)

Understory Vegetation Development Following Commercial Thinning in Southeast Alaska: Preliminary Results from the Second-Growth Management Area Demonstration Project

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Abstract

Five commercial thinning demonstration sites in southeast Alaska were treated in 1984-85 to evaluate commercial thinning treatments that could enhance the development of understory vegetation. The effects of these treatments upon the availability and quality of Sitka black-tailed deer forage were also evaluated. The five commercial thinning sites were re-assessed in 1998. The strip and strip + individual tree selection (ITS) treatments had the highest total biomass, 2,291 pounds per acre and 2,138 pounds per acre, respectively. Most of the biomass of these two treatments consisted of conifers. The ITS treatment had 1,357 pounds of total biomass per acre, of which 782 pounds per acre were of shrub/fern/forbs, which had more nutritional value for deer. The ITS treatment yielded better forage resources for deer (capacity for "deer days") than did any other treatment or the untreated control. Results from this study show that thinning treatments can improve deer forage availability when compared to no thinning treatment and that individual tree selection thinning can provide summer habitat for deer similar to the values provided by old-growth forest.

Keywords: Thinning, active stand management, individual tree selection, strip thinning, Sitka black-tailed deer, deer forage.

Introduction

Replacement of old-growth forest with even-aged young-growth is a major management issue for wildlife resources in Southeast Alaska. Several economically and socially important species such as the Sitka black-tailed deer are heavily dependent upon old-growth forests for sustenance and cover. Other species such as the Alexander Archipelago wolf, prey upon Sitka black-tailed deer and, thus, are indirectly dependent upon old-growth forests. Forest managers are seeking answers as to how well these species might adapt to younger forests and how could active stand management of young-growth stands bring about the desirable habitat features of mature and old-growth forests.

The natural southeast Alaska forest environment is characterized by a high-frequency, low-magnitude disturbance regime (Brady and Hanley 1984). The process of individual trees or small groups of trees dying or being blown down by wind is more or less a continuous process (Harris 1989). The old-growth forest is a succession of canopy gaps in space and time. With the forest floor light environment continuously shifting, no one species or group of species can gain a competitive advantage over others and shade them out. This equilibrium more or less continues until some extensive canopy disturbance such as windthrow or clearcut harvesting occurs.

New stand development after a major disturbance such as clearcutting follows a general pattern. A new cohort of advance regeneration and newly germinated western hemlock and Sitka spruce (>4000 trees/acre) reoccupy the disturbed site (Oliver 1981; Alaback 1982a; Deal et al. 1991). Following clearcutting, residual shrubs also respond with a rapid growth increase that peaks in cover (Robuck 1975) and biomass (Alaback 1980) between 15 to 25 years. Conifers begin to overtop shrubs by 8 to 10 years and crown closure may be complete by 25 years (Harris and Farr 1974). During this stage of stem exclusion, the decline of understory vascular plants is rapid, and their elimination occurs in 25-35 years (Alaback 1980). Continued suppression of understory vegetation and tree regeneration may last for up to 100 years with understory vegetation not becoming well developed until stands are 120-150 years old (Alaback 1982b, 1984; Tappeiner and Alaback 1989).

The lack of light is probably the most important factor limiting understory growth (Alaback 1980). Light reaching the forest floor of a closed-canopy conifer forest, even on a clear day, is but a small fraction (1,000 luxes) of levels (50,000 luxes or more) that fall in open areas (Klein 1979). It may require 250 years or more for stands to achieve old-growth overstory characteristics of widely spaced trees and complex multi-layered canopies that allow light of variable intensity to reach the forest floor (Alaback 1984). These characteristics promote the development of an understory shrub and herb layer of oval-leaf blueberry, red huckleberry, bunchberry, fern-leaf goldthread, five-leaf bramble, foamflower, skunk cabbage, and shield fern, all of which are key plant species for deer forage.

Precommercial thinning may delay the onset of the stem exclusion stage and loss of understory for a brief period if the thinning is performed when understory plants are well established. However, aggressive understory conifers will outgrow the other species and shade them out, or the overstory canopy will close and shade out the understory (Deal and Farr 1993).

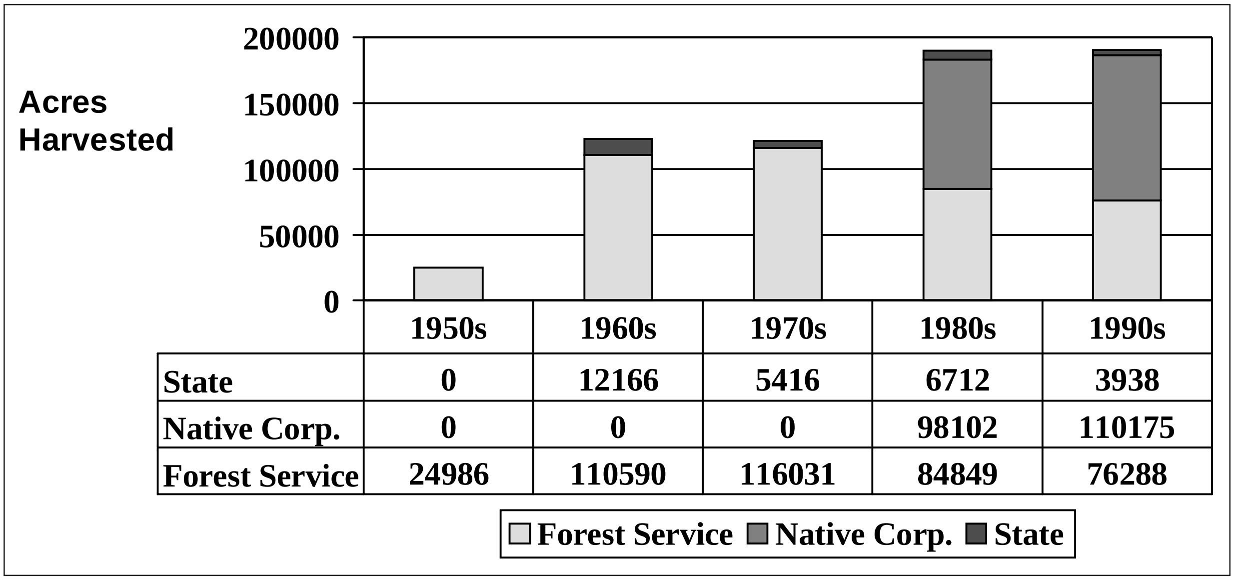
Prior to the 1950s, timber harvest practices in southeast Alaska consisted mostly of selective cutting of individual or small groups of trees to supply wood products for mining, fish canneries, and lumber for local southeast Alaska communities. Logging was mostly confined to easily accessible areas along the shoreline and lower river valleys. Harvested areas were generally less than 124 acres (Deal 1999).

The scale of timber harvest increased significantly in the 1950s with the establishment of long-term timber sale contracts on the Tongass National Forest. These 50-year contracts called for the harvest of over 13 billion board feet (USDA FS 1979) and construction of associated pulp mills in Ketchikan and Sitka. The objectives of these contracts were to provide a sound economic base in southeast Alaska, provide year-round employment, and replace a portion of the highly defective old growth with vigorous young growth to increase the productivity of the forest for wood fiber.

The scale of timber harvest in southeast Alaska was further increased through passage of the Alaska Native Claims Settlement Act in 1971. This Act authorized the transfer of about 44 million acres throughout the State of Alaska from Federal management to private ownership. Native regional and village corporations were given the opportunity to select land holdings from National Forest System lands. Of the total 550,000 acres the Native corporations selected from the Tongass National Forest, 460,000 acres are estimated to be productive forestland. A primary objective of these Native corporations was to provide an economic return to their shareholders. Many Native corporations harvested their forestlands to help meet their objectives.

As of 2000, slightly over 654,000 acres in southeast Alaska have been harvested: 416,400 acres on National Forest lands, 210,000 acres on Native corporation lands, and 28,000 acres on State of Alaska lands; all primarily using the clearcut method (fig. 1). Clearcutting is well suited to the timber species and conditions found in southeast Alaska. Western hemlock and Sitka spruce's thin bark makes them susceptible to logging damage and subsequent wound infection by decay fungi. Their shallow roots (due to shallow soils) make standing residual trees susceptible to windthrow. The risk of windthrow increases when partial cutting opens up stands. Clearcutting disturbs less area for a given amount of timber volume than does partial cutting. Compared to other harvesting methods, clearcutting is the most economical method (Harris and Farr 1974).

To address the question of how could active stand management of young-growth stands bring about the desirable habitat features of mature and old-growth forests, an Alaska Region Silvicultural Development Group was established in 1982. The objective of this group was to "…develop, implement, monitor, and demonstrate a program to monitor second-growth stands of hemlock and spruce forests on the Tongass National Forest to increase



	1950s	1960s	1970s	1980s	1990s
State	0	12166	5416	6712	3938
Native Corp.	0	0	0	98102	110175
Forest Service	24986	110590	116031	84849	76288

Figure 1–Acres harvested by decade and by ownership in southeast Alaska, 1950-2000.

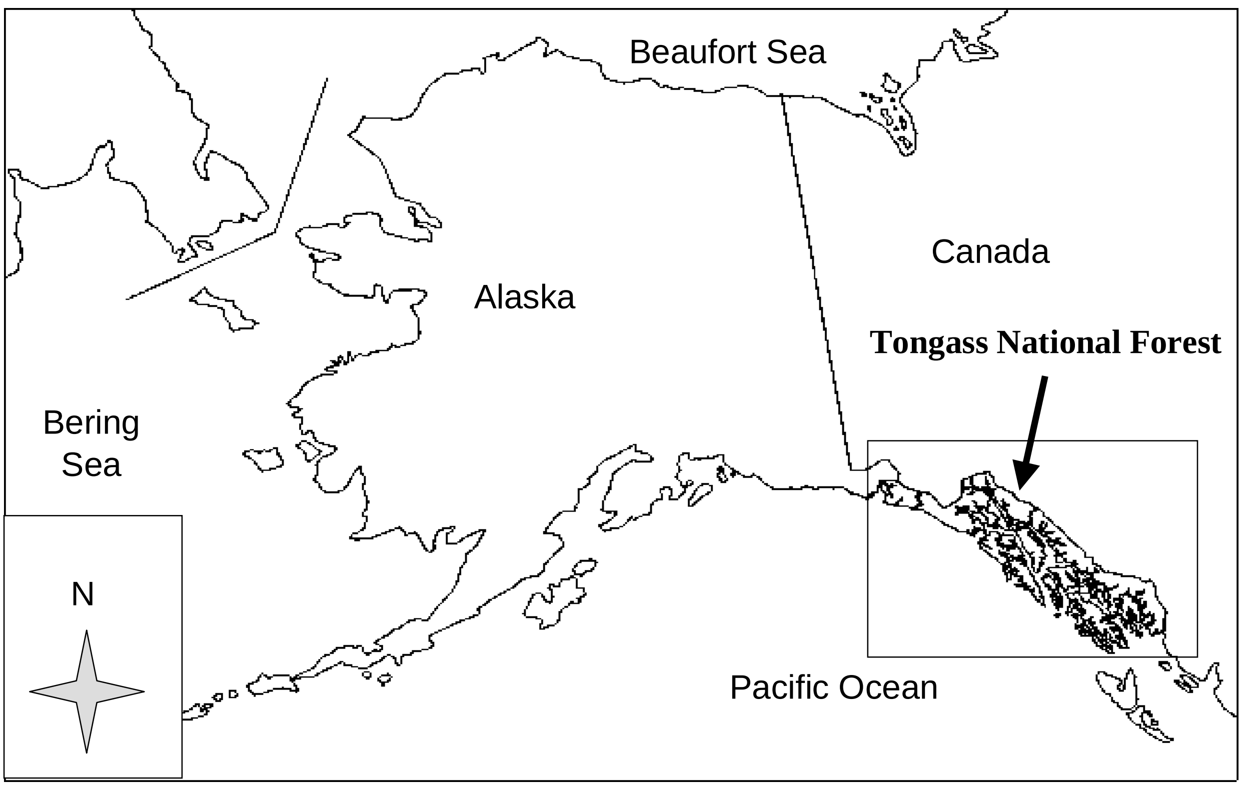


Figure 2–Vicinity map, second-growth management demonstration area .

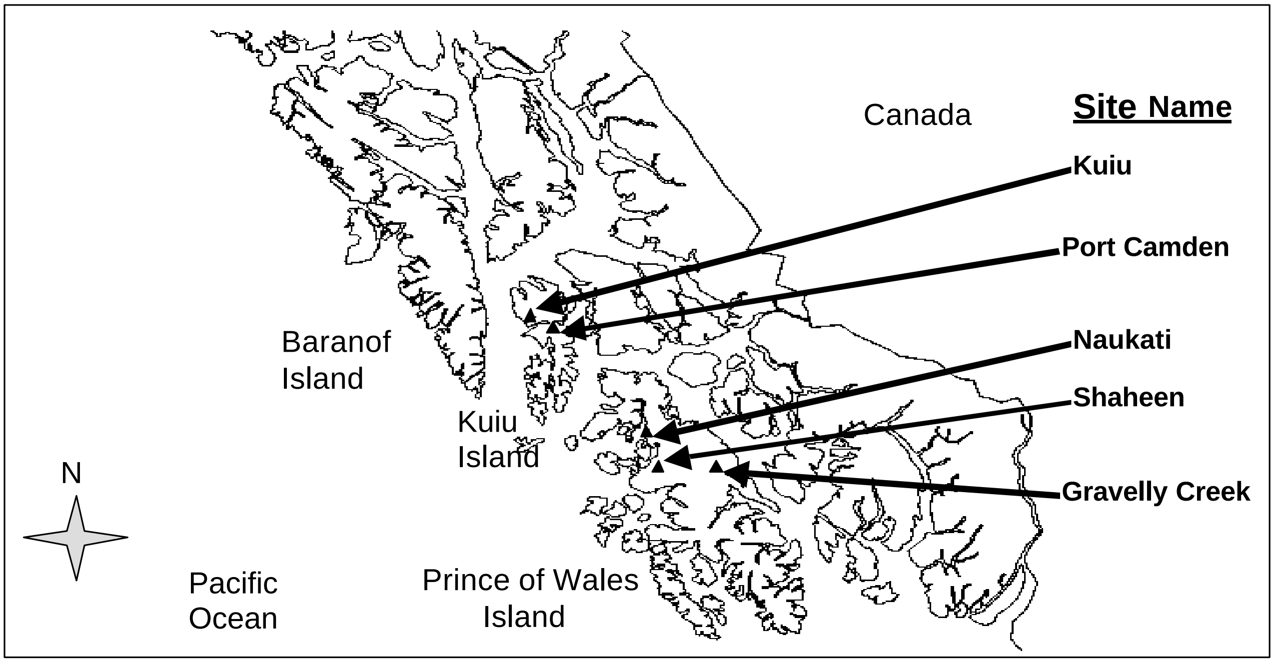


Figure 3–Location map, second-growth management demonstration area.

timber production and improve wildlife habitat capability." Emphasis was placed on implementing commercial and precommercial thinning projects to test their value for wildlife habitat improvement and timber production. The precommercial thinning projects were later abandoned because their remoteness caused logistical problems in monitoring, and the Forestry Science Laboratory was conducting other studies that were intended to address the values of precommercial thinning.

To achieve the above objective, the Second-growth Management Area Demonstration Project was developed. The purpose of the project was two-fold: to determine the effects of various commercial thinning treatments on understory diversity and abundance and to assess the effects of these treatments on deer forage availability. Five commercial thinning sites on the Tongass National Forest were chosen: three on Prince of Wales Island (POW) and two on Kuiu Island (figs. 2 and 3). Because the objectives of the study were to demonstrate the effects of different commercial thinning treatments on understory development for deer habitat, all sites were located in high-value deer winter range. All five sites were clearcut between 1890 and 1942 and commercially thinned in 1984 and 1985. Thinning treatments were: ITS—individual tree selection, trees thinned to 20- to 25-foot spacing (four sites); strip + ITS—combination of 30-foot wide cut strips alternated with 20- to 25-foot wide strips that were thinned to 20- to 25-foot spacing (three sites), and strip—alternating 20-foot cut strips and 20-foot no-cut strips (two sites) (fig. 4). One unthinned control was also established at each of the five sites.

Table 1 displays the site name, year harvested, year thinned, and treatment applied. Because commercial thinning was new to southeast Alaska, all of the falling and yarding was performed through a service contract to maintain better quality control over the logging operation.

Methods

Aboveground measures of biomass for all vascular species were obtained within 1.0-m^2 quadrats along transect lines established within each stand. Spacing of quadrats varied with the size and shape of each stand, but quadrats were spaced to ensure a uniform sampling of the entire stand. Twenty quadrats were used for herbs (forbs, ferns, graminoids), and 30 quadrats were used for shrubs and conifer seedlings. All aboveground biomass was harvested and weighed (fresh weight) by species within each quadrat. For each shrub species within each quadrat, a subsample of three stems (cut at ground level) was separated into leaves

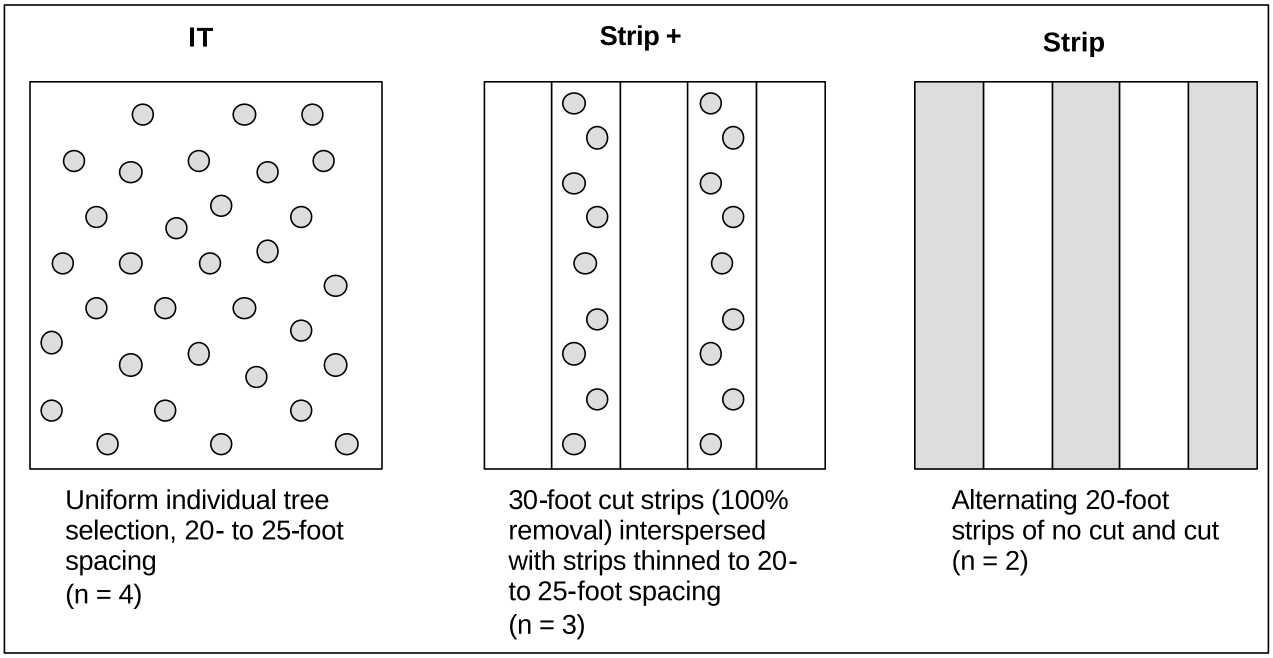


Figure 4–Schematic drawings of treatments.

Table 1—Treatment locations and treatments applied

Treatment Site	Location	Year Harvested	Year Thinned	Treatment Applied
Gravelly Creek 1	POW Island[a]	1920	1985	ITS
Gravelly Creek 2	POW Island	1920	N/A	Control
Naukati 1	POW Island	1925	1985	Strip
Naukati 2	POW Island	1925	1985	Strip + ITS
Naukati 3	POW Island	1925	1985	Strip + ITS
Naukati 4	POW Island	1925	N/A	Control
Shaheen 1	POW Island	1929	1985	Strip
Shaheen 2	POW Island	1929	1985	Strip + ITS
Shaheen 3	POW Island	1942	1985	ITS
Shaheen 4	POW Island	1929	N/A	Control
Kuiu 1	Kuiu Island	1890	1984	ITS
Kuiu 2	Kuiu Island	1890	N/A	Control
Port Camden 1	Kuiu Island	1935	1984	ITS
Port Camden 2	Kuiu Island	1935	N/A	Control

[a] POW (Prince of Wales).

(including flowers), current year's twigs, and stems (prior years' growth) and weighed. A subsample of three conifer seedlings for each species within each quadrat was similarly separated into current year's growth and prior year's growth and weighed. Subsamples of fresh material were oven-dried each day for each species to determine the dry weight per unit fresh weight. All understory biomass measures are expressed in terms of oven-dry weight (105°C).

Samples of the 18 most abundant understory species were collected within each stand in which they occurred, separated into leaves, twigs, and stems (shrubs), and current and prior years' growth (conifers), and oven-dried at 40°C for nutritional analyses. Nutritional analyses were conducted by the Range and Habitat Analysis Laboratory at Washington State University and included sequential detergent analysis (Goering and Van Soest 1970, as modified by Hanley et al. 1992) for fiber constituents and total nitrogen by the Kjeldahl method for all forage samples. Digestible dry matter and digestible protein were estimated with equations from Hanley et al. (1992), without incorporating effects of plant tannins on protein digestion.

The value of understory vegetation as food resources for deer was quantified with a nutritionally based model for calculating the number of deer days that could be supported by the food supply (Hanley and Rogers 1989). One deer day equals the forage needed to maintain one deer for one day at a specified metabolic requirement without losing weight. We calculated deer days for each stand under two different levels of metabolic requirements: one for an adult female at maintenance requirement (no weight gain or reproduction) and one for a lactating adult female with one fawn (i.e., reproduction requirement). Lactation requires higher average dietary standards of both digestible dry matter (i.e., energy) and digestible protein. The model makes no assumption about habitat other than the input data for food resources: the biomass of each forage species, its dry-matter digestibility, and its concentration of digestible protein. Food resources are considered as though they were harvested and fed to captive deer.

Results

Total biomass. Figure 5 shows the mean total biomass for the controls, treated stands, and seven old-growth stands in coastal Alaska (Alaback and Juday 1989). The strip and strip + ITS treatments had the highest total biomass, 2,291 pounds per acre and 2,138 pounds per acre, respectively. The ITS treatment had 1,357 pounds of total biomass per acre, and the control (unthinned) treatment had 111 pounds per acre. When compared to old growth, however, all treatments had less total biomass. The old-growth forest had 2,743 pounds per acre of total biomass.

Biomass by plant groupings. Figure 5 also shows biomass by plant groupings (forbs, ferns, shrubs, and conifers) by treatment and the old-growth forest. The strip + ITS treatment produced the highest amount of conifer biomass (1,894 pounds per acre) followed by the strip treatment (1,947 pounds per acre), the ITS treatment (575 pounds per acre), and the control (21 pounds per acre). The old-growth forest had 667 pounds of conifer biomass. The ITS treatment produced the highest amount of shrub/fern/forb biomass (782 pounds per acre), followed by the strip treatment (345 pounds per acre), the strip + ITS treatment (245 pounds per acre), and the control (90 pounds per acre). All of these treatments produced less shrub/fern/forb biomass than the old-growth forest (2,072 pounds per acre).

Deer forage availability. Table 2 shows the deer forage availability for each of the treatments. The strip and strip + ITS treatments provided almost the same deer forage availability, providing 161 and 160 deer days per acre, respectively. The ITS treatment provided 142 deer days and the control 26 deer days. All of these values however, were lower than the 251 deer days provided by upland old-growth forest (Hanley and Hoel, 1996).

When the nutritional requirements of a fawn are added in, the picture changes dramatically. The ITS treatment provides the highest number of doe + fawn days (34 days), followed by the control and strip (six days each), and the strip + ITS provided the fewest number of doe + fawn days (three days). In comparison, the old-growth forest provides 30 doe + fawn days.

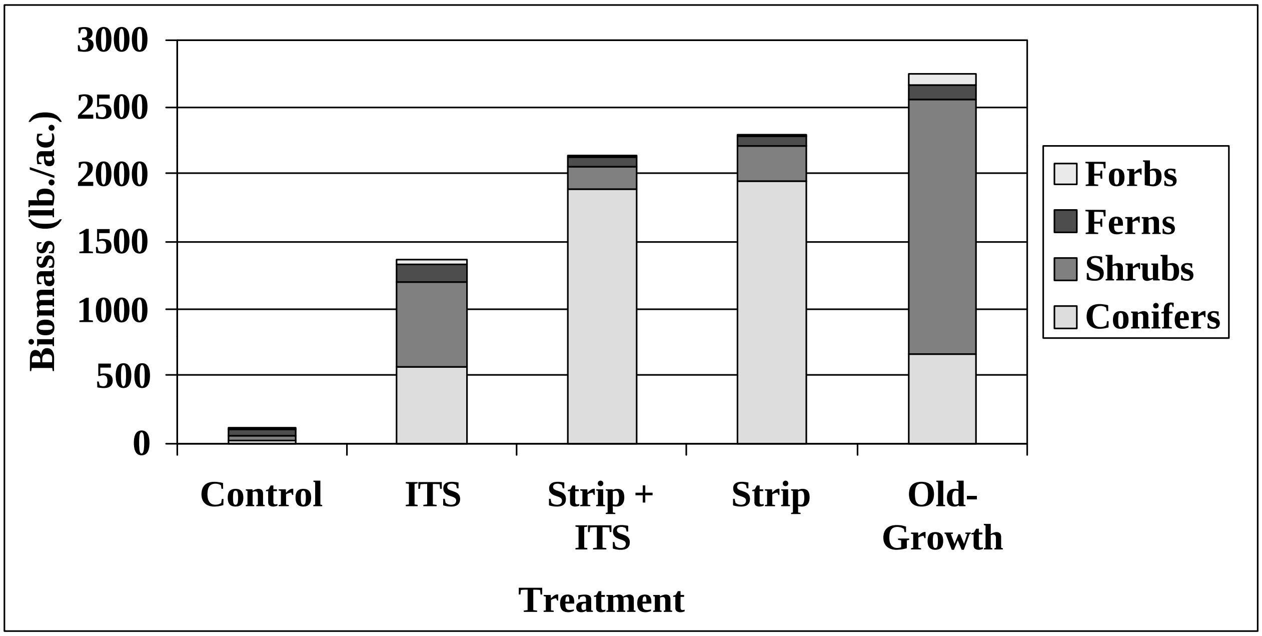


Figure 5–Total biomass and biomass by plant groupings.

Table 2—Deer forage availability by treatment

	Control	ITS	Strip + ITS	Strip	Old-Growth
N=	5	4	3	2	7
Doe only (days/ac)	26	142	160	161	251
Doe+1 fawn (days/ac)	6	34	3	6	30

Discussion

Care must be taken in interpreting the results of this demonstration project given the limited sample. However, some general observations can be made:

- Commercial thinning, regardless of type, appeared to enhance habitat of deer when compared to no commercial thinning.
- Habitat for deer reproduction was best improved by the ITS treatment, when compared to the other treatments and to no commercial thinning. Forbs were the forage class of highest nutritional value for deer–they typically contain less total fiber, fiber that is more digestible, and greater concentrations of digestible protein than all other forage classes (Hanley and McKendrick 1983, Parker et al. 1999). The number of deer days was strongly determined by the biomass of forbs, and this was especially true for the higher nutritional requirements of lactating deer (reproduction). The difference in carrying capacity (deer days) for reproductive versus non-reproductive deer, therefore, was much greater in treatments containing fewer forbs in their understory than in forb-rich understories. Although shrubs in the old-growth stands contributed more toward maintenance requirements of deer than they did in any of the thinning treatments, little of that shrub biomass was sufficient for meeting reproductive requirements. Carrying capacity of the ITS treatment for reproductive deer came very close to that of the old growth. However, our analysis applies only to summer conditions; deciduous leaves and snow-covered plants are not available to deer in winter.
- Opening the stand up too much, as in strip thinning, greatly increases the amount of conifer regeneration produced.
- Total biomass is not a good measure of deer forage resources. Forbs are the major determinant of carrying capacity for deer, and their biomass determines how much use can be made of the additional, lower quality foods such as shrubs, ferns, and conifers.

Acknowledgments

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Appendix

Common and Scientific Names of Plants, Trees, and Animals

Common name	Scientific name
Bunchberry dogwood	*Cornus canadensis* L.
Fernleaf goldthread	*Coptis asplenifolia* Salisb.
Five-leaf bramble	*Rubus pedatus* Sm.
Foamflower	*Tiarella trifoliata* L.
Oval-leaf blueberry	*Vaccinium ovalifolium* Sm.
Red huckleberry	*Vaccinium parvifolium* Sm.
Shield fern	*Dryopteris expansa* (K. Presl) Fraser-Jenkins & Jermy
Skunk cabbage	*Lysichiton americanus* Hultén & St. John
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Alexander Archipelago wolf	*Canis lupis ligoni*
Sitka black-tailed deer	*Odocoileus hemionus sitkensis*

Artificial Regeneration of Northern Red Oak and White Oak on High-Quality Sites: Effect of Root Morphology and Relevant Biological Characteristics

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Abstract

Northern red oak (*Quercus rubra*) and white oak (*Quercus alba*) are important components of high-quality mesic sites and are essential as lumber species and hard mast producers. Regeneration of these species has been difficult, and their absence in newly regenerated stands is a major concern of foresters and wildlife biologists. Several important biological traits of oak species may contribute to regeneration difficulties. These primary determinable biological traits may be shade intolerance and aging, which affects their reproductive potential. These factors, coupled with incompatibility of closely related individuals, greatly hamper natural regeneration efforts by decreasing adequate advance oak regeneration for future stands. Artificial regeneration can significantly increase the oak component because large oak seedlings that exceed the suggested size of advance oak regeneration can readily be produced in forest tree nurseries with specific nursery prescriptions. Seedlings produced in this fashion can readily be evaluated. Those from the top 50 percent, based upon first-order-lateral root numbers, have proven to be very effective in artificial regeneration of stands, in establishing plantings for seed orchards, and in establishing mast-producing areas within larger forested stands.

Keywords: Artificial regeneration, high-quality mesic site, northern red oak, nursery protocol, seedling evaluation, site maintenance, white oak.

Introduction

Much has been written about the difficulty of obtaining northern red oak (NRO) (*Quercus rubra*) regeneration on high-quality mesic sites. But, in spite of much effort, little has been accomplished to change our “luck.” We believe that luck has little to do with regenerating NRO. Instead, it is the biology or ecology of the species that has been ignored in attempts to find procedures that work consistently and can be prescribed with some degree of confidence.

Perhaps one of the basic problems is that “oak” tends to be used as a generic term that connotates a commonality among all species resulting in ignoring individual species’ silvicultural and ecological requirements. The silviculture of swamp chestnut oak (*Q. michauxii*), turkey oak (*Q. laevis*), and NRO is significantly different and thus, the biological requirements of the individual species must not be addressed as “oak” requirements. The single biological attribute of all oaks, however, is the near obligate requirement for full sunlight in order to survive and to produce adequate early growth that enables attainment of a dominant crown position.

We are going to restrict our discussion to NRO and white oak (WO) *(Q. alba*) because these are the two species we have studied the longest. We will not present an extensive literature review of oak because many have already been published. The most recent oak proceedings edited by Loftis and McGee (1993) contain detailed reviews on many specific subjects that may be helpful in understanding, if not alleviating, specific regeneration problems. We will briefly describe the biological factors that we found to be essential in regeneration of

NRO and WO on high-quality mesic sites. These two species have contrasting biology but also share many common attributes. In this context, we will discuss several important factors involved in NRO and WO regeneration. These factors are: 1) biological constraints; 2) nursery practices; 3) acorn availability; 4) seedling evaluation; and 5) pre and post planting site maintenance. We will present data on a few current cooperative studies between the Institute of Tree Root Biology (ITRB) and Southern Region of the USDA Forest Service.

Background

The basis for our research, as well as most oak regeneration research for the past 40 years, is the work by Sanders (1971, 1972) who demonstrated the importance of advanced oak regeneration before stands are harvested. His work was done primarily on lower quality sites (site index = $65_{\text{base } 50}$) where competition from faster growing species was minimal. Even on these sites, however, considerable time and effort were required to build up the advanced regeneration required to assure oak presence in future stands.

Johnson (1981) attempted to produce nursery grown oak seedlings of sufficient sizes to mimic Sander's advance regeneration. Various multi-year growing procedures were used to obtain adequate stem dimension that was considered comparable to Sander's recommendation. The best seedlings were then top clipped and root pruned to facilitate shelterwood underplanting. However, competition from faster growing species on better sites seriously reduced the effectiveness of his prescription. Ultimately, the procedure was recommended for use where oak site index$_{(50)}$ was 70 where faster growing competitors were not present (Johnson 1993).

Loftis (1983) attempted to develop advanced regeneration on high-quality mesic sites through natural regeneration techniques consisting of a series of partial crown releases to encourage natural oak regeneration. Periodicity of acorn production and severe competition from faster growing competitors were handicaps that reduced the effectiveness of this procedure. However, this procedure clearly established that a shelterwood system was very effective in obtaining hardwood regeneration on high-quality sites with one drawback: NRO was not being established in these stands.

Three major principles of NRO and WO regeneration emerged over the past 40 years. We recognized that: 1) advanced oak regeneration is essential; 2) altered nursery practices might produce the required stock; and 3) faster growing competitors would be a major impediment on high-quality mesic sites where obtaining oak regeneration is so critical. The major goal when research on NRO and WO began at the ITRB in the mid-1980s was to develop a reliable nursery protocol that would consistently produce seedlings of adequate size for advanced oak regeneration in cleared areas. This nursery fertility protocol became, and still remains, the keystone of our oak research (Kormanik et al. 1994a; Kormanik et al. 1994b). Its consistency in producing acceptable seedlings made it possible to conduct research in physiology, mineral nutrition, and development of 1-2 hectare mast-producing areas that will provide for future acorn production for oak regeneration efforts and hard mast production for wildlife maintenance.

Biological Constraints

One of the biggest impediments to successful NRO and WO regeneration on high-quality sites is adequate sunlight: too little sunlight and oak regeneration cannot survive, abundant sunlight and the competitors take over the stand. This is closely followed in importance by the reduction in acorn production as the tree ages. When height growth slows down after age 50, only several cm of the current years' branch tips may be available for acorn development. This fact is simply overlooked, and mature stands are maintained under the illusion that they are providing acorns for hard mast and for regeneration.

Inbreeding in natural oak stands may be a most critical problem that is rarely addressed (Cecich 1993). Acorns remain close to the trees that bore them and thus, clumping of closely related oak can be expected. It is now commonly believed that the callose plugs that precede pollen tube penetration through the styles' transmitting tissue may be indicative of pollen incompatibility. This could be brought about by selfing or pollination by closely related individuals (Cecich 1993). The problem may be common within many *Quercus* species and not unique to NRO and WO.

Several studies showed that full-sun-grown NRO seedlings have higher net photosynthesis rates (Pn) than shaded seedlings (Crunkilton et al. 1992; Kubiske and Pregitzer 1996; Sung et al. 1998). Photosynthesis rates for 1- and 2-year-old NRO and WO seedlings grown with 30 percent light were about 65 percent of the Pn for full-sun-grown seedlings (Sung et al. 1998). Two-year-old 30 percent-light-grown NRO seedlings had about half as much total biomass as the full-sun-grown seedlings. More importantly, however, is that these shaded NRO seedlings had different biomass allocation patterns than the sun seedlings. In two-year-old full-sun NRO seedlings 10, 30, 37, and 23 percent of dry weight was allocated to leaves, stem plus branches, taproots, and lateral roots, respectively (Sung et al. 1998). However, in 30-percent-light-grown NRO, 14, 43, 34, and 9 percent of biomass was found in these corresponding seedling components. The 14-percent reduction in lateral roots is important because it eliminates a significant portion of the feeder root complex. Similar effects of shade on biomass allocation patterns were observed in WO (Sung et al. 1998).

In addition to the reduction in feeder root development, understory oaks must adapt to full sun when the overstory canopy is removed. With increasing light intensity, choloroplasts engage a xanthophyll cycle-mediated photoprotection mechanism to safely dissipate the excessive absorbed light energy as heat. However, leaves from shade-grown plants have smaller xanthophyll cycle pools and lower photoprotection index values as compared to sun leaves (Faria et al. 1996, Logan et al. 1996). Sung et al.1997 reported that Pn for NRO planted under hardwoods (less than 5 percent full sun) or pine (less than 40 percent full sun) was 5 and 30 percent of the Pn from oaks planted in clearcut areas. Similar results were found for WO. Oaks under hardwoods had very small photoprotection index (0.1), whereas oaks in the clearcuts had a photoprotection index of 0.8 (Sung et al.1997). Thus, release of oaks from the understory can result in at least 1-year delay in maximum photosynthesis because shade-grown oak chlorophyll probably would not have been protected from sun bleaching once the overstory canopy was removed. With little ability to protect the leaves from sudden increase in light intensity, and with small percentage lateral root biomass, it might take these released oaks several years to adapt to full sun and begin rapid growth. However, in the presence of faster growing competing species, these oaks will soon be shaded.

Acorn Production

Obtaining adequate acorns for nursery research can be a frustrating endeavor. Adverse environmental and edaphic conditions, predation, and various insects, are known to destroy more than 95 percent of the acorns in a heavy mast year and entire crops during poorer mast years. White oak acorns rapidly germinate after abscission. The radicles penetrate into the soil, and thus, it is not unusual to obtain large cohorts of seedlings following a bumper mast crop. These seedlings usually die within 2-5 years. Seldom, if ever, are such massive cohorts of NRO observed because the long stratification period required for germination often results in desiccation and reduced viability. Spring controlled burning in NRO stands in the spring after a heavy fall mast crop generally reveals abundant acorns but essentially none that germinated. This is due to severe desiccation since their maturation and abscission. It is evident that acorn-producing areas are critical, and proper collection and storage of acorns are essential if artificial regeneration is to be a viable alternative to natural regeneration.

Nursery Protocol

The development of a reliable nursery management protocol was considered essential even before problems encountered with acorn availability were considered. The basic nursery fertility protocol was developed in the mid-1980s for sweetgum (*Liquidambar styraciflua)* and with some modifications, still remains the keystone of our oak regeneration effort. Its consistency in producing reliable seedling crops has permitted the development of a biologically based seedling evaluation protocol. The protocol has resulted in the establishment of 1-2 hectares of oak mast-producing areas and other stand regeneration prescriptions. It has also proven successful in producing quality oak seedlings from 10 oak species and many other hardwoods (Kormanik et al. 1994a, 1994b).

Table 1—First-order lateral roots family means broad sense heritability estimates for *Quercus rubra* and *Q. alba* in several studies

Study	Heritability	Standard Error
Q. rubra		
1	0.898	0.153
2	0.870	0.114
3	0.843	0.235
Q. alba		
1	0.843	0.138
2	0.918	0.073
3	0.843	0.235
4	0.949	0.026
5	0.893	0.116

Although NRO and WO respond similarly to the standard fertility protocol, WO must be watered lightly almost daily during early spring in order to obtain 80 cm or more heights. During this time, seedlings are undergoing a lengthy period of extensive feeder root development without stem elongation. If feeder root development is not encouraged, one can expect the substandard WO seedlings that are characteristically being produced by forest tree nurseries. In contrast, the same early watering regime for NRO will result in too much early height growth and excessively large seedlings. These contrasting responses to watering regimes necessitate sowing these species in nursery beds under separate irrigation lines. Acorn sowing for both species should be completed very soon after collection. If drought persists throughout the winter, occasional light irrigation will be required to prevent NRO acorns from desiccation and to prevent damage to the developing taproot of WO.

Acorns are sown to obtain a bed density of 60-70/m^2 and seedling morphological development is controlled by $NH_4 NO_3$ applications and irrigation. For outplanting, we prefer NRO and WO to have a minimum root collar diameter (RCD) of 8 mm, height (HGT) of 0.80-1.2 m, and the first-order lateral root (FOLR) number should be at or above the average for that group. The nursery soil is analyzed before each growing season, and all fields are brought up to specifications. We are, thus, developing a data base for nutritional requirements of individual oak species that are characteristically produced in the Georgia Forestry Commissions' (GFC) nurseries.

Seedling Evaluation

Seedling quality consistency at our experimental nursery near Athens and the two GFC state forest nurseries has permitted the development of a seedling evaluation system. The evaluation system is based on FOLR numbers and also specifies the minimum RCD and HGT for both species. First-order-lateral-root morphology is a highly heritable trait and is ideal for comparing progeny of half-sibling seed lots and comparing progeny from different mother trees (table 1). Although heritability estimates only apply strictly to the experiments from which they were obtained, consistently high values from repeated tests tend to substantiate the importance of a specific trait (Wright 1976).

Seedling RCD and HGTs have been the standard criteria for evaluating seedling quality. However, simple modification of bed density, fertility regime, or irrigation schedules may affect these seedling parameters, and thus, render their use questionable. First-order-lateral-root development remains consistent for a given seedling bed density even under different growing conditions and fertility regimes.

Tables 2 and 3 contain typical nursery data for NRO and WO, respectively, progeny produced by GFC using our protocol. Note the wide range in specific growth parameters is found that if an individual seedling exceeds the mean FOLR for its half-sibling group, then it will most likely also exceed the RCD and HGT means for that group. In evaluating progeny from hundreds of mother trees, seldom do more than 50 percent of the seedlings meet or exceed our outplanting standards. The seedlings from the lowest 30 percent of the crop seldom have more than a single FOLR and usually are less than 1/3 of the HGT and RCD of the better 50 percent of the crop. Evaluating and discarding the poorest 30 percent of seedlings are rapid procedures effectively done at the nursery during lifting and packing.

Sowing by mother tree seedlots permits early evaluation of the competitive ability of specific progeny groups (tables 2 and 3). Characteristically, sibling lots that perform poorly in the nursery environment develop poorly after outplanting. Mother trees from future collections whose individuals produce few FOLR and are generally substandard in both RCD and HGT are discontinued, e.g., mother tree 2-23-850 in table 2. Conversely, potentially

Table 2—Morphological and growth characteristics of 1-0 northern red oak (*Quercus rubra*) seedlings grown in 1995

	FOLR Number		Seedling less than mean[a]	RCD (mm)		HGT (cm)	
Family	*Mean*	*Range*	*%*	*Mean*	*Range*	*Mean*	*Range*
1-14-915	6.4	0-26	58	9.8	3.9-18.7	125	22-223
2-10-540	5.7	0-23	54	8.4	3.7-15.8	135	40-262
2-19-630	4.6	0-25	57	9.0	2.9-17.1	131	43-238
2-23-850	2.3	0-25	72	6.2	1.0-16.9	73	8-207
2-29-565	5.2	0-24	58	9.8	3.2-19.2	134	18-260
2-6-735	4.0	0-16	63	9.1	3.4-17.6	117	28-211
3-3-526	4.9	0-19	54	9.1	3.3-15.7	114	33-243
4-2-902	3.6	0-15	63	8.4	3.6-15.2	124	46-223
4-4-882	4.0	0-19	57	8.8	3.9-16.4	126	47-243
4-14-2459	5.9	1-20	52	10.5	3.4-18.9	125	22-253
4-27-100	4.2	0-19	56	9.3	2.9-17.9	141	33-243
6-14-200	5.0	0-20	58	8.5	3.0-15.69	121	41-232

[a] The percentage of seedlings in a given family with their FOLR less than the mean FOLR number for that family.

Table 3—Morphological and growth characteristics of 1-0 white oak (*Quercus alba*) seedlings grown in 2000

	FOLR Number		Seedling less than mean[a]	RCD (mm)		HGT (cm)	
Family	*Mean*	*Range*	*%*	*Mean*	*Range*	*Mean*	*Range*
ASO-5	6.7	0-28	53	9.3	2.7-18.6	86	14-198
ASO-16	5.8	0-27	56	10.3	2.0-19.0	89	12-180
ASO-18	4.8	0-28	56	9.8	2.6-19.8	98	22-183
ASO-42	5.2	0-42	55	9.2	2.1-22.4	90	8-188
SRS-585	3.6	0-26	56	8.2	2.3-16.8	82	21-158
SRS-588	4.2	0-24	57	8.5	2.7-15.6	81	11-153
SRS-592	4.7	0-29	57	8.7	1.6-17.8	88	7-161
SRS-593	4.0	0-25	56	8.4	1.1-15.1	77	7-161
SRS-596	4.2	0-23	65	6.8	1.1-15.3	47	6-139
SRS-597	4.4	0-26	56	8.8	2.7-14.9	93	23-159
SRS-598	2.6	0-17	57	8.2	2.2-15.2	84	20-178
SRS-599	5.2	0-29	57	8.4	1.6-16.0	83	7-163
SRS-601	3.3	0-17	51	8.9	2.5-14.3	77	15-135
SRS-602	3.3	0-14	53	8.6	2.4-15.5	71	12-145
SRS-603	5.0	0-29	57	8.7	1.2-15.4	85	10-152
SRS-606	3.6	0-28	59	8.1	2.3-15.6	87	14-141
SRS-607	3.6	0-29	56	8.9	2.0-16.3	75	6-144
SRS-608	3.4	0-17	57	9.9	2.6-16.2	92	19-153

[a] The percentage of seedlings in a given family with their FOLR less than the mean FOLR number for that family.

Table 4–Morphological and growth characteristics of 1-0 white oak (*Quercus alba*) seedlings from grafted mother trees

	FOLR Number		**Seedling less than mean[a]**	**RCD (mm)**		**HGT (cm)**	
Family	*Mean*	*Range*	*%*	*Mean*	*Range*	*Mean*	*Range*
KYWO 11	3.4	0-17	63	7.5	2.0-13.8	46	12-128
KYWO 31	3.0	0-19	66	8.4	3.0-15.3	35	8-104
NAWO-01	2.5	0-16	67	7.2	3.2-13.6	28	8-87
NAWO 23	4.1	0-22	62	8.2	2.9-15.2	48	8-142
NAWO-24	3.8	0-21	60	7.9	2.8-15.0	39	14-147
NAWO-28	2.1	0-18	72	6.5	2.5-11.6	24	6-68
NAWO-29	2.3	0-18	67	6.5	1.0-15.3	25	8-100
SAWO 3	3.9	0-27	61	8.7	3.6-18.0	39	12-110
SAWO 7	3.6	0-23	61	9.0	2.7-17.4	48	12-134
SAWO 12	2.8	0-16	58	7.4	2.4-13.0	36	11-112
SAWO 14	4.6	0-32	64	8.6	2.7-18.4	46	12-151
SAWO 28	6.2	0-36	64	8.4	2.2-19.3	45	12-171

[a] The percentage of seedlings in a given family with their FOLR less than the mean FOLR number for that family.

better progeny groups can be identified after a single nursery growing season. In the 2000 nursery season, we identified individual NRO selections that had less than 15-20 percent substandard seedlings. This is encouraging that inclusion of such potent genetic material in seed orchards should be effective in improving the number of plantable seedlings from each nursery crop.

Establishing NRO and WO individuals in seed orchards from the very best individuals with the highest FOLR numbers has resulted in acorn production by age five. At age seven, individual WO have produced sufficient acorns for nursery testing and establishment of seed orchards by the GFC.

While seedling seed orchards have been very effective for both NRO and WO, grafted white oak seed orchards maintained by the USDA Forest Service at the Beech Creek Seed Orchard near Murphy, N.C., have not been satisfactory in terms of progeny development in the nursery (table 4). Progeny from this grafted seed orchard have been tested for 5 years, and germination normally varies from 5-50 percent. Transplanting these progeny even under ideal seed orchard conditions has not resulted in acceptable growth in most areas. The reason for this poor performance of acorns from grafted material is unclear. Investigation into this is needed since grafting specific individuals with outstanding attributes could be a valuable tree improvement tool.

Pre and Post Site Maintenance

The shelterwood method of naturally regenerating hardwoods on high-quality mesic sites works well except for lack of regeneration in the valuable oak component. Left unattended, these two oak species cannot compete against the faster growing competitor species (Loftis 1983). Unfortunately, neither will artificially regenerated NRO or WO compete under these same circumstances. They need abundant sunlight and minimal root competition to be competitive. However, a clearcut followed by an effective burn, if necessary, usually is sufficient to maintain these large artificially regenerated oak seedlings for 3-5 years. In all cases, however, stumps should be treated with a silvicide to prevent sprouting because no individual seedlings, regardless of their origin or phenotypic characteristics, can successfully compete with stump sprouts of yellow poplar (*Lilodendron tulipfera*), red maple (*Acer rubrum*) or Carolina silverbell (*Halesia carolina*) present on a high-quality mesic site. With adequate pre-planting vegetation control, the oak seedlings should be able to compete against individuals of seed origin for 3-5 years, but will usually need additional release between ages 7-15.

Initial post planting maintenance is primarily concerned with stump sprouts, but by year two blackberries (*Rubus* spp.) and grape (*Vitae* spp.) on specific sites can become a severe problem, especially when both occur simultaneously. To establish seedling seed orchards, we prefer that no thinning be attempted until acorn production is initiated between ages 5-10. Acorn production under such conditions has been achieved at ages 4-7 for both NRO and WO. However, under forest conditions, age of acorn initiation is unknown but will depend heavily upon crown competition and early fertilization.

Current Trends of ITRB Research

The nursery protocol and its potential benefits used in producing oak planting stock have been published elsewhere and need not be repeated here (Kormanik et al. 1994a, 1994b). Close examination of data in tables 1-3 reveals why a sound biologically based grading system is an essential first step in developing an effective artificial regeneration initiative. If a seedling cannot compete effectively in an ideal nursery setting, it is unlikely to be competitive in the field under significantly greater stressful conditions. This data can also serve as a wake-up call to the difficulty in obtaining advance regeneration through traditional management procedures where a high percentage of seedlings may be inherently poor competitors. Preliminary data suggest that late germinating acorns produce a disproportionally large share of these substandard seedlings.

Our initial NRO artificial regeneration study is 11 years old, and the results comparing seedling performance in a clearcut and in a shelterwood has been presented at the 11th Biennial Southern Silviculture Research Conference (Kormanik et al., in press). No pre or post planting maintenance was performed beyond the initial treatment, except at age 7 when a circle (0.9 m radius) was cleared around each tree to release the dominant individuals in the clearcut. At the same time, the overstory was removed from the shelterwood. Three years after shelterwood removal, the 11-year-old NRO seedlings had a mean HGT growth of approximately 0.60 m since outplanting. The mean HGT for the best seedlings was 1.6 m and many were overtopped by more rapidly growing competitors. Comparable individuals established in the clearcut had mean HGTs of 3.5 m and some of the dominant ones had HGTs of 5-6 m.

A NRO mast evaluation trial was installed in a small clearcut established in a hurricane-damaged stand below the scenic Brasstown Bald Visitor Center on the Chattahoochee National Forest near Blairsville, GA. Progeny from 25 mother trees represented by 1250 half-sib progeny showed considerable growth differences. Unlike the 11-year-old study, this regeneration study was maintained regularly and the competition was effectively controlled through the third year, when the crowns began controlling competition. Initial mean HGT and RCD for these trees were 0.87 cm and 9.9 mm, respectively. Mortality over the 5 years has been 21 percent due almost entirely to vole (*Microtus* spp.) damage during years 1 and 2. At year 5, mean HGT and DBH were 2.76 m and 22.9 mm, respectively. Almost every family had individuals 3.5 - 5.5 m in HGT with excessive crown competition developing in adjacent rows. Thinning will be initiated in 2001 because of this competition. Acorns have not been observed as yet, and hopefully, maintenance of competition-free crowns will encourage early acorn production.

A second NRO mast evaluation study using 17 different half-sib progeny groups was established in 1995 on an old pasture near Morganton, NC, in cooperation with the NC Division of Forest Resources. There were 765 seedlings in this test. Initial mean HGT and RCD were 0.94 m and 12 mm with mean FOLR of 9.9. Mortality during the initial 5 years was 1.6 percent, and some of this was mechanical damage that occurred in the first year. After the fifth growing season, mean HGT and DBH were 5.3 m and 52.7 mm, respectively. Many families had individuals whose HGT exceeded 7.0 m with DBH exceeding 90 mm at age 5. Crown competition was excessive after the sixth growing season, and thinning was necessary before the seventh year growing season. An appropriate herbicide was used to control the fescue sod. In our two other large studies that were planted where herbicide use was not permitted, thousands of seedlings died the first year due to excessive competition and allelopathic effects from heavy fescue sod.

The initial WO planting established by the ITRB that consists of progeny from 30 different mother trees with 1200 seedlings has just completed its third growing season in year 2000. When this study was initiated, we did not know the importance of early season irrigation. Mean HGT and RCD of the nursery stock was 0.67 m and 9.8 mm, respectively, with mean FOLR of 9.6. After three complete growing seasons, mean HGT and DBH were 1.87 m and 10.3 mm with a mortality rate of 9 percent. Progeny from almost all families was well represented by individuals with HGT and DBH exceeding 3.0 m and 32 mm, respectively.

During year 1, herbicide usage on the site was not permitted. Only stump sprouts in direct competition with the planted seedlings were controlled by mechanical procedures. During the second and third year, stump and root sprouts continued to be serious competitors but by then, herbicide usage was permitted on the sites. This treatment was effective in maintaining the WO in a dominant position.

Conclusions

A viable component of both NRO and WO are essential on high-quality mesic sites if we are to maintain the biological diversity so critical to the long-term health of the forests and organisms that depend so heavily upon them for their existence. Partial crown removals or single tree selection appear to be counter-productive as a procedure for obtaining and maintaining these oak species as a viable component. These oaks are intolerant of shade and will continue to decline in numbers and importance in future stands on these higher quality sites if we fail to provide adequate stand conditions that will permit them to be competitive.

Metric Equivalents

1 inch = 0.39 centimeters (cm)

1 foot = 0.304 meters (m)

1 inch = 25.4 millimeters (mm)

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Chapter 3

Aquatic Systems

Does Red Alder Enhance Wildlife, Aquatic, and Fisheries Resources in Young-Growth Western Hemlock-Sitka Spruce Forests of Southeast Alaska?

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Abstract

Red alder (*Alnus rubra* Bong.) appears to influence the productivity and community composition of young-growth conifer forests and affect the major resources (timber, wildlife, and fishes) of forested ecosystems in southeast Alaska. We propose that landscapes may be managed to concurrently enhance these resources. Historically, red alder has often been regarded as an undesirable species by forest managers and has been thinned from riparian and upland forests. We present an integrated approach to study the function of young-growth forest ecosystems and to understand how alder influences selected trophic linkages and processes in managed landscapes. We will assess the physical disturbances that are associated with alder establishment. We will also investigate mixed red alder-conifer forests and determine if these forests provide a greater biomass of understory vegetation and forage for herbivores (e.g., deer) and invertebrates than young-growth conifer forests. We will determine the effect of mixed red alder-conifer forests on the abundance of aquatic, riparian, and terrestrial invertebrates that provide food for fish, bats, and birds. We will also determine if most red alder trees die standing (as opposed to uprooting or bole snapping), and assess woody debris and sediment input in streams. We will investigate whether red alder in mixed stands may enhance conifer growth and total wood production. The inclusion of red alder in young-growth stands may allow clearcutting in areas where purely even-aged conifer forests would compromise wildlife, fish, and aquatic resources.

Keywords: Red alder, young-growth forests, headwater streams, geomorphology, invertebrates, fish, wildlife.

Introduction

Red alder (*Alnus rubra* Bong.), a relatively short-lived, shade-intolerant pioneer with rapid juvenile height growth, is the most common hardwood tree in the Pacific Northwest (Harrington 1990). It occurs mostly as a lowland species along the northern Pacific Coast, and its range extends from southern California to southeast Alaska. In Alaska, red alder is commonly found along beaches and streams, on snow avalanche and landslide tracks, and as a pioneer species with Sitka spruce (*Picea sitchensis* (Bong.) Carr.), black cottonwood (*Populus trichocarpa* (Torr. & Gray), and willows (*Salix* spp.) on exposed mineral soils (Harris and Farr 1974, Ruth and Harris 1979). Logging has increased the amount of alder in the forests of southeast Alaska, particularly in upland areas with heavy soil disturbance. However, little information is available about the growth and ecological role of red alder in Alaska. Basic information on silvics, stand growth and yield, tree species mixtures, succession, tree mortality and decay, and understory vegetation is lacking, and most knowledge about alder is based on information from other regions.

In the Pacific Northwest, red alder grows in both pure and mixed stands, with pure stands typically confined to stream bottoms and lower hill slopes (Harrington et al. 1994). In Alaska, pure red alder stands are rare, and alder is a frequent associate in mixed alder-conifer stands with Sitka spruce, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western redcedar (*Thuja plicata* Donn ex D. Don). Red alder has rapid early height growth, but growth slows after the juvenile stage. Observations of mature forests in the Pacific Northwest indicate that alder trees may be replaced by longer-lived conifers, and on an average site, associated conifers and red alder can attain the same height at about age 45 years (Harrington 1990). The establishment and growth of shade-tolerant conifers such as Sitka spruce and western hemlock probably control which successional trajectories will be followed; however, the successional sequences in mixed alder-conifer stands are not well understood.

In southeast Alaska, even-age forest management has been used almost exclusively in the region for wood production, and stands have been regenerated through clearcutting and natural reproduction. However, the dense, uniform, even-aged stands that quickly develop are recognized as having broadly negative consequences for wildlife and fish (Wallmo and Schoen 1980; Schoen et al. 1981,1988; Thedinga et al. 1989; Hanley 1993; Dellasala et al. 1996). Canopy closure generally occurs 25 to 35 years after cutting followed by a nearly complete elimination of understory vegetation for 100 years or longer (Alaback 1982, 1984; Tappeiner and Alaback 1989). Following canopy closure above small streams, trophic status changes from autotrophic (organisms manufacture own energy) to heterotrophic (organisms are consumers) (Sedell and Swanson 1984, Hetrick et al. 1998). The removal of streamside trees also reduces the amount and size of large wood with the subsequent loss of bird[1] and fish habitat (Bryant 1985, Bisson et al. 1987). Changes in forest structure may result in an alteration of supply, storage, and transport of woody debris and sediment through processes including mass-wasting, windsnap and blow-down, and bank erosion (Smith et al. 1993, Hennon 1995, Johnson et al. 2000). There is increasing interest in developing forest management practices that maintain or enhance biodiversity and assure long-term sustainability of forest products, wildlife, and aquatic resources.

[1] De Santo, T. L. Unpublished data. On file with: Forestry Sciences Laboratory, 2770 Sherwood Lane, Suite 2A, Juneau, AK 99801.

Recent studies of mixed red alder-conifer stands have indicated that different successional pathways are possible following clearcutting in southeast Alaska. These alder-conifer stands have both species-rich and highly productive understory vegetation with biomass similar to that of old-growth stands of the region (Hanley and Hoel 1996, Deal 1997, Hanley and Barnard 1998). Habitat quality for some small mammals in even-aged, alder-conifer stands may be equal to that of old-growth forests (Hanley 1996). Although inclusion of alder will not provide mitigation for all wildlife-habitat problems (e.g., lack of snow interception for deer winter range), it may accomplish more than is possible by thinning even-aged conifer stands. Attempts to reestablish understory herbs and shrubs through thinning young-growth conifer stands have led to mostly conifer regeneration with little new herbaceous colonization (Deal and Farr 1994). Further, there may be more benefits with the inclusion of alder in riparian forests. The abundance of terrestrial invertebrates is affected by the composition of forest vegetation, and there is greater density and biomass of invertebrates on some riparian plant species (Mason and Macdonald 1982). In southeast Alaska, over half of the prey biomass ingested by juvenile salmonids is terrestrial prey that fall into streams from adjacent riparian vegetation, and forests with alder may produce more prey for salmon than forests without alder (Wipfli 1997). If similar invertebrate community responses occur in upland forests, increased invertebrate production may provide more food for animals including birds, bats, small mammals, and fish downstream, thereby also increasing vertebrate abundance and production.

We are using an integrated, comparative study of alder-conifer stands versus pure conifer stands to assess differences in physical disturbance history associated with tree composition, stand structure and tree mortality, understory vegetation, bird and bat communities, and invertebrates, (e.g., food resources) for fish, birds, and bats (figs. 1 and 2). This study involves a broadly integrated research program to address ecological processes that are critical for the establishment and growth of alder-conifer forests. An assessment of both forest disturbance history and geomorphic processes is being used as a framework to evaluate habitat

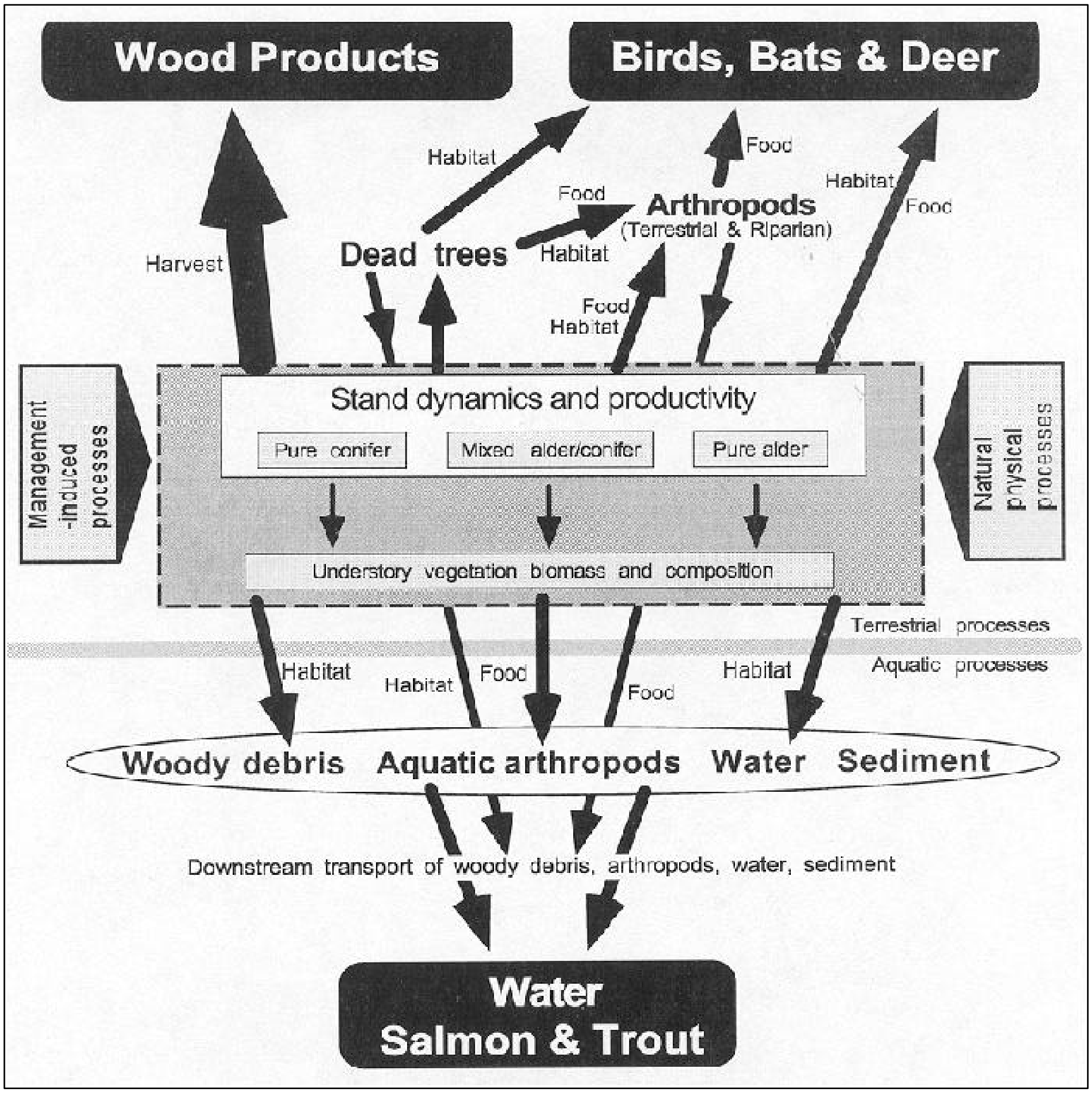

Figure 1—Influence of alder in the ecosystem: vegetation, birds, bats, invertebrates, wood, and fishes.

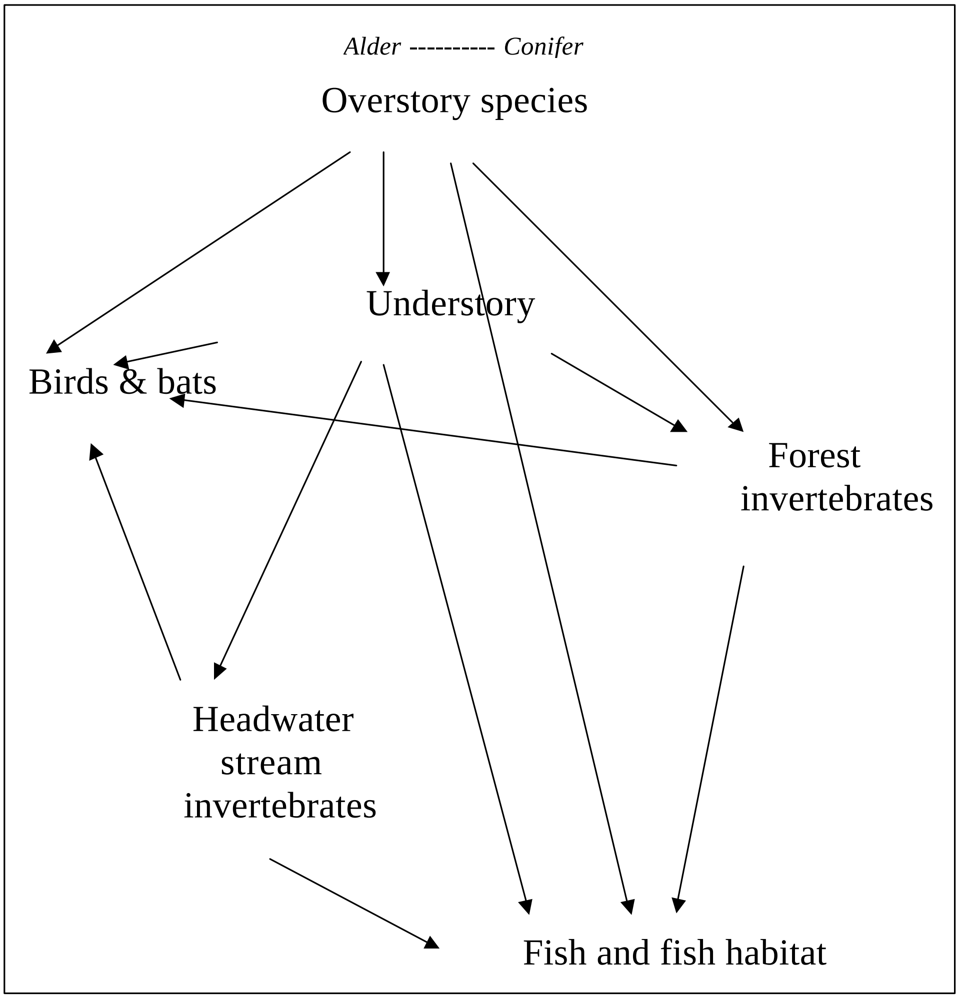

Figure 2—Influence of alder on ecosystem linkages and processes.

changes in managed forests. We are evaluating the role of headwater physical processes (Bilby and Bisson 1998, Bisson and Bilby 1998) within a landscape context to assess conditions necessary for the establishment of mixed alder-conifer stands. Critical processes for maintaining downstream fish habitat are being assessed including the supply, storage, and transport of wood and sediment (fig. 3). We also are determining the compatibility and potential tradeoffs between the amount of red alder in forests, the production of understory vegetation, and growth and yield of Sitka spruce and western hemlock. The potential of red alder as a 'tool' for restoring important ecosystem functions in regenerating forests of southeast Alaska is being evaluated.

Approach

We are sampling across a continuum of alder-conifer mixtures using the composition of tree species as a main site selection criterion to assess the role of red alder in young-growth forests and to determine the effect of alder on forest and aquatic resources. We selected study areas in the Maybeso and Harris watersheds, Prince of Wales Island, Alaska, to reduce the range of site variability. These watersheds were chosen because they have large areas of relatively uniform stand age and site productivity with a wide range of alder-conifer mixtures.

The objectives for each component of the study requires specific selection criteria, but about half of the sites are being used in common for all resources including timber, wildlife, and fish. Twelve sites were selected and sampled during FY 2000

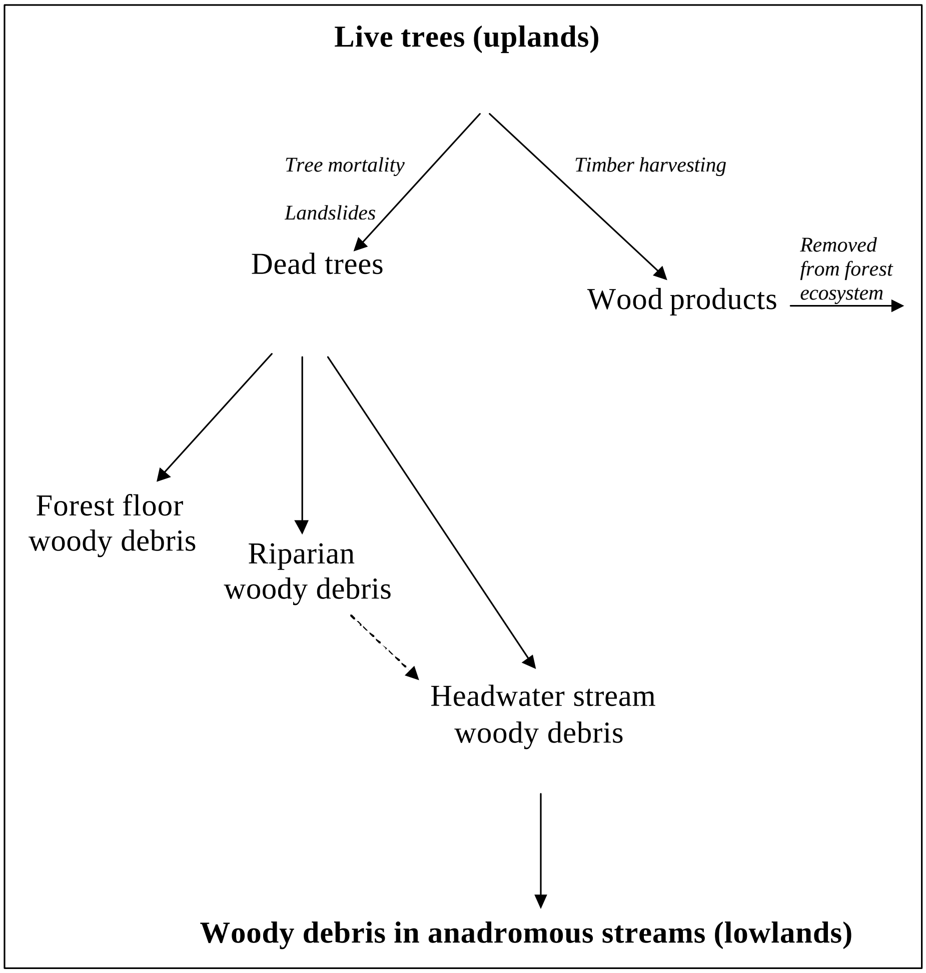

Figure 3—Flow of wood among habitats – from uplands to lowlands.

and will be sampled again in 2001 to investigate biological and physical linkages between terrestrial and aquatic systems. We are describing and relating disturbance history with tree species composition. We are also installing overstory and understory plots to assess stand structure and growth, tree species composition, understory plant diversity and abundance, frequency and type of tree mortality, and wood decay. We are determining the abundance and types of invertebrates found in association with living and dead trees and leaf litter in terrestrial and aquatic habitats, and characterizing bird and bat activity by direct observation of foraging birds and electronic recordings of ultrasonic emissions of foraging bats. Processes that transport wood and sediment to streams are being assessed in relation to fish habitat.

There are three main integrating themes of this research: (1) influence of alder in the ecosystem—vegetation, birds, bats, invertebrates, wood, and fishes (fig. 1); (2) influence of alder on ecosystem linkages and processes (fig. 2); and (3) flow of wood among habitats–from uplands to lowlands (fig. 3).

Methods

Methods are summarized by each major discipline. More detailed information on specific objectives, hypotheses, sampling methodology, and analyses is contained in an unpublished study plan[2].

[2] Wipfli, M.S.; Deal, R.L.; De Santo, T.L. [and others]. 2000. Managing young upland forests in southeast Alaska for wood products, wildlife, aquatic resources and fishes. Unpublished study plan for Wood Compatibility Initiative. On file with: Forestry Sciences Laboratory, 2770 Sherwood Lane, Suite 2A, Juneau, AK 99801.

Wood Production, Vegetation, and Tree Disease

Stand density, tree-species distribution, and abundance are being assessed in 20 variable-radius plots within each stand. The proportion of alder basal area in young-growth stands is being analyzed in relation to stand density and wood production. Understory plant biomass data are being collected in vegetation quadrats throughout the stand. Biomass data is combined by stand and is being analyzed to determine how the proportion of alder basal area affects species richness and biomass of all vascular plants. Stand and tree growth, tree regeneration, and tree height and diameter distribution are being measured in five large fixed-area plots in each stand. Plot data is combined by stand and is being analyzed to determine how the proportion of alder basal area affects stand growth, tree height and diameter growth, and tree regeneration. In addition, riparian overstory and understory vegetation are being sampled in fixed-area plots along upper and lower 300 m reaches of each of the 12 streams used in the aquatic and riparian ecology studies. Vegetation immediately adjacent to study streams is being analyzed and compared with non-riparian vegetation.

Dead trees are being measured in variable-radius and fixed-area plots to estimate species and size of recent tree mortality for woody debris recruitment. Trees as small as 3 cm diameter are included in sampling because this is the minimum threshold of "small woody debris" used in woody debris assessments (Gomi et al., in review). Tree mortality is being classified as dead standing, broken bole, or uprooted to investigate the dynamics of tree mortality and stand development. We are analyzing whether stand composition influences the size or species of trees that have died, and how the proportion of alder in young-growth stands influences the amount and type of woody debris recruitment. The presence and type of wood decay (white or brown rot) from dead alder and conifers is being recorded and quantified from the vegetation plots. These two decays produce distinct physical residues that may differ in their influence on biological processes. The proportion of total woody debris recruited in both decay types is being estimated.

Aquatic and Riparian Ecology

Twelve small permanent streams (~10-20 ha subbasins) in upland forests across a range of 0-80 percent alder are being sampled for invertebrates that colonize alder and conifer woody debris in streams. Abundance and composition of aquatic invertebrates are the response variables. Riparian stands along these same 12 streams are being sampled for abundance and composition of invertebrates that colonize riparian woody debris. Transport of aquatic and terrestrial invertebrates is also being sampled between May and September, immediately upstream of fish habitats, to assess the amount of food delivered by these headwater streams to downstream fish habitats.

Terrestrial Invertebrates

Passive sampling of terrestrial invertebrates is being conducted in 12 stands of three forest habitat types (conifer young growth, alder-conifer young growth, and old growth) from May through September, a period during which invertebrates are developing and active. Traps on tree boles and foliage clippings are being used to sample invertebrates on all tree species (Sitka spruce, western hemlock, western redcedar, red cedar, and red alder). Malaise traps are being used to sample flying insects. The number of invertebrates in samples is being quantified, and specimens measured (length) and classified to family. These measures are being compared among habitat types and tree species within habitat types.

Wildlife

Breeding bird communities (bird abundance and species composition) are being censused by the point-count method (Verner 1985, Ralph et al. 1993) in 12 sites of three forest habitat types (conifer young growth, alder-conifer young growth, and old growth). Census points, located $\geq$150 m apart and $\geq$50 m from habitat edges are being visited three times during the breeding season (May through July). Species richness and abundance are being compared among sites. An index of relative nest predation among habitat types is being determined by placing artificial nests in four stands of each habitat type. Nests are baited with plasticine eggs to aid in the identification of nest predators. Natural nests within each habitat type are also being located and monitored. Nesting success is being analyzed by the Mayfield method (Mayfield 1961, 1975) if adequate sample sizes are obtained; simple percentage of success (e.g., number of successful nests/total number of nests) is being calculated otherwise. To document possible differences in diet and use of foraging substrates between mixed alder-conifer and conifer stands, we are observing foraging birds, documenting substrates used for foraging, and analyzing diets of mist-net captured birds by using the stomach flush method (Major 1990). Foraging observations and diet analyzes are being coupled with analyses of invertebrates collected on different tree species within different habitats (see Terrestrial Invertebrate Section). Diet analyses will be particularly useful should we find differences in the types of invertebrates associated with different tree species or habitats.

Bats are being censused with ANABAT II detectors deployed within corridors where alder is a major component of the adjacent forest vegetation (alder treatment), and in paired plots within nearby corridors where alder is mostly absent (conifer treatment). Sampling duration will vary from 24 to 72 hours depending on bat activity, but is identical for paired treatments. Total bat activity is the response variable. It is also assumed to be a surrogate of feeding activity and thus, is an index of the quality of sites as bat foraging habitat.

Correlations between overstory and understory variables are being determined from each alder-conifer stand sampled in this study. Understory variables include biomass and canopy coverage of vascular plant species. Analyses will quantify potential trade-offs between overstory structure and understory variables. Understory species composition and biomass are being quantified in terms of food value for deer (deer days per hectare) by use of a nutritional model for deer habitat (Hanley and Rogers 1989).

Fish

Thirteen streams are separated into three gradient zones and are being sampled seasonally. All streams are fed by headwater tributaries dominated by alder or conifer riparian forests. The three gradient zones include: the general upper range of salmonid habitat (gradient 7-15 percent); moderate gradient reaches (gradient 3-7 percent); and floodplain reaches (gradient 0-3 percent). Fish densities and species distribution are being compared among treatments (alder vs. conifer) and among gradient zones. Each stream is being surveyed using a modified tier III survey (USDA FS 2001). Key habitat measurements include large wood size and volume (Gomi et al., in press), substrate composition, and pool metrics including area and residual depths.

Geomorphic and Landscape Processes

The association between disturbance history and tree species composition is being assessed at 22 sites within three forest types (conifer young growth, alder-conifer young growth, and old growth). The relative magnitude of woody debris and sediment inputs by various disturbance processes including landslides, blowdown, bank erosion, and tree death are being estimated (and field verified) by using current inventories of landslides and process models. Site characteristics described include average slope gradient, substrate size, landform type, landslide history, and an estimate of contributing area. Pool formation in the upper and moderate gradient zones of salmonid habitat is categorized as no pools, one pool, or multiple pools. Results for pool occurrence are being compared between alder- or conifer-dominated streams.

Research Objectives

We are broadly assessing the influence of red alder in the ecosystem and the linkages among overstory and understory vegetation, birds, bats, invertebrates, wood, and fishes (fig. 1). We are investigating mixed red alder-conifer forests and determining if these forests provide a greater biomass of understory vegetation and forage for herbivores (e.g., deer) and invertebrates than young-growth conifer forests. We are assessing the effect of mixed red alder-conifer forests on the abundance of aquatic, riparian and terrestrial invertebrates that are food resources for bats, birds, and fish (fig. 2). We are determining if most red alder trees die standing (as opposed to uprooting or bole snapping), and examining the woody debris and sediment input into streams. We also are investigating the flow of wood among habitats and the linkages between tree mortality and woody debris in riparian, headwater and lowland streams (fig. 3). We are determining the effect of red alder in mixed stands on conifer growth and total wood production. Our research is evaluating whether the inclusion of alder in young-growth stands may allow clearcutting in areas where purely even-aged conifer stands would compromise fish, wildlife and aquatic resources.

Management Implications

Although our current research focuses on young-growth forests of southeast Alaska, the potential exists to expand our understanding of the occurrence and role of red alder in unmanaged ecosystems to the landscape and regional levels. In addition, our research approach of integrating disparate disciplines can be used as a framework to study the role of alder in other regions or the manipulation of vegetation in relation to multiple, complex resource objectives. Knowledge gained from this research may find management applications elsewhere as summarized below.

Forest Vegetation

- Evaluate the compatibility and potential tradeoffs in wood production and biodiversity between conifer- and alder-dominated stands.
- Evaluate the relationship of stand structure and composition of mixed alder-conifer stands to wildlife, aquatic, and fisheries resources.
- Assess tree mortality and wood decay and evaluate woody debris input for aquatic and terrestrial forest habitats.

Hydrology and Geomorphology

- Relate disturbance history to composition of forest vegetation.
- Develop improved criteria for riparian buffer requirements.
- Develop guidelines for headwater channel management.

Aquatic and Riparian Ecology

- Develop guidelines for restoring headwater stream function and trophic biological and physical processes that support fish and wildlife.
- Develop guidelines for watershed restoration management to protect salmonid habitat.
- Evaluate invertebrate diversity and abundance and the potential for improving the insectivorous food base for fish and wildlife.

Terrestrial Invertebrates

- Evaluate vegetation for improving invertebrate diversity and abundance.
- Evaluate invertebrate diversity and abundance and prospects for improving insectivorous food base for wildlife.

Wildlife Ecology

- Evaluate potential for improving nesting and foraging habitat for birds in young-growth alder-conifer forests.
- Evaluate potential of alder-conifer forests for improving bat habitat.
- Improve wildlife habitat in young-growth forests by increasing understory vegetation and food resources for birds and mammals.
- Evaluate potential for mitigating losses of wildlife habitat from clearcut logging.

Acknowledgments

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Chapter 4

Social Systems

Combining Social and Ecological Needs on Federal Lands: A Global Perspective

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Abstract

For the past few centuries the human elements of Earth's ecosystems have not been in steady state; growth has far exceeded loss. That growth has consumed ever-increasing amounts of land, water, energy, crops, wood, and biodiversity. Sustainable forestry cannot stop at the forest border; it must encompass the human enterprise as well. Increasing global consumption, along with the easy transportation and global marketplace that has developed over the last 50-plus years causes demand on forest resources to be felt throughout the world. Increasing affluence in the United States and other developed parts of the world leads to high rates of individual consumption. In the past four decades, substantial areas of federal forestland have been "set-aside" through reservations for uses and values other than wood removal. The decline in harvest on federal lands has led to an ecological change in these forests. Inventories have built up to high, often unsustainable levels. Developing economically feasible and socially acceptable silvicultural techniques to restore healthy forest ecosystems, through removal of smaller, understory trees, is the major challenge we face in nearly 17 million hectares of federal forests. Actions are needed to supply the world's need for renewable forest resources. If applied judiciously to federal lands, these actions can make for healthy, sustainable forests. Providing ecological diversity, producing more wood, using more wood (instead of nonrenewable resources), and application of scientific knowledge to forest management, are essential components of federal forest management. To be successful in improving the ecological health on a global basis, we must look at each decision in a global context.

Keywords: Ecosystems, natural resource management, sustainability, global demand, consumption.

Introduction

The Multiple-Use and Sustained Yield Act of 1960 mandated that the USDA Forest Service manage the National Forests to provide sustained yields for its natural resources. In the early 1990s, the Forest Service adopted ecosystem management as a holistic approach to meet the mandate, as well as the demands and preferences of the diverse publics. Ecosystem management is defined as the use of an ecological approach that blends the needs of people and environmental values in such a way that the National Forests and National Grasslands sustain diverse, healthy, productive, and adaptable ecosystems (Robertson, 1992).

This paper addresses some perspectives on the evolving use and management of U.S. National Forest lands, and their relationship to natural resource management issues in a global context. While emphasizing federal forestlands in the U.S., addressing the topic of forest sustainability must include consideration of worldwide resource use and demand, population growth, and relationships between the human and nonhuman parts and processes of ecosystems to make sense of a very complex, global context. This paper will also address some perspectives on key resource issues facing the world today, and how these issues pertain to managing the National Forests.

The Forest Service ranks above the rest in ecosystem science. This is well documented in this report. However, we must consider more than just ecosystem science to determine where, how, and for what purpose we apply ecological knowledge. In order to do "intelligent tinkering" as Aldo Leopold suggested, good science has to go well beyond the environmental science we traditionally deal with to cover the issues that pertain to managing the National Forests. While ecological, silvicultural, genetic, and wildlife management information are needed for ecosystem management and sustainability, more is required if we are going to be prepared for a doubling in the population and the related increase in consumption and use of our forests. The following are themes on which this concept was developed:

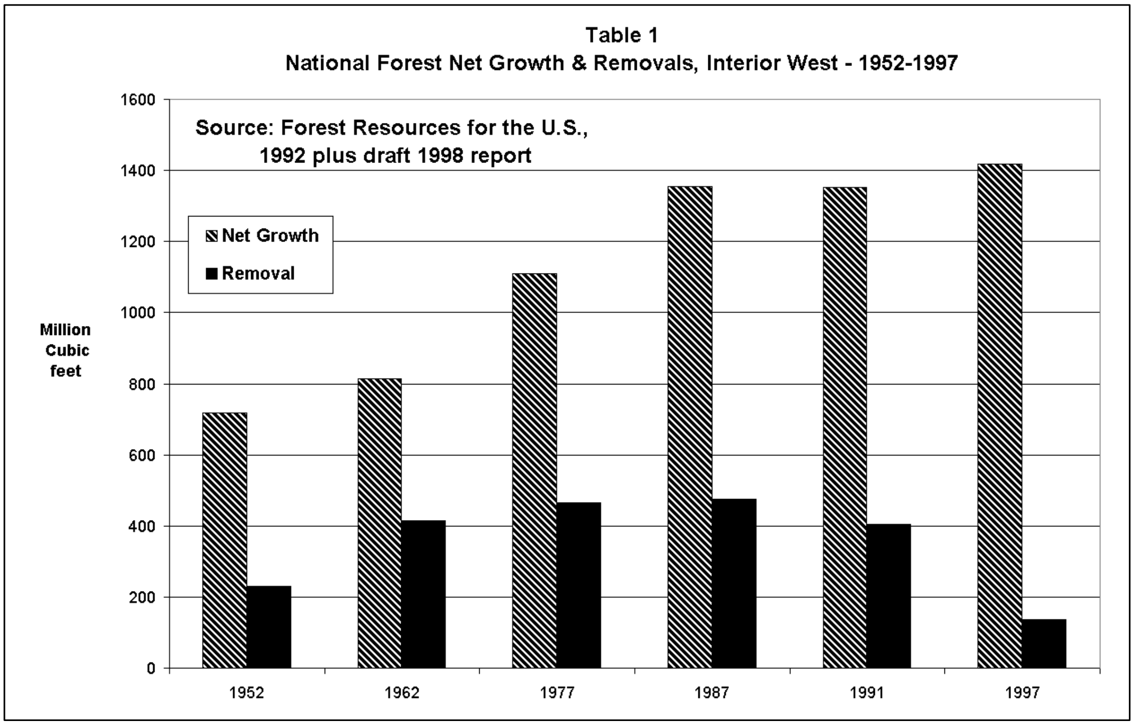
1. **Global demand and consumption. All humans** use natural resources, some more than others. We live in a global marketplace that satisfies its demands from one resource or another, or with resources from one place or another. The global population passed six billion in 2000. It has been estimated that population growth will double again before leveling off late in this century. Even the most conservative estimates indicate a population of around eight billion by mid-century. Feeding, clothing, and sheltering six billion people already consumes a high percentage of the world's resources. Unless personal habits of affluent cultures change, the impacts of projected population growth on world resources could be greater than just that reflected in the increase in numbers of people. For example, since 1970, the average family size in the United States has dropped by 16 percent, while the size of an average single-family house being built has increased by 48 percent (USDC 1970-1997). The use of paper has increased by 40 percent; printed-paper and paper checks by 100 and 200 percent, respectively; and fax paper use is also increasing. The following trends are expected during this period of population growth in the United States:

- Relative stability in forest area.
- Fourteen percent increase in domestic timber supply.
- Sixteen percent increase in housing starts.
- Increased demand for nonwood forest values including recreation, water, wildlife and wilderness.
- Increased biomass accumulation leading to more fire and forest health problems.
- Annual wood consumption is projected to increase from 525 million cubic meters (about 18.5 billion cubic feet; one cubic meter equals 35.3 cubic feet) in 1991 to 710 million cubic meters in 2040.

Between 1990 and 1997, timber harvest from U.S. federal forestlands, which formerly supplied about 25 percent of U.S. softwood timber production, declined from about 66 million cubic meters per year to 24 million cubic meters (Draft 2000 RPA Assessment). Because domestic demand for wood products did not decline in similar fashion during this period, this has caused a shift in tree harvest to U.S. private lands and to Canadian forests. Between 1990 and 1997, U.S. softwood lumber imports from Canada rose from 42 to 63 million cubic meters, increasing from 27 to 36 percent of U.S. softwood lumber consumption (Howard 1997, USTR 1996). Imports of panel products from Canada increased as much as lumber. Much of this increase in lumber imports has come from native old-growth boreal forests of eastern Canada. In Quebec alone, the export of lumber to the United States has tripled since 1990 (MacCleery). This is a prime example of the global transfer effects of domestic resource policies that consider only supply and only one sector of the potential supply source.

Due to the combined effects of world population increase and land use conversion, the amount of forestland available to each person has declined globally by 50 percent since 1960, to 0.6 hectares (about 1.5 acres). By 2025, projections indicate it will drop by another one-third to 0.4 hectares. Each U.S. citizen uses approximately 2.1 cubic meters of wood per year and this value is relatively constant over time. Annual consumption for the nation was 525 million cubic meters in 1991 and is projected to rise to 710 million cubic meters by 2040. Our net annual growth is 612 million cubic meters, so today the United States could supply its own needs without imports but would have to increase growth or continue to increase imports to do so by mid-century.

Substituting nonrenewable resources as wood alternatives needs serious consideration. On a daily average basis, each of the six billion people on Earth consumes about 1.6 kilos of wood. Half of that wood is used for energy by a segment of the population that cannot afford gas or other energy sources. What are some alternatives to wood use? All known wood substitutes are more energy consumptive to produce and labor consumptive to use, often by many times the cost. Steel, aluminum, cement, and plastics, for example, are nonrenewable resources, but their consumption pollutes the atmosphere with carbon dioxide. Wood alternatives



for paper includes fibers such as kenaf, hemp, and cotton. All of these substitutes may suffice for wood alternatives in the short term, but may not be better for the environment on a long-term basis. Nonrenewable wood alternatives may have less impact on the environment if they include, for example, electricity generated from fossil fuels that move tons of carbon from underground to the atmosphere. Transfer effects also need to be seriously considered.

2. **Global effects of local marketplace resource decisions**. The National Forests contain about 45 percent of the softwood lumber in the U.S., but supply only about one percent of the nation's needs. What are the global transfer effects of obtaining the balance elsewhere? Was it good science to stop harvesting on millions of acres of timberlands in the U.S. in the last decade under the auspices of protecting species, or to "protect biodiversity" or preserve roadless conditions where excessive fuel densities threaten to turn a lightning strike into a catastrophic wildfire? Have we done this in full consideration of the secondary effects? In North America, no species has ever become extinct due to timber harvesting. Growth on the National Forests (outside wilderness and other classified areas) is about 93 million cubic meters, yet we have decreased removals from around 42 million cubic meters in the late 1980s to less than 10 million cubic meters in recent years. Have we adequately considered the broad ecological effects, as well as economic effects, of moving this amount of harvest to other lands or of letting it accumulate on-site?

In the Southwest, net annual growth on the National Forests is five million cubic meters, enough solid wood to cover a football field to a depth of about one mile. This would also provide enough wood to build 95,000 homes of 1800 square feet. each! In recent years we've only removed about 1/10 of the annual growth; however, our consumption has not declined. We have moved much of the extraction of resources to other parts of the globe. This is often called "NIMBYism," referring to the "not in my back yard" philosophy. Table 1 compares growth to removal for the Interior West on National Forests.

3. **The role of wood removal in sustainable forestry and ecosystem health**. Since the 1960s, environmental laws have been legislated, each with a specific objective to either allow for public participation in land management, or to protect a specific value. Since 1970, challenges to the various environmental laws on a site-by-site basis have resulted in sweeping changes in how

National Forest lands are managed. Former Forest Service Chief Jack Ward Thomas (1996) stated: “It has become increasingly obvious that the overriding de facto policy for the management of Federal lands is the protection of biodiversity. That de facto policy has simply evolved through the interaction of laws, regulations, court cases, and expedient administrative direction. This de facto policy, I believe, is the very crux of the raging debate over the levels of commodity production that can be expected from Federal lands.”

Without a national debate on this issue, resource outputs, such as wood products, have become byproducts of lands managed for other purposes. Some environmental interest groups are now promoting a total logging ban on National Forests. However, timber harvest is a major tool for reducing stand density, and recent estimates indicate that there are more than 16 million hectares of western U.S. forestlands seriously overstocked, mostly with small trees.

In much of the world, over-harvesting and conversion to non-forest land uses are the most serious threats to forest sustainability. Over the last several decades, many National Forest lands in the U.S. have become seriously overstocked due to reduced natural fire levels and “under-harvesting.” The concept of “under-harvesting” as a problem is relatively new, and it is primarily a concern in short-fire-interval ecosystems where removal of this biomass by fire and decomposition has been interrupted. In these areas the risk of catastrophic disturbance and associated losses are grave. In many Interior West forests, precipitation has been above the long-term average for three decades, exacerbating the imbalance between forest growth and biomass removals. Some meteorologists are predicting a change to much dryer conditions; however, a major concern is that dryer conditions will lead to wildfire losses beyond tolerance, from which ecosystem recovery will be difficult, costly or both. To this end, the Forest Service is designing activities to restore more natural biomass density and biological diversity in these forests.

In some cases, with change from production forestry to restoration forestry, we still find a substantial yield of wood products. If wood is not removed from the land mechanically or by natural processes, such as cool ground fires, it will build up to levels that lead to catastrophic levels of fire, insects or disease.

Contrary to the Organic Act, Multiple-Use Sustained Yield Act, and the National Forest Management Act, many would have society believe that the National Forests have no significant role in supplying wood to meet societal needs. Yet, many believe that the National Forests still have a significant role in providing wood in an environmentally sound manner. Harvesting, for example, is a tool that can be used to move forests toward the desired future conditions of health and sustainability, as well as provide needed resources and jobs for society. The amount of wood removed may vary greatly depending on the forest ecosystem and also the effects of past management activities.

Shifting the Paradigm

Fewer actions can be taken to remedy problems and reach a more sustainable global environment. Obviously, some actions are within our control as resource managers, while others require society at large to be involved. Some key opportunities that have benefits are as follows:

1. **Provide diversity**. Avoid cookie-cutter prescriptions. Thinning from below, for example, will accomplish one goal; it will reduce fire hazards. However, such a prescription will create a new monoculture and depose natural diversity. U.S. southwestern forests are so far out of their natural balance that we need not worry about prolonged and extensive restoration treatments, as long as we provide a variety of conditions.

2. **Produce more wood**. Forests are self-renewable ecosystems. They produce more wood, more biodiversity, more wildlife, and other more renewable products. If forests can renew themselves from total annihilation by glaciers and volcanic eruptions, just think how much more they can produce with our growing knowledge of forest science, silviculture, biodiversity conservation, soils, and genetics. While providing a renewable source of raw materials using clean solar energy, they will also provide an abundant supply of habitat for the thousands of other species that depend on the forest for their survival.

3. **Use more wood**. The "use less wood" policy is anti-environmental because it would result in increased carbon dioxide emissions and reduce the rate at which "non-productive" private forests are converted to other uses. From an environmental perspective, the more appropriate policy is "grow more trees and use more wood." In other words, use wood responsibly instead of using nonrenewable resources.
4. **Understanding the role of science in decisionmaking**. In 1996, Jack Ward Thomas stated*:* "There is not a 'science solution' to today's problems. The sciences merely are a tool. All managerial decisions are moral, not technical. Science won't give you 'the answer.'"
5. **Apply scientific knowledge to managing forests and decisionmaking**. Forest ecosystems are complex, but our current legal/social situation is even more complex. There seems to be little connection between scientific knowledge of forest ecosystems and many of the decisions being made through the courts. The power to make decisions on managing forests has been taken from the majority (voters) and placed in the hands of a few. Those who have taken control are using the courts and various laws, particularly the Endangered Species Act, as tools to advance their agendas.

Conclusion

In summary, the National Forests are dynamic ecosystems, yet they face many challenges in the 21st century. Ecological, economic and political sustainability, forest products, forest health, biodiversity, endangered species, late-successional forests, lifestyles, accountability, public participation, trust, and increasing demand and consumption are foremost among these. In addition, they do not maintain a "steady state" balance, but over the long-term, growth and loss will stabilize.

The goal of ecosystem management is sustainability—from individual sites to the global biosphere. Given the immense consumption of natural resources by a world population of 6 billion and growing, and given the impacts of wood substitutes on the Earth's ecosystems, using available wood resources to restore desired conditions, might be a prudent strategy to achieve the goal of sustainability. Whatever the course, reducing the overall impact of the human enterprise on the Earth's ecosystems will be a necessary component of sustainable forestry.

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Summary

The Future of Silviculture Research—Thoughts from the Yale Forestry Forum

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Abstract

The 1999 Yale Forestry Forum, sponsored by Yale University and the USDA Forest Service, brought together a number of experts in an academic setting to discuss the future of silviculture research in the next century. Four participants in the plenary session outlined three areas that will characterize the future of silviculture research—sustainability, flexibility, and rigor. Sustainability includes two elements—sustainability of practices at different scales of management, and striking the appropriate balance of conditions across the landscape. Flexibility has three elements—feasible 'silvicultural pathways' for species of interest, research within and among a wide scale of intensities of management, and silviculture for a variety of 'at risk' situations. Rigor has two elements—silviculture research as a subset of a larger array of response variables, and maintenance of high standards of statistical design for silvicultural research. The implications of these and other elements raised for future funding of silviculture research remains unclear, but will give the silviculture research community an opportunity for enhanced discussion of priorities in the immediate future.

Introduction

In October 1999, staff from the Office of the Deputy Chief for Research of the USDA Forest Service collaborated with faculty and professional staff from the School of Forestry and Environmental Studies at Yale University to exchange ideas on the future of silviculture research (Wishnie et al. 2000). Organized under the auspices of the Yale Forestry Forum, the program was highlighted by a plenary session in which invited experts from government, industry, academia, and a non-government organization presented views from each perspective on the prospects for silviculture in the next century, and the research that would be needed to support those prospects. Following the plenary session, a roundtable discussion was held that featured the invited experts as well as a number of other active and respected silviculturists from academia, government, and the private sector. Adding to the value of that discussion was the participation of the graduate student body at Yale and the College of Environmental Sciences and Forestry from the State University of New York at Syracuse.

This paper presents highlights and key concepts from the session. It should not be considered to represent the views of the USDA Forest Service, or of the Yale School of Forestry and Environmental Studies. Rather, the ideas brought forward here represent the authors' view of the concepts and priorities for silviculture research based on comments of the forum participants during both the plenary session and the roundtable discussion. Nor should these ideas be considered as the ultimate contribution on the subject. The virtue of hindsight, enabled by a review of transcripts of the session, and the opportunity to consider perspectives and input from other experts not available to those at the meeting, can lead to the introduction of new ideas or the heightened awareness of others raised but not dissected in detail at the Yale Forestry Forum. These will, and should, also contribute to the larger discussion as well.

Thus, rather than the final word, this paper should be viewed as the beginning of a larger discussion among the profession about the future of silviculture research. The authors hope that this work can promote that larger discussion in a number of appropriate venues, including this 2001 National Silviculture Workshop.

Methods

Organizers of the Yale Forestry Forum invited four keynote speakers to kick off the symposium, and arranged for the participation of a dozen other practicing research and academic silviculturists. Most, but not all, in attendance were from institutions—Yale and others, and the Northeastern Research Station of the USDA Forest Service—located in the northeastern part of the country.

The Forestry Forum was organized in two sessions—a plenary session and a roundtable discussion. The Plenary Session was conducted as four half-hour presentations, followed by a general question and answer period. Participants in the Plenary Session were:

1) Dr. Greg Aplet, Research Ecologist, The Wilderness Society, Washington DC;
2) Dr. Chadwick D. Oliver, Professor of Forestry, School of Forest Resources, University of Washington, Seattle WA;
3) Dr. Susan Stout, Research Forester and Project Leader, Warren Forestry Sciences Laboratory, Northeastern Research Station, USDA Forest Service, Warren, PA; and
4) Dr. John Hodges, Woodlands Manager, Anderson-Tully Company, Memphis TN, (former faculty member, Department of Forestry, Mississippi State University, Starkville, MS).

The Roundtable Discussion included these experts and others. Opportunities for extended input were given to a half-dozen other prominent academic and agency research silviculturists, and to several practitioners attending the forum. Finally, a round of opportunities for comments were taken from the floor, and prominent among these were what might literally epitomize the future of silviculture research—members of the Yale graduate student body. Thus, the discussion pool included largely individuals from one region of the country, and largely one philosophical perspective—virtually everyone at the meeting would not hesitate to conduct active interventions in a stand should conditions so warrant. Results from the discussion should be interpreted from this perspective.

Both sessions were taped, but with different formats. The plenary session was videotaped. This offered good opportunities to review speakers' overheads, provided that they were of sufficient clarity and resolution to review on the VHS format. The roundtable discussions were taped by using cassette audio tapes. This provided a few different problems in review. Not all speakers identified themselves or were known to the reviewers of the tape; others spoke too softly, or were seated too far from the microphone to allow their comments to be clearly heard. By and large, however, the authors think that these comments allowed for a reasonably complete capturing of the comments raised by the Forum's many participants.

In such circumstances, the challenge to the authors was not too little material, but too much. The challenge of this review-through-media format is to collect, organize, synthesize, and evaluate the material raised by those attending the Forum. Any shortcomings in interpretation or omission of comments are to be blamed on the authors.

Results

Plenary Session

A number of major comments arose from the comments of the four speakers at the plenary session. These were centered in three key areas: sustainability, flexibility, and rigor. Specific comments can be broken down into eight key areas:

Sustainability

Sustainability of practices at different scales of management. The definition of sustainability at the stand and landscape scale is not clear in existing silvicultural literature. Nor is the contribution that silviculture can make a clear one to understand. Delinking the public's assumption that silviculture is synonymous with timber production is a key element.

Striking the appropriate balance of conditions across the landscape. Several speakers pointed to the need for more thought and research to the dynamic distribution of conditions across the landscape, and the silvicultural contributions to that balance. A strong analysis and discussion of the intensive plantations, reserves, integrated management approaches from the financial, social, and economic perspectives is needed and has yet to occur.

Flexibility

Feasible 'silvicultural pathways' for species of interest—Despite some seven decades of productive research on specific species, many species of interest to land managers are underrepresented in the scientific literature. This is especially the case when considering reproduction cutting methods such as the shelterwood and single-tree selection, or intermediate treatments such as the use of prescribed fire. Learning more about applying a wider variety of silvicultural treatments to a wider variety of situations is a high priority.

Research within, and increasingly among, a wide scale of intensities of management—While plenary session speakers disagreed about the details of this key area, there is support for continued research in intensive management among industry clients and expanded research in natural stand management.

Silviculture for a variety of 'at risk' situations—Enhanced understanding of how silvicultural practices can be used for hazard reduction (acute, such as pestilence, or chronic, such as extensive herbivory or buildup of fuels near areas that require fire protection). Techniques for restoration of plant communities underrepresented on the landscape (such as longleaf-wiregrass restoration, restoration in the lower southeastern Coastal Plain or shortleaf pine-bluestem restoration in the Interior Highlands) would also be of interest. Especially valued would be an understanding and acceptance that silvicultural manipulations can be applied in specific instances to improve habitat of endangered, threatened, and sensitive species. There are instances in the literature where this has been documented.

Rigor

Increasing understanding the context for and variety of responses to silvicultural manipulation—More and more, participants held the view that silviculture of the next century would not remain viable in the absence of experiments that embrace a broader variety of response variables. The professional interactions that result when silvicultural research is conducted in juxtaposition with wildlife, social science, economics, and other disciplines adds not only to the studies themselves but also to the perspective of silviculturists.

Maintenance of high standards of statistical design for silvicultural research—Finally, plenary session participants were of the opinion that rigorous experiments should be the norm rather than the exception. It is critical that new experiments be subject to statistical evaluation before installation. The difficulty in this challenge is to capture appropriate degrees of experimental error by using appropriate statistical designs as spatial and temporal scales increase.

Roundtable Discussions

A number of points were raised in the discussion session that differed from the concepts raised in the plenary session. In some cases, the discussion expanded considerably on the main elements initially raised in the plenary session. In others, new elements were introduced. The main elements follow:

Cohesion across ecogeographic boundaries—Several participants commented on the potential value of a common experimental design and data structure in the context of silvicultural practices research. For example, a new group selection study might be developed using a common study design and similar measurement protocols across a variety of forest types. By comparing and contrasting results across forest types, scientists could develop better conceptual models for group selection that clarify what elements of the prescription apply for a specific forest type, and which elements appear to hold across all forest types.

Enhanced understanding of social needs—Some participants observed that the understanding of silviculturists about society's larger needs from forests was limited at best. Few would disagree that improvements in understanding the values of society and the needs of society for forests in the next century might be good information to have in designing silvicultural experiments.

Technology transfer—Information about accepted sound forest management practices was available in the literature, but was not getting into the hands of private landowners or forest managers. Periodically, foresters find themselves in conflict with their peers not because either is wrong, but because one has had the opportunity to learn something the other one hasn't. This seems to be an especially persistent problem on private non-industrial lands where exchange of information, both researchers to practitioners and practitioners to practitioners, can be limited. Moreover, some foresters cross the line of accepted ethical application in withholding certain silvicultural recommendations from private landowners if implementing those recommendations might reduce the fee the forester could collect. State extension offices, technology transfer experts within the Forest Service, and professional societies such as SAF should revisit the mechanisms needed to link research with the on-the-ground folks, the consultants, the field foresters for industry and government agencies, and the state service foresters. Research findings are of minimal value unless they can be translated to application in the woods.

Attentions to a broader spectrum of landowners, especially small-parcel NIPF landowners—Landowners with small ownerships on the order of 20-300 acres provide a particular challenge for foresters, given the marginal operability for many silvicultural practices, and the marginal profitability for consulting foresters, on tracts in this size. Many landowners don't have the resources to pay for good silviculture or management practices. To this end, ways should be identified to make a quality job of vegetation management on small parcels affordable to landowners. Understanding the development of these stands and possibilities of a range of benefits and costs from manipulating that development is the key information that needs to be developed and transferred.

Silviculture for values other then timber—An important transition for silviculturists is to increase the breadth of silvicultural research beyond simply timber growth and yield. The great bulk of landowners are not just going to produce timber, but are very interested in what effects the production of timber has on related resources. People's values don't always mesh very well with the information that silviculturists are trying to peddle—especially smaller landowners and, increasingly, the general population with respect to public lands. Moreover, time has shown the weakness of the post-war axiom that 'good forestry for timber is good for everything else.'

Silvicultural implications of the 'range of natural variability' concept—From the research perspective, a focus on silviculture as applied stand behavior and ecology rather than as a tool for production of timber or creation of habitat for a single endangered species may carry greater flexibility to meet uncertain future resource issues. Studies developed broadly in the context of ecological fundamentals rather than the question of the day will have a better chance of producing relevant research over time.

Role of traditional production research— A small but important component of the forest land ownership base—forest industry—will continue to emphasize research on intensive silviculture. This is especially the case in making refinements in development of genetically improved planting stock (such as for enhanced physiological uniformity or resistance to herbicides), improvements in strategy and tactics of chemical silviculture ("weed and feed" mixtures of herbicides and fertilizers, or increased precision in application rates depending on seedling or sapling attributes within a stand), and tailoring of silvicultural practices to anticipated products. Finally, companies are discovering that fewer people in the woods leads to fewer liability issues, but the challenge of maintaining rates of production with fewer workers will lead to continued research on the operations side of silviculture.

Economic interpretations of silvicultural experiments—Many silviculturists lack extensive training in financial analysis, but added value would immediately result from application of economic and financial analyses to silvicultural studies. For example, many long-term, large-scale habitat studies lack this component, and as a result, it can be difficult to convince landowners of the costs and benefits of silvicultural practices. Information on the financial aspects of management is critical when translating research results using language to which landowners, especially NIPF landowners, can relate. And this can, in most instances, be done with very little additional effort, but should be incorporated into the planning of the work.

Discussion

This document represents the first step to capture the thoughts and opinions of scientists and practitioners of silviculture regarding the future of their field. A broader review will be conducted through staff members and field scientists in Forest Service Research and Development to build upon some of these issues, discount others, and raise new issues not brought forth to date.

The panelists and roundtable participants consistently held that silviculture must increasingly encompass a greater diversity of treatments, larger scales, longer timeframes, more disciplines, and more landowners. There is clearly a role for traditional production research, especially in the high-technology arena of tree breeding for resistance to herbicides, insects, and pathogens, but there's a corresponding interest in applying silviculture in the context of restoration of natural systems. And, clearly, more attention must be given to the distribution of research products—through technology transfer and to clients that have not been reached by using the extension tools of the past few decades.

For scientists, the challenge will be in implementing these changes; for research administrators, the challenge will be in development of the support infrastructure to support their implementation. It may be that different organizational pathways and research work unit structures must be developed to implement and fund these changes. But the general tenor of discussion is clear—silviculture is not just for timber management any more, if it ever was.

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