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Use of large-scale silvicultural studies to evaluate management options in Pacific Northwest forests of the United States

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Abstract

A suite of large-scale silvicultural experiments has been established to develop and assess operational silviculture options for the Pacific Northwest Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) forests. This paper summarizes three such studies that focus on three major stages in the life of managed stands – early development, midrotation, and regeneration harvest. Development of silvicultural treatments that are needed to restore and maintain Oregon white oak (*Quercus garryana* Dougl. ex Hook.) within mixed-species stands in western Oregon and Washington are also presented. In addition to responses of overstory trees and understory plants to silvicultural treatments, several other aspects, such as coarse woody debris retention, residual stand damage, soil disturbance, economics, and public acceptance of treatments, are also being investigated in one or more of the studies. Advantages, special considerations, and challenges of conducting large-scale, operational silviculture research studies are discussed.

Keywords: silviculture research, stand manipulation, forest structure, habitat

1 Introduction

The forest landscape in the Pacific Northwest (PNW) region of the United States of America has changed dramatically over the last century. This is particularly evident in the Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) region in western Oregon and Washington. Large areas of old-growth forests were harvested and replaced with young-growth stands, agriculture, or urban development. During the last three decades, this change in forest cover became a national focus for the environmental movement's efforts to preserve old-growth forests, galvanizing the public's displeasure with clearcutting as the primary harvest method for these forests. During this same period, several plant and animal species in the region that are dependent on older forest structures were identified as threatened or endangered with extinction under the Endangered Species Act of 1973 and the National Forest Management Act of 1976 (USDA Forest Service, 1993). These listings, coupled with legal actions by concerned groups and the public's dislike for clearcutting, stimulated interest in development of alternative forest management strategies and silvicultural practices.

Over the last decade, managers have proposed and implemented many strategies and associated practices for managing young-growth forests for multiple objectives. In many cases, practices are intended to maintain or accelerate development of forest structural components that are common to older, natural forests and needed as habitat for species dependent on particular forest types. In addition, options for harvesting and regenerating young-growth stands with less impact than clearcutting on visual aesthetics and other forest values are being implemented.

1.1 Past research and management experience in the Douglas-fir region

In general, past research and management practices in the Douglas-fir region focused on clearcutting followed by establishment and management of even-aged plantations. This traditional approach emphasized managing one (or a few) primary tree species in uniform stands. Early management practices were designed to reduce competition from non-timber 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 maintenance of non-commercial plant species or habitat for animal species associated with older forest structures. CURTIS *et al.* (1998) reviewed the historical development of silvicultural regimes in the PNW and point out how practices used for wood production 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.

Unfortunately, there is little research or operational experience to validate success of new silvicultural approaches now being proposed and implemented for managing young-growth stands. Most of the existing work with alternatives to even-aged management in the Douglas-fir region was done in old-growth stands and has little relevance to management of young-growth stands (CURTIS 1998). Several new studies have been designed and implemented in the PNW, but results will require decades of careful remeasurement (PETERSON and MONSERUD 2002).

Proposed silvicultural approaches are generally intended to develop stand structures that mimic observed characteristics in older stands that developed following natural disturbance. It has been assumed that it is desirable to increase both species diversity and structural heterogeneity within stands. However, no young-growth stands have been managed and rigorously studied for an extended period of time under these proposed alternative regimes. Even less research has been conducted to validate silvicultural treatments for maintaining or restoring uncommon forest communities such as mixed conifer-oak (Oregon white oak or Garry oak [*Quercus garryana* Dougl. ex Hook.]) woodlands in western Oregon and Washington. Thus, estimates of treatment responses, costs, and benefits are based on major extrapolations from quite limited data. In addition, there has been very limited integrated experimentation focused on how a variety of factors (i.e., understory and overstory species composition, vertical and horizontal distribution of trees, snags, coarse woody debris [CWD] within a stand, and age and size distribution of trees) affect plant and animal populations or how altering these factors will impact tree growth, stand differentiation, habitat functions, or the production of forest products.

1.2 Large-scale silviculture experiments for multipurpose forest management

Today in the PNW region, forest managers are required to balance often competing societal values attributed to forests (e.g., wood production, wildlife habitat, water quality, recreation, and visual landscape aesthetics). When evaluating silvicultural options intended to produce diverse forest values, experiments must be designed to measure appropriate response variables for all forest values for which statistical inferences are to be drawn. There are several benefits associated with such large-scale, multi-values experiments; however, several aspects require special consideration at the planning stage.

Benefits:

- *Excellent demonstration areas* – Large-scale silviculture experiment sites provide outstanding demonstration and tour sites. They provide on-the-ground examples that interested managers, scientists, and the public can view and use to develop their own opinions regarding alternative silvicultural options. They also provide a venue for conducting public education on natural resource issues.
- *Operational experience* – During the course of installing large-scale operational silviculture experiments, forest management staff gain experience with designing and implementing alternative silvicultural prescriptions. Likewise, forest contractors gain experience dealing with operational challenges presented by each alternative (e.g., variable density thinning on steep mountainous terrain).
- *Integrated examination of silvicultural effects on multiple values* – Given the complexity of interactions between forest flora and fauna and stand structure, it is only through large-scale silvicultural experiments that we can simultaneously investigate multiple responses that affect diverse forest values at differing scales.
- *Testing of existing growth and yield models* – These large-scale studies provide operational-scale empirical growth datasets that can be used to check or update existing growth and yield models. Most existing models were developed using data collected from uniformly spaced trials. Such uniform spacing is not what actually occurs in operational forest management units, particularly in many of the alternative silvicultural options now being implemented. Large-scale, variably-spaced treatments tested in these studies provide ample opportunity to quantify deviations in actual growth response from predictions made with existing models.
- *Study sites provide testbeds for future studies* – These large, heavily sampled areas with diverse forest structures provide excellent sites and vegetation data for other studies (e.g., testing remote sensing techniques for measuring forest vegetation structure).
- *Unique examples for future studies* – Large-scale silviculture experiments create large units with diverse and often uncommon forest stand structures. These units may provide unique sites for future scientists and managers to address questions that will only become apparent long after the original experiments were designed.

Special considerations:

- *Large treatment units* – Responses to silvicultural treatments with respect to diverse forest values (e.g., wildlife population changes, stand growth, changes in visual aesthetics, operation costs and production rates) vary at different scales; therefore, large-scale silviculture experiments are often required to encompass treatment units large enough to sample response measurements at appropriate scales and intensities. For instance, many wildlife species of interest are quite mobile. In order to study them, large enough treatment areas are needed to develop many of the stand structures of interest (e.g. gaps and variable density stands) and to capture patterns in habitat use. Operational-size units are required to measure production and to examine changes in visual aesthetics at both stand- and landscape-levels.

- *Operational implementation of treatments* – When large treatment units are required, it is usually impossible to fund and install such units unless they are designed to be implemented as part of typical, ongoing forest operations. This has the advantage of paying for treatment implementation, but also the challenge of limiting treatment designs to those that can be reasonably implemented with standard forest operations contractors and standard contracting mechanisms.
- *Increased sample sizes and larger measurement plots* – Measurement plots must be large to allow better characterization of multiple-scale response variables. More plots are often needed to better account for higher variations in pre-treatment conditions found in larger treatment units. It is often difficult to find sufficiently large study sites that have treatment units with similar stand age and structure.
- *Higher costs than simple growth and yield experiments* – Large-scale silviculture experiments are more costly to conduct than traditional growth and yield studies. If one is only interested in tree growth response, plot-level experiments can be installed in smaller, more homogeneous sites (with correspondingly fewer plots needed to achieve the same desired standard error of estimate).
- *Coordination and cooperation between scientists, management staff, and forest operations contractors* – When many diverse forest values are evaluated on the same study sites, scientists, forest site managers, and forest operations contractors from many organizations and locations are usually involved in the experiment. Scientists responsible for each aspect of a large multi-disciplinary experiment must work together to develop an overall statistical study design that will allow subsequent analysis of treatment differences. Prior to initiating field measurements, sampling protocols designed to accommodate multiple analyses must be agreed upon by all parties. Considerable coordination is required to insure that sample plots are properly located, installed, measured, and monumented prior to treatments, that appropriate operations records are maintained by both forest managers and contractors, and that scientists and field technicians are available prior to, during, and after treatment implementation to collect time-sensitive data (e.g., soil disturbance, stand damage, or harvest system production data).
- *Long timeframes for sampling* – If changes in wildlife populations are to be examined, sampling of populations often must be conducted for one or more years prior to implementation of treatments to establish baseline population dynamics. If treatments are delayed for several years, pre-treatment surveys may need to be repeated to maintain accuracy. Likewise, post-treatment wildlife surveys must be completed on schedule and usually conducted for several years to determine effects of treatments. Tree growth plots must be periodically remeasured, usually for many decades and often long after the original scientists have retired. Therefore, the science teams that enter into such large-scale, long-term experiments must be reasonably confident that funds and staff will be available for such remeasurement activities. Also, documentation of procedures, treatments, operations and measurements, along with the creation of databases, is critical for long-term viability of the study.
- *Land management organization cooperation and long-term commitment* – It is essential to find a forest management agency that is willing to commit the necessary forest land base on which to install such long-term studies. The land management organization must be willing to instruct its forest operations staff to cooperate with scientists in the layout and implementation of treatment units. Additionally, scientists must communicate frequently with the agency to insure that managers and planners know where the study is located and that it must not be disturbed without first consulting with scientists. The cooperating

land management organization must also be willing to incur additional management costs associated with implementing non-traditional forest operations. Organizations may have to forego maximizing revenues on study site lands that may have harvests delayed for decades due to study requirements.

Given that large-scale silviculture experiments require long-term (usually several decades) commitments of funding, staff, and land, they should be carefully planned and not initiated without reasonable confidence that they can be maintained for many years into the future.

2 Silvicultural options experiments in the Douglas-fir region

The Silviculture and Forest Models (SFM) Team of the USDA Forest Service, PNW Research Station is conducting several studies of silvicultural options for young-growth stands. These studies are evaluating the results of management options intended to produce multiple resource outputs and habitat values. Four such studies are briefly 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 stand development (precommercial thinning, generally within 20 years of stand initiation), midrotation (commercial thinning, generally from 20–80 years after stand initiation), and regeneration harvest (generally between 40–100 years after stand initiation).

2.1 Early stand development options – alternative silviculture in young Douglas-fir plantations: Clearwater Creek

In recent years federal natural resource management agencies in the PNW region have placed increased emphasis on young stand management, including ways of directing some stands onto pathways leading to the development of old-growth structural characteristics. A study has been established that is investigating silvicultural options for creating diverse stand structures by treating young, even-aged plantations. The study area is in the Clearwater Creek valley of the Mount St. Helens National Volcanic Monument in the Gifford Pinchot National Forest in western Washington. The forests in the area were completely destroyed by the 1980 volcanic 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 SFM 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 therefore habitat.

2.1.1 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.

2.1.2 Study design

Five treatments were designed and replicated five times in the study area, resulting in a total of 25 plots. A brief summary of the main aspects of each treatment is given below.

A) Control plots with no treatments planned for several decades. Plots were not thinned. These plots have stands that are very uniform with one primary species (Douglas-fir), a fairly dense spacing of 1680 trees per hectare (ha), and very simple stand structure (one canopy layer and very little understory vegetation).

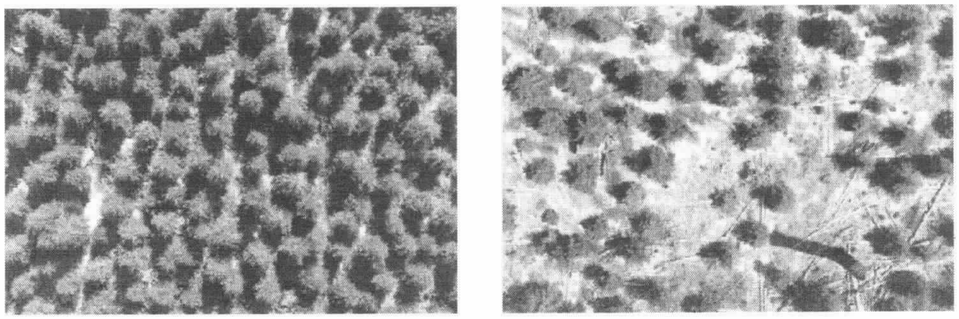
B) Thinning (Fig. 1a) to emphasize uniformity of species composition and stand structure. Plots were evenly thinned to approximately half their original density. Stand treatments were not intended to alter species composition and are similar to traditional silvicultural practices within the region designed to maximize economic return on the production of timber. 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. Also, 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 following the initial uniform thinning, an additional 250 Douglas-fir trees per ha were removed to form small, evenly spaced openings (approximately 150 m^2). 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, preference for leave trees 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 following the initial thinning, an additional 250 Douglas-fir trees per ha were removed in unevenly spaced clumps that created circular openings of three sizes: approximately 75, 150, and 225 m^2. 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, 75 large, vigorous trees per ha are to be selected for growth enhancement via fertilization. Fifty of these large trees will be kept in an open growing 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 250 m x 250 m (6.25 ha) including a 27.5 m treatment buffer. Within each plot, two or three 40 m x 60 m measurement subplots were located after initial treatments were applied in 1994 or 1995. 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).



a) b)

Fig. 1. Aerial View of uniform (a) and irregular (b) thinning in the Clearwater Creek valley. The plantation was 12 years old at time of thinning, when these photos were taken.

2.1.3 Current status

Trees in subplots were tagged and measured immediately after initial treatments were applied and then remeasured three and five years after treatment. Understory and ground vegetation surveys in the form of small area plots and transects were conducted two and five years after initial treatments.

All plots were juxtaposed over a large, highly homogeneous area with regard to climate, aspect, topography, and soil. This resulted in a high degree of similarity among and within treatment plots prior to manipulation, 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 due to the extreme nature of the volcanic disturbance made it relatively easy to manipulate species composition by planting and seeding. Although no wildlife surveys have yet been initiated, one might expect that wildlife populations would vary between treatments as stand structure differentiates over time.

2.2 Midrotation options – Olympic habitat development study

Well-stocked stands in the Douglas-fir region with closed canopies often have very 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 low in plant diversity for many decades. However, retrospective studies suggest that the presence of well-developed understory and midstory vegetation, cavity trees, and coarse woody debris (CWD) could result in young, managed stands functioning as habitat 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 SFM and Ecological Foundations of Biodiversity Teams from the PNW Research Station 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 in northwestern Washington.

2.2.1 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.

2.2.2 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 6–10 ha in size. Study stands are 30- to 70-year-old 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 (20 m x 20 m) gaps to allow increased light to reach the understory without undermining stand wind resistance, and 75 percent lightly thinned from below (removal of 25 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 are the five treatments that are being applied:

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 non-merchantable logs were not sufficient to meet CWD targets, additional trees would be felled and left as CWD. The CWD clumping treatments were also 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).

2.2.3 Current status

Pretreatment baseline data on small mammal and amphibian populations were collected during 1995–1998 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 were also used to study forest floor and soil seed banks, understory species root characteristics, and invertebrates associated with CWD.

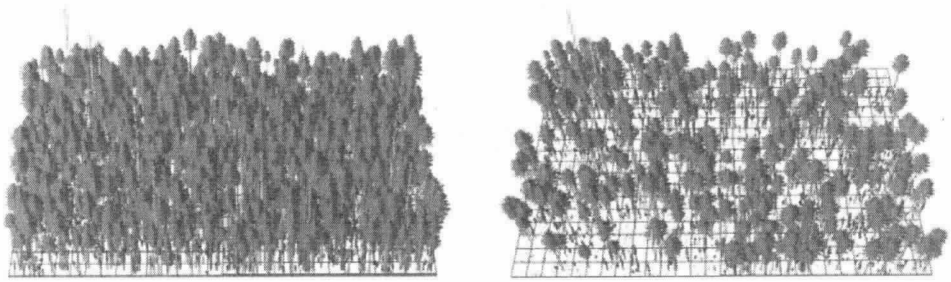


Fig. 2. Computer-simulated images of a portion (3.2 ha) of one of the stands in the Olympic Habitat Development Study before (a) and after (b) application of the variable thinning treatment. Height of snags is exaggerated to increase their visibility. Note that uncut patches were located to preserve snags.

Thinning treatments are being implemented through the timber-sale program of the Olympic National Forest. Five blocks were thinned during the period from 1997 to 1999; one block was thinned in spring 2003; one block remains to be thinned in 2004–2005; and, the last block is not currently scheduled for thinning. The original plan called for all blocks to have been thinned by 1999. Thinning treatments were delayed on the last three blocks because additional field surveys for species of concern were required by the Northwest Forest Plan (TUCHMANN *et al.* 1996).

A retrospective analysis of the influence of residual CWD and vegetation on small forest mammals was completed (CAREY and HARRINGTON 2001). Post-treatment surveys of windthrown trees and residual stand damage were completed on four of the thinned blocks. Surveys of understory vegetation three years after thinning were completed on two blocks and reported by HARRINGTON *et al.* (2002). Three blocks have had some of the CWD treatments and supplemental plantings implemented following thinning. The first two blocks to be thinned were remeasured to estimate tree growth during the five years since treatment. Analysis of these tree growth data will provide an indication of the spatial variation in responses to variable density thinning.

2.3 Regeneration harvest options – silvicultural options for harvesting young-growth forests: Capitol State forest

The wood-producing roles of state, industrial, and private forests have become increasingly important as timber harvesting from federal lands has declined. The Washington State Department of Natural Resources (DNR) is one of the largest non-federal forest owners in the PNW region, 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 has stimulated interest in, and encouraged limited application of, a variety of 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 SFM 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 maintaining a high level of timber production.

2.3.1 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.

2.3.2 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 three replications. All blocks are on DNR Capital State Forest, a highly productive young-growth forest southwest of Olympia, Washington. Treatments are being installed as part of the 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 will also permit evaluation of foreground and landscape-level visual effects. Treatments are applied in harvest units of 10 to 30 ha each. The initial treatments are (Fig. 3):

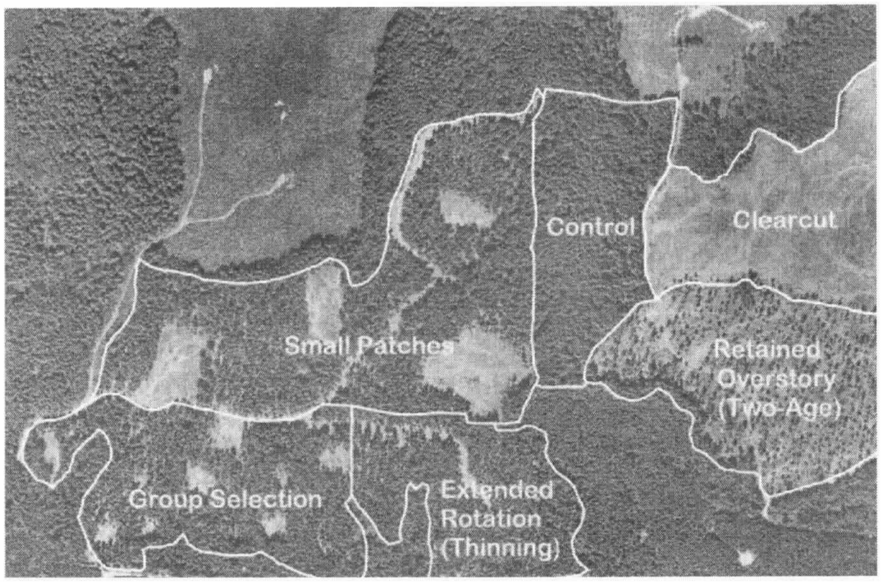


Fig. 3. Aerial photograph taken in 1999 of the Blue Ridge study site showing initial treatment units (yellow).

A) Clearcut – a conventional even-aged system widely used in the Northwest and elsewhere. All merchantable and nonmerchantable (diameter-at-breast-height > 2.5 cm) 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 40 evenly spaced trees per hectare left as the residual stand.

C) Small patch cutting – an even-aged system in which small openings (0.6 to 2 ha 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 0.6 ha 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 approximately 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.

Regeneration in treatments A to D will be achieved primarily by planting in openings that are larger than 0.05 ha, with some supplemental 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 60–75 years, with precommercial and commercial thinnings conducted as stand densities exceed desired targets.

Treatment B plots will be managed similar to the clearcut plots, except that the residual overstory (40 trees per ha) will be retained for several decades. Plots that initially receive treatments C to E will be retreated (using the same guidelines that were used during initial treatment) approximately every 15 to 20 years when stand densities exceed target ranges.

Permanent, circular, fixed-area plots (0.08 ha) were installed and measured prior to treatment. Plots were located on a regular grid within each plot. Regeneration and shrub cover were measured on small, fixed-area plots.

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

2.3.3 Current status

The first replication (Blue Ridge site) was harvested in the summer of 1998 and replanted in the spring of 1999. Pre- and post-harvest tree and vegetation measurements have been completed, as well as residual stand damage and soil disturbance levels. Logging production and cost information and wood products yields were collected. Pre- and post-harvest photographs within each treatment unit have been taken, and a survey of public preferences for treatments has been conducted by University of Washington cooperators. A post-treatment survey of song birds has been completed by the Ecological Foundations of Biodiversity Team. CURTIS *et al.* (2004) summarize the establishment and early results from the Blue Ridge replication. The Blue Ridge site is scheduled for its first remeasurement in the fall of 2003.

The second replication (Copper Ridge site) was harvested in the summer of 2002 and replanted in the spring of 2003. In contrast to the Blue Ridge replication, which is located on relatively gentle terrain and was harvested using a ground-based system, the Copper Ridge replication is located on steep terrain and was harvested using a cable logging system. As was done in the first replication, pre- and post-harvest tree and vegetation measurements have been taken. Information was collected on harvesting production and costs and wood products yields from each treatment unit. Photographs of the treatment landscapes have been taken in order to assess public preference and acceptance of each treatment. Post-harvest residual stand damage and soil disturbance surveys were completed. Song bird abundance surveys are planned in 2003. Remeasurement of the Copper Ridge replication is scheduled for fall of 2007.

The third replication (Rusty Ridge site) has been designed and pre-harvest growth plots have been established and measured. Harvest is scheduled in 2004. In addition to these three replications in Washington State, the British Columbia Ministry of Forests (BCMOF) plans to install three replications of the study on Vancouver Island, Canada. The first BCMOF replication was installed and harvested in 2001. The second BCMOF replication is planned for 2004.

Basic comparisons between treatments that will be made include tree growth and stand development, public response to visual impacts, harvest operation productivity and economic assessments, levels of soil disturbance, and song bird abundance. 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.

2.4 Restoration options – management of Oregon white oak woodlands: Fort Lewis

Oregon white oak (also commonly known as Garry oak) savannas (areas with low-density of trees and a grass-dominated understory), oak fringes around prairies, and oak woodlands provide unique habitat for many plant and animal species in the Pacific Northwest. These habitats are rapidly disappearing as conifers invade these communities and eventually overtop the shorter, shade-intolerant oaks or as woodlands are converted to conifer production or agricultural or urban uses.

In pre-European settlement times, these oak communities underwent frequent low-intensity burning by the native peoples. Native Americans regularly set fires to keep areas open for hunting, to promote development of favored plants such as camas (*Camassia quamash* [Pursh] Greene [Liliaceae]) or bracken fern (*Pteridium aquilinum* [L.] Kuhn), and to make it easier to collect seeds from several plants used as food. This frequent burning regime helped maintain the oak component of the stands as it reduced invasion by less fire-tolerant conifer species (AGEE 1990). Since cessation of burning, many of the oak communities have been heavily invaded by conifers (mostly Douglas-fir) and by both native and non-native shrubs and other plants. These invasions have dramatically changed the appearance and function of the oak communities.

The greatest concentration and many of the largest oak communities remaining in western Washington are on Fort Lewis Military Reservation near Tacoma. In many of these stands oak is now a minor component in the midstory or understory of what appears, at least to the casual eye, to be a conifer stand. The conifers are generally twice as tall as the oaks, and in the future the conifers will continue to outgrow the oaks. The remaining shade-intolerant oak trees at Fort Lewis have probably survived in midstory or understory positions because of repeated thinning of the conifers to periodically reduce stand density and promote growth of the residual conifer trees. Given the current disparity in relative heights between the dominant conifers and the suppressed oaks we suspect most of the oaks will not survive over the next few decades without silvicultural intervention.

Fort Lewis is used for military training, but most of the area is available for forest management activities. The forest management staff has a long-term interest in restoring oak and prairie communities. We are currently working with Fort Lewis on two projects related to oak restoration – simulation and visualization of oak management alternatives on a landscape basis and field trials of response of individual oak trees to thinning release.

2.4.1 Simulation and visualization of oak management alternatives

Under the first component, we used simulation techniques to depict current landscape conditions and likely changes under various management alternatives (HARRINGTON and KALLAS-RICKLEFS 2002). For this simulation effort, we selected and inventoried current forest cover for the Tenalquot Planning Area, a 3000-ha section of Fort Lewis composed of a mosaic of conifer and hardwood stands, oak savannas, prairies, and wetlands. We produced a computer-simulated landscape visualization of current conditions to illustrate distribution and size of oak, prairie, and conifer communities using the EnVision landscape visualization system (MCGAUGHEY 2001). This required creating a tree list (numbers of trees per hectare by species, diameter class, and crown length) for each stand and locating each stand on the landscape. We then showed how the area would look if we implemented four alternative silvicultural options for the area (Fig. 4).

Fig. 4. Landscape visualizations of the current Tenalquot planning area vegetation (a) and restored oak woodland vegetation (b). Oak vegetation is shown as orange, conifer vegetation is shown as green, and grass prairie is shown as tan.

We next used the ORGANON growth model (Hann *et al.* 1997) to project changes in these stands for 50 years. The proposed management options range from very conservative (continue current conventional management, including thinning Douglas-fir in Douglas-fir-oak stands and burning of grass prairies) to radical (recreate large areas of oak and Douglas-fir savanna, oak woodlands, and prairies across the landscape, similar to the vegetation recorded in the 1870 land survey).

Such simulation exercises are helpful for presenting alternative management options and can help focus discussion on desired objectives for both stand and landscape management. However, the simulations do not represent what the area would actually look like if these scenarios were implemented due to: lack of detailed inventory information for each stand; lack of realistic tree form data (especially for oak); broad stand typing (current inventories often combine different stand conditions into a unit of practical size for management); alternative scenarios based on untested assumptions about treatment feasibility and growth responses of specific treatments; and stand projections based on growth models developed with data from different types of stand conditions. Even given these serious limitations, this type of landscape simulation is more useful than individual stand projections because it allows examination of how stands are spatially located in relation to each other, to other vegetation categories such as prairies or wetlands, and to other features of interest such as roads or ownership boundaries.

2.4.2 Individual oak tree release study

Under the second component of our oak research, we are conducting field studies of individual tree release options so that improved oak-conifer interaction models may be developed (HARRINGTON and KERN 2002). This study was installed in former oak stands where oak trees have survived but have been overtopped by Douglas-fir. The oak trees vary in size but are generally small in stem diameter and exhibit signs of overtopping, such as small diameter crowns and dead branches. The study tests three levels of release in four different oak stands. The trial is designed to determine if overtopped oaks respond to release treatments by increasing growth rates or by expanding crowns. It is also hoped that the trial will identify tree and stand characteristics that can be used to predict response of suppressed oaks to release treatments. This response information will be used to design treatment plans for restoring oaks across the landscape.

The oak release treatments were applied in the spring of 2001. Preliminary results are encouraging. Release treatments increased acorn production, epicormic sprouting of oaks, and growth of understory oaks. Acorn production is desirable because one management objective is to produce mast (food) for birds and squirrels (especially the western gray squirrel [*Sciurus griseus*] which the Washington Department of Fish and Wildlife considers to be threatened by extinction).

A new field study involving a range of oak release treatments and fertilization was installed in the winter of 2002–2003. This study has two components: 1) to determine if fertilization will increase the response of released trees or the growth rate of non-released oaks; and 2) to determine how overstory removal and understory response influence environmental conditions, especially soil moisture, for the released oak trees. Results from oak release studies will help in designing silvicultural prescriptions for both simulations and on-the-ground activities.

3 Discussion and conclusions

Over the last decade the SFM Team has gained considerable experience with the design, installation, and maintenance of large-scale silviculture experiments. 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 forest 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 forest managers.
- Treatments are intended to stimulate development of a variety of 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 and visual aesthetics 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 and long-term funding commitments from science organizations.

The SFM Team has several significant challenges with ongoing monitoring of these studies:

- *Lack of long-term funding for remeasurement* – All studies were initiated and installed with short-term supplementary funding; however no increased long-term funds are available for future remeasurement of study plots; therefore, remeasurement costs must be met with existing SFM Team funding. This lack of supplemental monitoring funding, coupled with the SFM Team's commitment to long-term remeasurement and analyses of studies, is an opportunity cost that limits the team's resources for pursuing new research questions as they arise.
- *Loss of road access to study sites* – The Clearwater Creek early stand development study is located in the Mount St. Helens National Volcanic Monument. Unfortunately, many of the roads that provided access for installation of study plots were blocked or destroyed by occasional ash and pumice landslides during the 15 years following the 1980 volcanic eruption. Consequently, the Monument administration decided to not repair access roads, but rather, to decommission the road system by removing bridges and culverts. This decision eliminated road access to many of the study plots. Field work in many plots now requires hiking many kilometers through rugged terrain, greatly increasing the cost of remeasurement.
- *Lack of funding and partners to conduct wildlife surveys* – The Clearwater Creek early stand development study, the midrotation OHDS, and the Capitol State Forest regeneration harvest study were all designed with large treatment units to allow measurement of wildlife responses to stand structure differences; however, no funding was secured to conduct long-term wildlife research. In some cases, limited initial wildlife surveys have been accomplished, but securing funding for resurveying of wildlife populations is an ongoing challenge.
- *Delay of treatment implementation* – Because the OHDS was implemented through normal forest thinning contracts that were delayed due to forest management issues commonly encountered on federal lands, installation of treatments was delayed for several years on some study units. These lengthy delays will confound analyses of future wildlife surveys. It will be difficult, if not impossible to separate natural background variations in wildlife populations from wildlife responses due to silvicultural treatments, given the differences in the year each treatment was implemented.
- *Delays in publication of results with full replication* – Due to the large scale of these studies, each study site took several years to plan, design, and implement. Therefore, it will be many years before fully replicated remeasurement of responses will be complete. For instance, in the case of the Capitol State Forest regeneration harvest study, planning for the first replications began in 1996; harvest treatments in the final block is scheduled in summer of 2004; therefore, five-year growth plot remeasurements from all three replications will not be available for analysis until spring of 2010 – 14 years after initial planning of the study. Until such replicated remeasurements are complete, all analyses of individual study blocks are simply case studies that preclude rigorous statistical analyses and associated publication of results.

In spite of these challenges, large-scale silvicultural experiments are essential for providing the scientific foundation needed to evaluate evolving forest management strategies. The group of studies described in this paper establishes a highly accessible showcase of silvicultural options that address all phases in the management of young-growth forests in the Douglas-fir region. They address many questions that can only be answered by experiments that are both large in spatial scale and long-term in nature. As they develop, they will provide examples of forest structures that can be created by different approaches to managing these forests. With time, the studies will also provide opportunities for public education and professional training on the advantages and disadvantages associated with each silvicultural option.

The SFM Team has found that large-scale silviculture experiments present many opportunities for the simultaneous investigation of the effects of alternative silvicultural treatments on multiple forest values. However, they also require huge commitments of resources and good cooperation and coordination between large networks of scientists, forest managers, and forest contractors to be successfully installed and maintained. Therefore, before initiating such experiments careful experimental design, planning, and ongoing financial commitments are necessary.

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