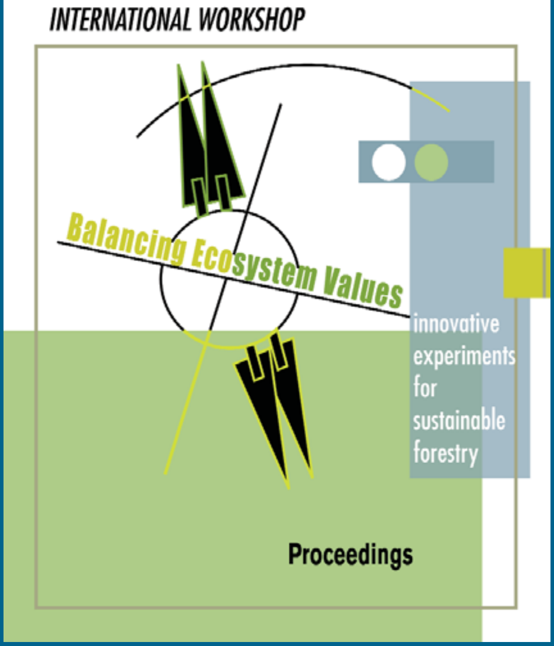

# MODELING AND SIMULATION

This page was intentionally left blank.

# Application of Simulation Models to the Design and Analysis of Silvicultural Systems in British Columbia

James W. Goudie,[1] C. Mario Di Lucca,[2] Walt Klenner,[3]
Ian R. Cameron,[4] Roberta Parish,[5] Kenneth R. Polsson[6]

## ABSTRACT

The Ministry of Forests in British Columbia supports the development of three stand-level simulation models—the Tree and Stand Simulator (TASS) (Mitchell 1975a, Mitchell and Cameron 1985), Prognosis$^{BC}$ (Zumrawi et al. 2002), and SORTIE/BC (Coates et al. 2003). Each model has unique characteristics, capabilities, and applications to ensure accurate projections of the diverse forest conditions in British Columbia. This paper focuses on TASS, which supports traditional silvicultural decisions and timber supply analysis. It is also used to design, project, and evaluate nontraditional silvicultural systems and stand management strategies. TASS also is used to simulate variable retention systems, a need arising from recommendations of the Clayoquot Scientific Panel (1995) that harvesting systems be based on an ecosystem management approach. MacMillan Bloedel Ltd. (now Weyerhaeuser) was the first company to adopt an approach that eliminated clear-cutting in coastal forests in favor of retaining components of the preceding forest on every cut block. Previously, trials addressing alternative silvicultural systems were primarily implemented by research staff, but often with unknown growth and yield consequences. Computer models are effective tools that can provide useful information to help develop policy and design innovative field experiments.

This paper briefly reviews progress to date, available applications, and needs for further model development and application.

KEYWORDS: Simulation, modeling, variable retention, growth and yield.

## INTRODUCTION

British Columbia (BC) is a large, geographically diverse province in western Canada that occupies about 950 000 km$^2$ of land. It is almost as large as California, Oregon, Washington, and Idaho combined. It has over 26 million ha of productive forest land that is categorized into 14 biogeoclimatic ecosystem classification (BEC) zones (Pojar et al. 1987). Substantial north-south mountain ranges intercept moisture and produce annual rainfall that varies from over 300 cm on the extreme west coast to under 40 cm in the desert-like conditions of the Fraser River Canyon. The forests differ accordingly—lush, temperate cedar-hemlock rain forests on the coast; dry, low elevation Ponderosa pine (*Pinus ponderosa* P. & C. Lawson) forests in the southern interior; and cold, high elevation Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)—subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) forests in the Rocky Mountains. The

---

[1] Research Leader, Stand Development Modelling Group, MOF Research Branch, P.O. Box 9519 Stn. Prov. Govt., Victoria, BC V8W 9C2, Canada. Email for corresponding author: jim.goudie@gems4.gov.bc.ca

[2] Growth and Yield Applications Specialist, Stand Development Modelling Group, MOF Research Branch, P.O. Box 9519 Stn. Prov. Govt., Victoria, BC V8W 9C2, Canada

[3] Wildlife Habitat Ecologist, MOF Southern Interior Forest Region, 515 Columbia St., Kamloops, BC V2C 2T7, Canada

[4] Consultant, 1481 Chinook Place, Kamloops, BC V2E 1A4, Canada

[5] Research Scientist, Ecological Processes, Silviculture Systems and Forest Dynamics, MOF Research Branch, P.O. Box 9519 Stn. Prov. Govt., Victoria, BC V8W 9C2, Canada

[6] Stand Modelling Analyst, Stand Development Modelling Group, MOF Research Branch, P.O. Box 9519 Stn. Prov. Govt., Victoria, BC V8W 9C2, Canada

Ministry of Forests supports the development of three simulation models to project the dynamics of forests growing under these diverse forest conditions. The goal is to produce models that are

- **Accurate** - predict the future state of the forests with acceptable accuracy;
- **Applicable -** cover a diversity of sites, species and stand structures;
- **Adaptable -** expandable to address emerging practices and issues;
- **Accepted -** conform with known information, and inspire confidence;
- **Affordable -** relatively inexpensive to develop, maintain and support; and
- **Available -** distributed freely and supported rigorously.

Two of the models, Prognosis$^{BC}$ and SORTIE/BC, were parameterized for and otherwise adapted to British Columbia conditions over the last 5 to 10 years. Prognosis$^{BC}$ (Zumrawi et al. 2002) is a variant of the Forest Vegetation Simulator originally developed in the intermountain Pacific Northwest (Stage 1973, Wykoff et al. 1982). It is a non-spatial, tree list model that projects existing stands in the southeastern region of the province. SORTIE is a spatially explicit model that was originally developed to estimate successional sequences in deciduous forest conditions in eastern United States using predicted light conditions (Canham 1988, Pacala et al. 1993). SORTIE/BC was parameterized to estimate understory succession patterns for partial cutting regimes in interior cedar-hemlock (ICH) forests in northern British Columbia (Coates et al. 2003). SORTIE has also been adapted to other regions across Canada.

The Tree and Stand Simulator (TASS) (Mitchell 1975a, 1975b) has produced yield tables for second-growth managed forests for over 20 years (e.g., Mitchell and Cameron 1985). These tables are now electronically distributed via the Table Interpolation Program for Stand Yield (TIPSY) (Mitchell et al. 2000). TASS can estimate the effects of intensive silvicultural treatments on financial return (e.g. Mitchell 1995) and the effects of stand tending on the habitat requirements of several wildlife species (Greenough et al. 1996). Application of the model to nontraditional harvesting strategies has increased rapidly since recommendations of the Clayoquot Scientific Panel (1995) were accepted. MacMillan Bloedel Ltd. (now Weyerhaeuser) was the first company to eliminate traditional clearcutting from coastal forest land (private and licensed). Other companies have since adopted similar strategies. Over a dozen field installations established in British Columbia since 1990 examine alternatives to clearcutting because there is little knowledge about the probable effects. This paper discusses some ongoing applications of TASS that assist the development of non-timber management strategies and the design of silvicultural systems trials.

## MODEL DESCRIPTION AND HISTORY

Mitchell (1969) conceived and coded the original TASS I in the mid-1960s for managed stands of interior white spruce (*Picea glauca* (Moench) Voss). Simulated trees were positioned on a flat, 1-foot grid and crowns competed for growing space in a two-dimensional environment. A major reconfiguration, TASS II, occurred in the late1960s when the focus shifted to coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (Mitchell 1975a, 1975b). Tree crowns are represented by concentric smooth shells (fig. 1) that compete in **three-**dimensional computer space. Dominant height growth is the key driver, and every tree is assigned a height growth that ranges from about 50 to 120 percent of site trees. Each tree is also assigned a rate of crown expansion relative to height growth (see equation 2, in Mitchell 1975a). Crowns compete for three-dimensional space, and vigorous trees eventually overtop weaker neighbors. Competitive mortality occurs when trees are overtopped by a critical distance—a surrogate for light attenuation (fig. 2). Annual bole increment is primarily a function of the amount of volume the crown shells occupy, a proxy for foliar biomass (equation 19, in Mitchell 1975a). TASS II is calibrated to a large database of 15,000 permanent sample plots and validates against independent thinning experiments (Goudie 1998). Available silvicultural treatments in the system include initial density, spatial distribution, thinning, pruning, fertilization and genetic improvement.

Like most early computer models, TASS II was originally coded in Fortran IV and executed on large mainframe computers. Visualization of the simulations has always been an important element because our experience shows that realistic graphic representations

- Facilitate model verification and de-bugging;
- Improve communications between modelers, audiences and colleagues (e.g., scientists, managers, students, general public);
- Generate confidence among clients (e.g., scientists, practitioners, managers, politicians); and
- Improve the success of research grant proposals.

Figure 1—Stylized depiction of crown shape in TASS II. Concentric lines indicate crown profile over 5 years that represents foliar volume.

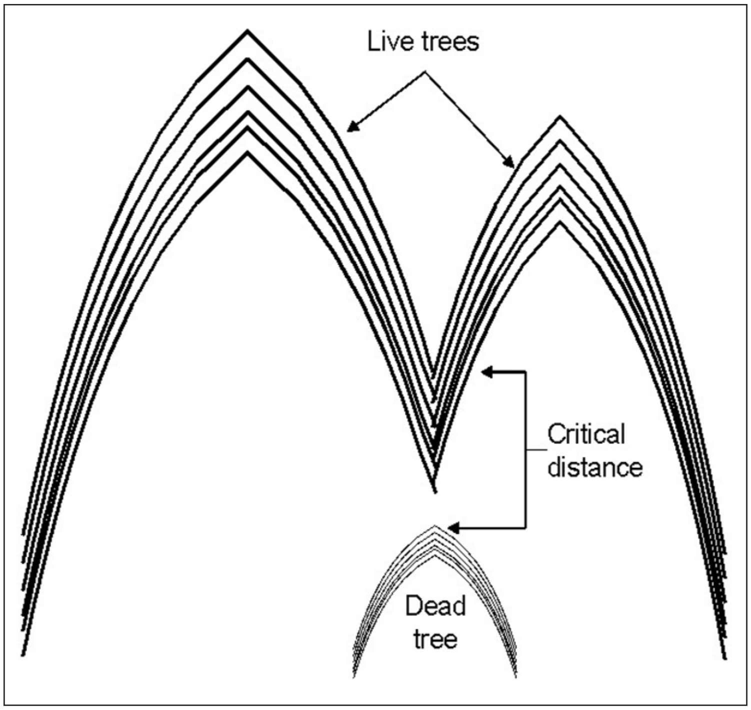

Figure 2—Tree competition and mortality in TASS II.

Graphic visualizations have improved considerably over the years (fig. 3). Before 1988, paper maps were printed from the internal program grid and crown perimeters were laboriously hand drawn to examine model behavior and demonstrate the competitive dynamics (fig. 3a). Algorithms were created to use 16-color EGA capabilities (fig. 3b) after TASS was converted to an appropriate computer language (C) that facilitates graphical representations and transported to a microcomputer environment in 1988. Images were drawn directly to the screen and captured to verify and illustrate the system. By 1990, 256-color VGA accommodated more realistic portrayal of tree crowns when viewed from different positions (figs. 3c and 3d). Canopy depth is depicted by darkening shades of green. Even greater realism was possible with the introduction of 32-bit color in the early 1990s (fig. 3e). By 1998, images could be written to files that facilitated transport to other programs. We can now start simulations from either bare ground or existing stand data and predict light conditions at any position on the three-dimensional grid, now that a light simulation model, tRAYci (Brunner 1998), has been developed and integrated with TASS (fig. 3f).

TASS has a wide array of available cutting prescriptions. Single tree selection can be applied manually or randomly. Tree list thinnings are commonly used in even-aged stand simulations where trees are sorted by one variable (e.g., diameter, height, crown area, basal area) and then a specified range is removed (e.g., the largest). Spatial thinnings such as row, checkerboard, or systematic groups are also available. Another option mimics a field crew walking through a stand and selecting the best tree to retain within a specified distance. A recent improvement for simulating actual variable retention blocks is displayed in figure 4. An aerial photograph (fig. 4a) or GIS map (fig. 4b) generates a black and white thinning layer (fig. 4c). TASS reads and automatically scales the image to the desired plot size and then instructs the program to treat the regions differently. In this example, TASS removed all trees in the white areas at age 60 and retained all trees in the black areas.We then planted 1400 simulated western redcedar (*Thuja plicata* Donn ex D. Donn) trees per hectare in the open areas (fig. 4d) and grew both cohorts for another 40 years (fig. 4e). Summaries can be produced at any time for the entire block, for either cohort, or for a user-specified summary area (fig. 4f). The creation of the summary area means that

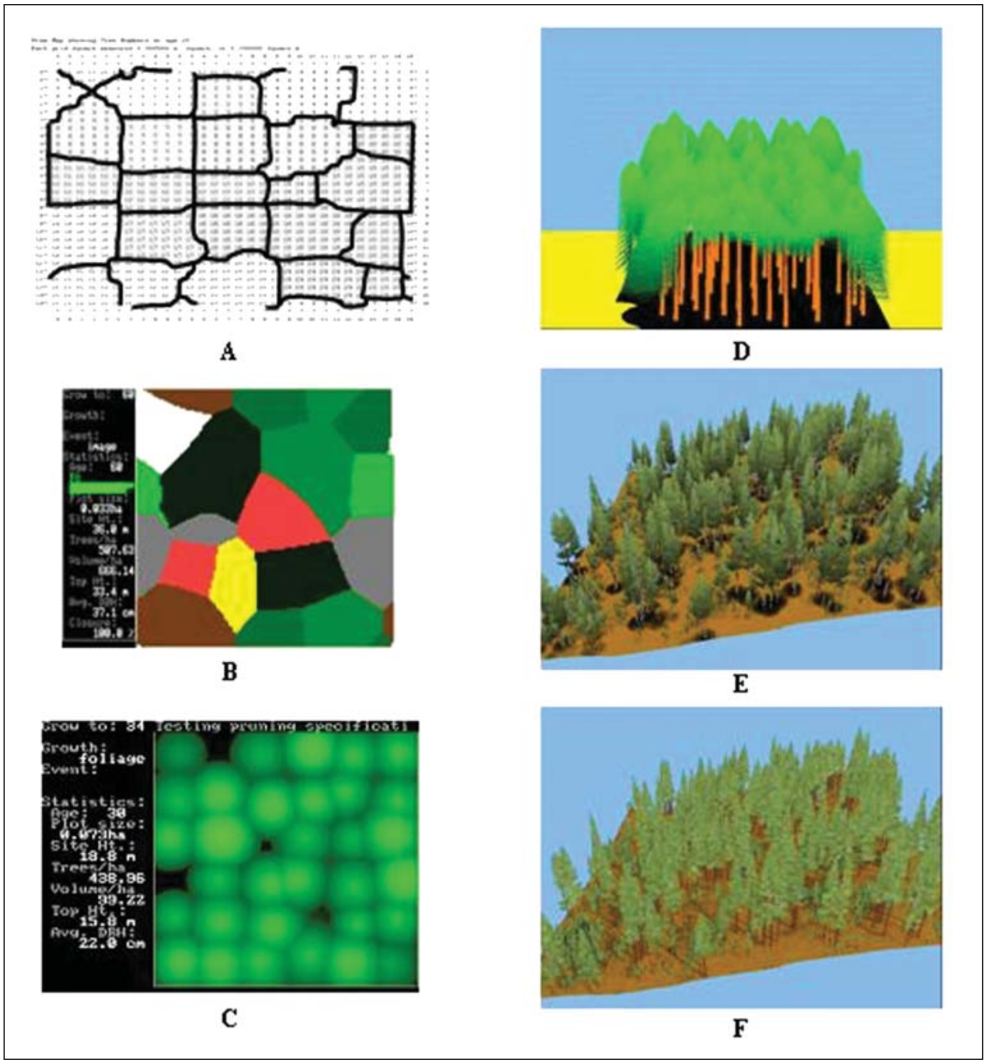

Figure 3—Graphic representations produced by TASS. (A) Before 1988 conversion to C language (Note that crowns on the edge of plots grow into the opposite side(s) to avoid edge bias.); (B) Screen capture of an EGA representation of crowns in 1988; (C) VGA representation of crowns circa 1990; (D) VGA representation at an oblique angle; (E) true color representation of an actual 1-ha plot circa 1995; (F) True color with tRAYci active.

TASS no longer requires square or rectangular plots, provided a buffer is created around the irregular polygon.

Numerous future improvements will create a new version (TASS III) that is better suited to the modeling of complex stand structures. For timber supply applications, users can now quickly estimate the simulated effects of variable retention systems on regenerated stand components with TIPSY[7] (Di Lucca et al. 2004). Predictive equations that reduce regenerated stand yields relative to those of a standard clearcut were fit to meta-data generated by several thousand TASS simulations. The key entry variables are species, percent retention, length of edge created around individual trees and groups, and the average group size. If not known, edge length can be estimated from other variables.

## CASE STUDIES

Four case studies (two from the coast and two from the Interior) illustrate how TASS helps design field installations and assists decisionmaking. The applications focus on the

---

[7] TIPSY can be freely downloaded from http://www.for.gov.bc.ca/hre/software/

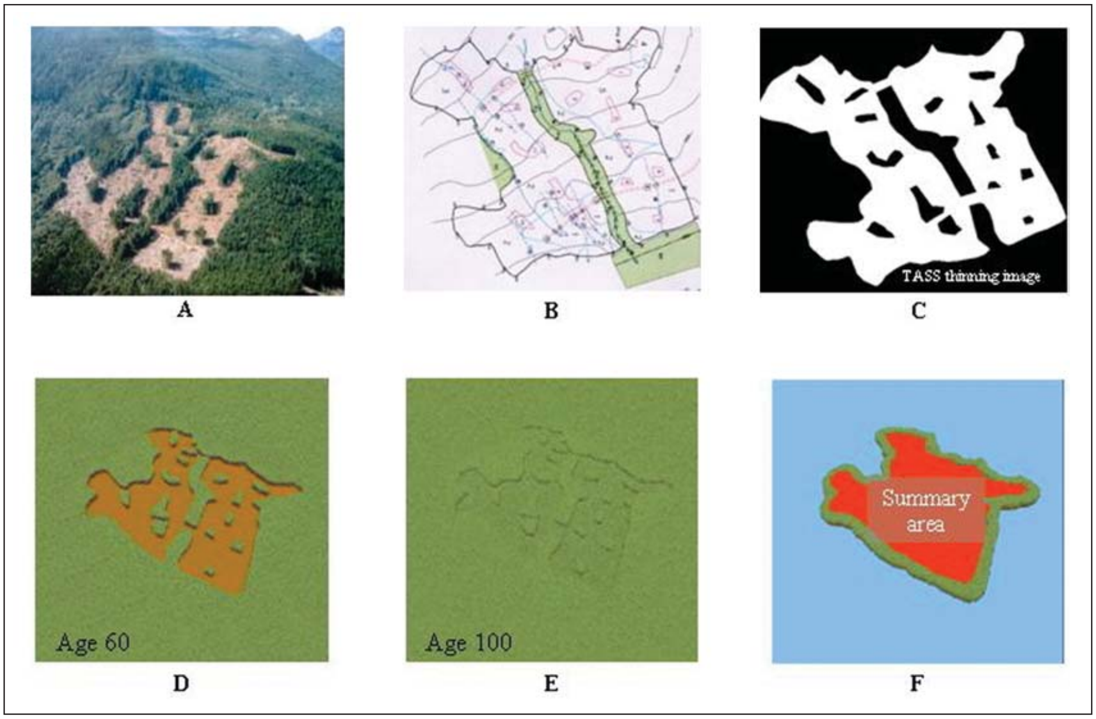

Figure 4—Variable retention simulation in TASS. (A) Polygon in the Fraser Timber Supply Area near Chilliwack, BC; (B) GIS map of opening; (C) TASS thinning image to govern removal; (D) Simulation at stand age 60; (E) Simulation at stand age 100; (F) Summary layer and buffer strip.

design of innovative experiments in the modeling environment.

### Case Study 1—Simulation of Partial Cutting in Mountain Caribou Habitat

In the Interior, forest management has changed the traditional habitat of mountain caribou (*Rangifer tarandus caribou*) from large, contiguous expanses of mature and old forests to a highly interspersed mosaic of even-aged cutblocks and residual patches of mature forests. This appears to have increased predation by wolves (*Canis lupus*) and harassment by humans. Mountain caribou are now a red listed (endangered) species in British Columbia. Early winter forage critical to survival consists largely of arboreal lichen species associated with old-growth conditions in the high elevation forests of the interior Engelmann spruce-subalpine fir BEC zones (Hatter and Kinley 1999, Stevenson et al. 2001). Mountain caribou strongly prefer lichen in the genus *Bryoria* over *Alectoria* (Rominger et al. 1996). *Bryoria* spp. occupies upper, well-ventilated portions of the canopy and *Alectoria* the lower, more humid and protected regions (Goward 1998, Campbell and Coxson 2001). A retrospective study (Lewis 2004) suggested that the transition from *Bryoria* to *Alectoria* moves down the crown on trees that remain after partial cutting.

Based on this information, TASS helped address the following question: What partial cutting regimes would best promote the abundance and availability of *Bryoria* spp.? To investigate the potential crown dynamics, a suite of TASS simulations retained groups or single trees at levels of 20, 40, 60 and 80 percent. In addition, we simulated single tree selection and three patch sizes for each level (25, 50 and 100 m square patches). The tRAYci light model provided data for maps of proportion of above canopy light (PACL, fig. 5) that are processed by subsequent models to predict branch and lichen production that help identify appropriate management strategies to achieve specific goals.

### Case Study 2—Designing the Isobel Lake Silviculture System Experiment

Ungulates require abundant, nutritious winter forage to ensure high survival rates. Managers in the interior Douglas-fir stands wish to increase bunch grass and reduce pine grass by creating open stand conditions, without dramatically reducing timber supply. Unanswered questions include, “How much should we open the stand?” and, “What is the impact on timber supply?” TASS helped design a field experiment that tested levels of partial retention in the interior

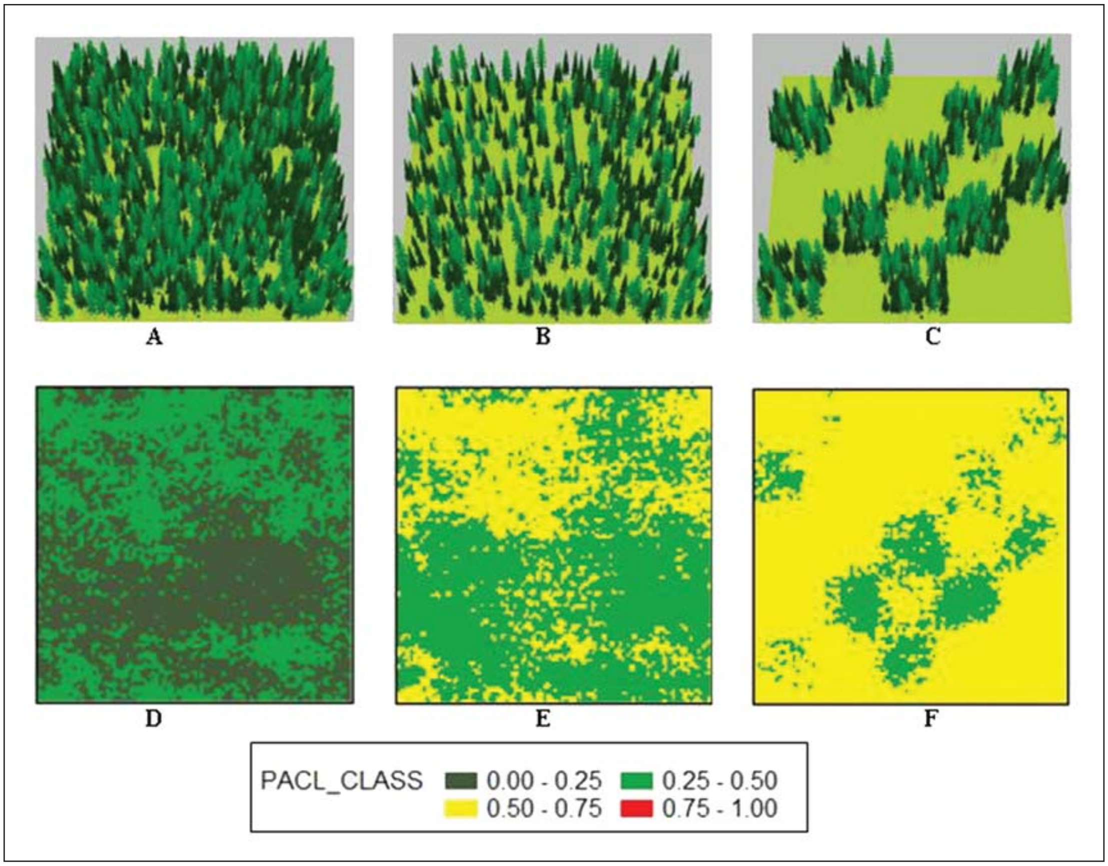

Figure 5—Caribou habitat simulation in TASS for 40-percent retention. Crown representation of prethinning (A), single tree selection (B) and 25-m retention patches (C); Proportion of above-canopy light (PACL) maps before (D) and immediately after (E, F) treatments.

Douglas-fir zone north of Kamloops, BC. A suite of simulations varied the radius of the retained patch (2-5 m) and the distance between circular patches (12, 13, 15, 17, 20, 24, and 30 m). Figure 6a shows the pattern of retention immediately after treatment and figure 6b the associated PACL maps. The patterns were evaluated in terms of preferred light conditions that are known to encourage bunch grass (roughly the left-to-right diagonal band of yellow-orange). A logging protocol was developed to achieve the intended light condition considering operational constraints. We will compare the simulations with field results to test model performance.

### Case Study 3—Analyzing the Effect of Partial Cutting on Spotted Owl Habitat and Timber Supply

The range of the northern spotted owl (*Strix occidentalis caurina*) extends along the west coast of North America to the southwest portion of British Columbia. The owl resides in late-seral forests on the leeward side of the Coast Mountains and both the windward and lee sides of the Cascade Range. Forest management practices have been modified in these areas to create habitat appropriate for spotted owls and other species dependent on old-growth or late-seral forest structure. Removal of high volumes of timber is permitted, but 15 of the largest 30 trees are retained in wet maritime ecosystems (western part of the range) and 40 of the largest 80 trees in dry maritime ecosystems (eastern part of the range). The removal of low volumes of timber, about 30-percent basal area, in second-growth stands promotes old growth conditions favorable to spotted owl. The effectiveness of the treatments on timber production and habitat maintenance is not known for British Columbia. We simulated several of the proposed treatments to predict both timber effects and habitat features. In figure 7, we demonstrate some of the information available to forest managers: potential distribution of snags in a mixed Douglas-fir–western hemlock forest over time after the low volume harvest (fig. 7a); canopy depth (indicated by vertical lines below triangles) for a Douglas-fir overstory and a western hemlock understory under a low volume removal scenario (fig. 7b); and, the estimated timber production for different types of regeneration strategies under high volume removal

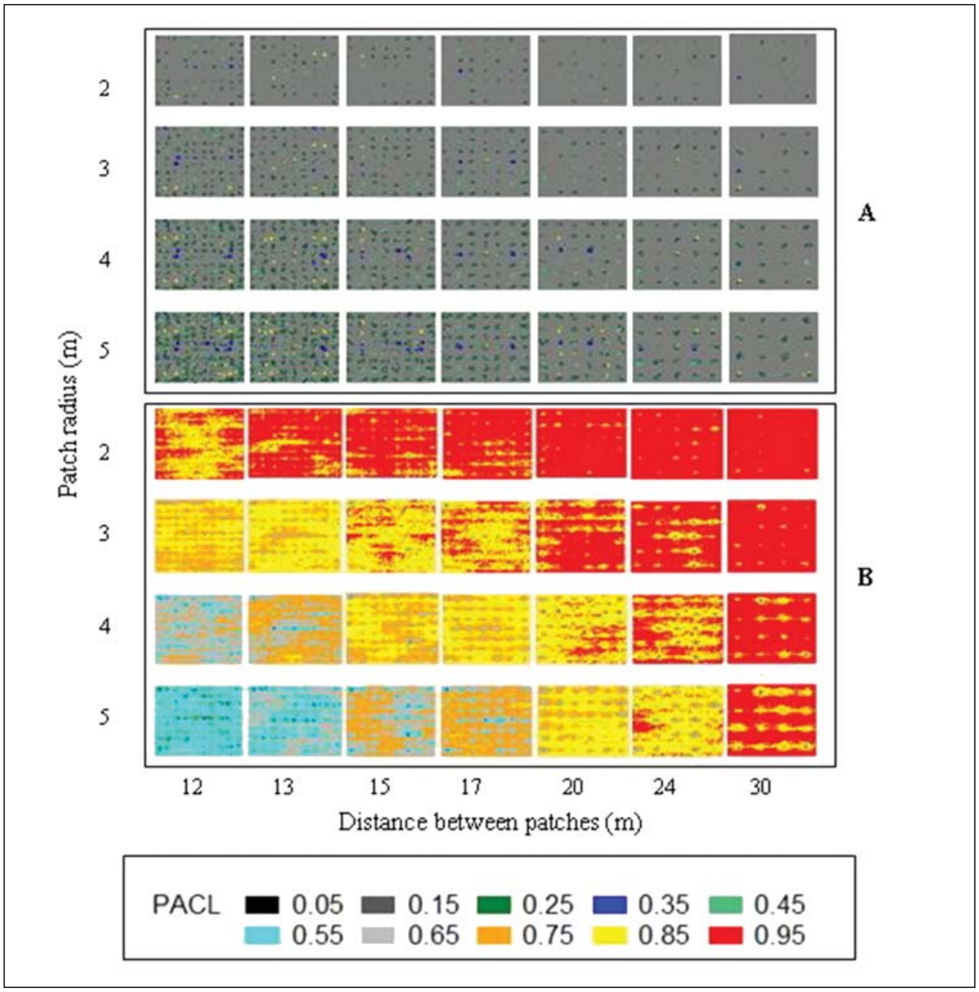

Figure 6—Simulations of the Isobel Lake silvicultural treatment experiment immediately after treatment showing maps of crown cover (A) and PACL (B).

in the dry maritime ecosystems (fig. 7c). TASS estimates dozens of other variables that allow comparisons of different stand components of interest to forest practitioners.

### Case Study 4—Designing the Silviculture Treatment for Ecosystem Management in the Sayward (STEMS) Experiment

TASS computer simulations helped promote the establishment of the STEMS field installation (de Montigny 2004, 2005), a repetition of the Capitol Forest Study in Washington State (Curtis et al. 2004, Marshall and Curtis 2005). In the planning stage, we simulated five patch cuts across a 20-ha block over 100 years as depicted in figure 8. The first replication of the STEMS project was installed in 2001 on Vancouver Island near Campbell River, BC. Figure 9 shows an aerial photograph of the study with three of the seven blocks highlighted (aggregated, dispersed, and clearcut with reserve) along with TASS representations of these treatments. We plan to simulate the four other treatments (extended rotation, extended rotation with commercial thinning, group selection, and modified patch cut) in the near future. The levels of retention are 26 and 8 percent by ground area for the aggregated and dispersed polygons, respectively. For the purposes of this analysis, we analyzed the clearcut as if it had zero retention because the retained group was bounded by a road on two of the three sides and would have little impact on the regenerated stand growth. The merchantable volume projections for these treatments plus the clearcut presented in figure 10 suggests that because the percentage of retention of the dispersed treatment is three times less than the aggregated, the yields of the regenerated stands under both overstorys will be very similar (77 and 74 percent of clearcut). However, for similar levels of retention, TASS predicts that dispersed residual trees reduce

*(text continues on p. 184)*

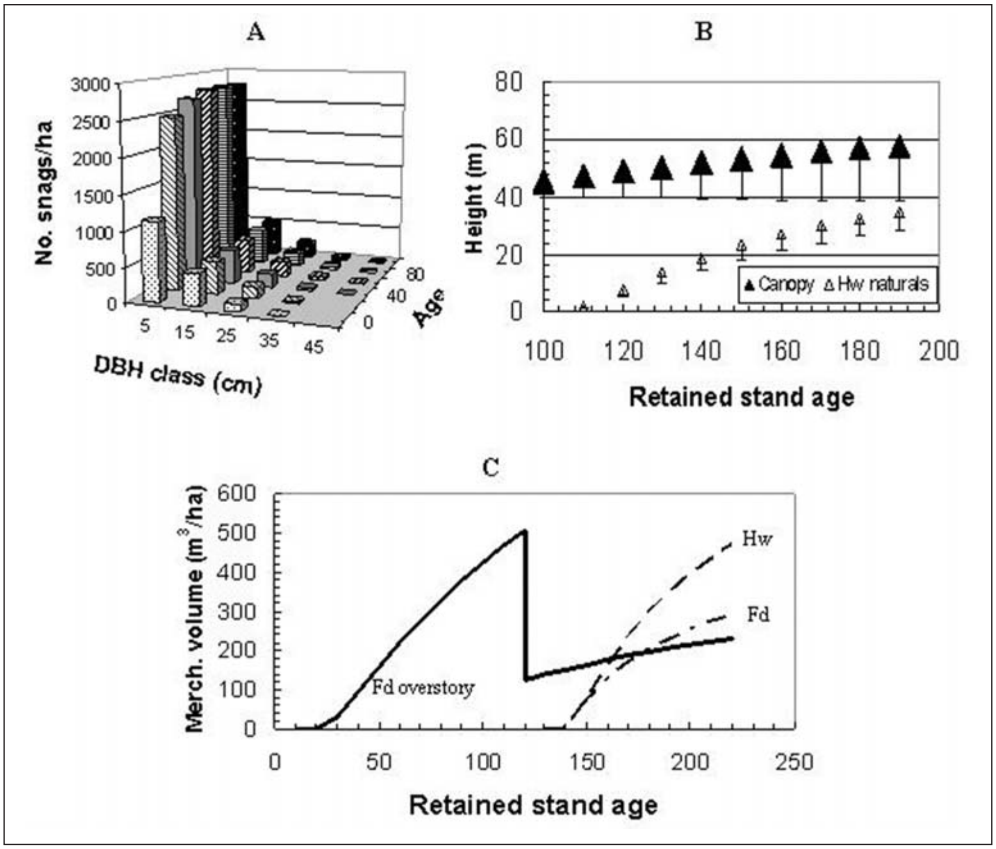

Figure 7—Simulation of management prescription for spotted owl habitat. (A) Distribution of snags over time; (B) Understory and overstory canopy depth over time; (C) Volume production of partially retained overstory and plantings of potential understory species (Hw=western hemlock, Fd=Douglas-fir).

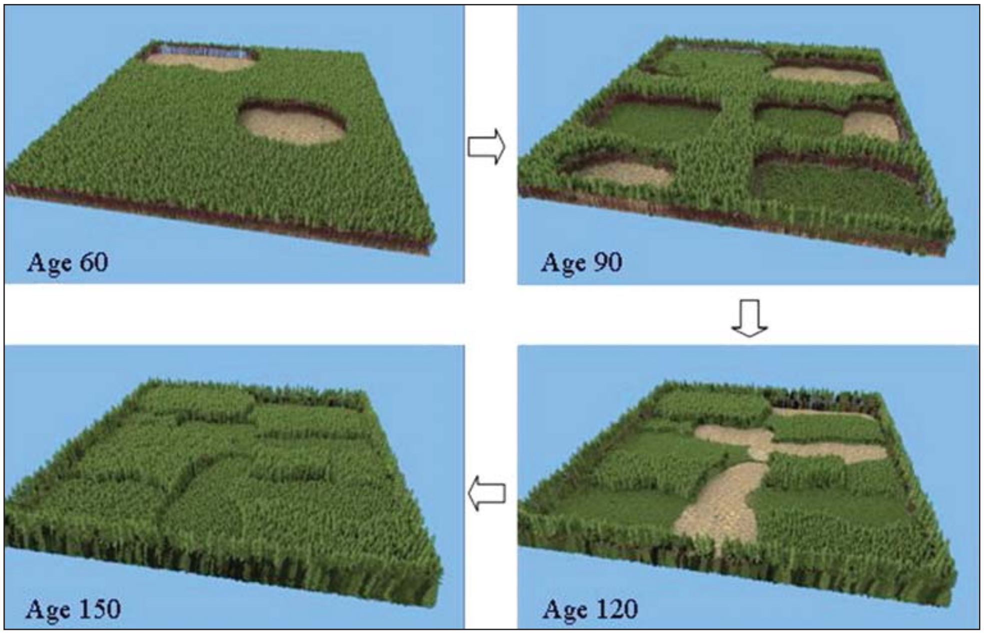

Figure 8—Demonstration runs for the planning stage of the STEMS experiment showing structures at four ages. Patches were removed every 15 years between ages 50 and 110.

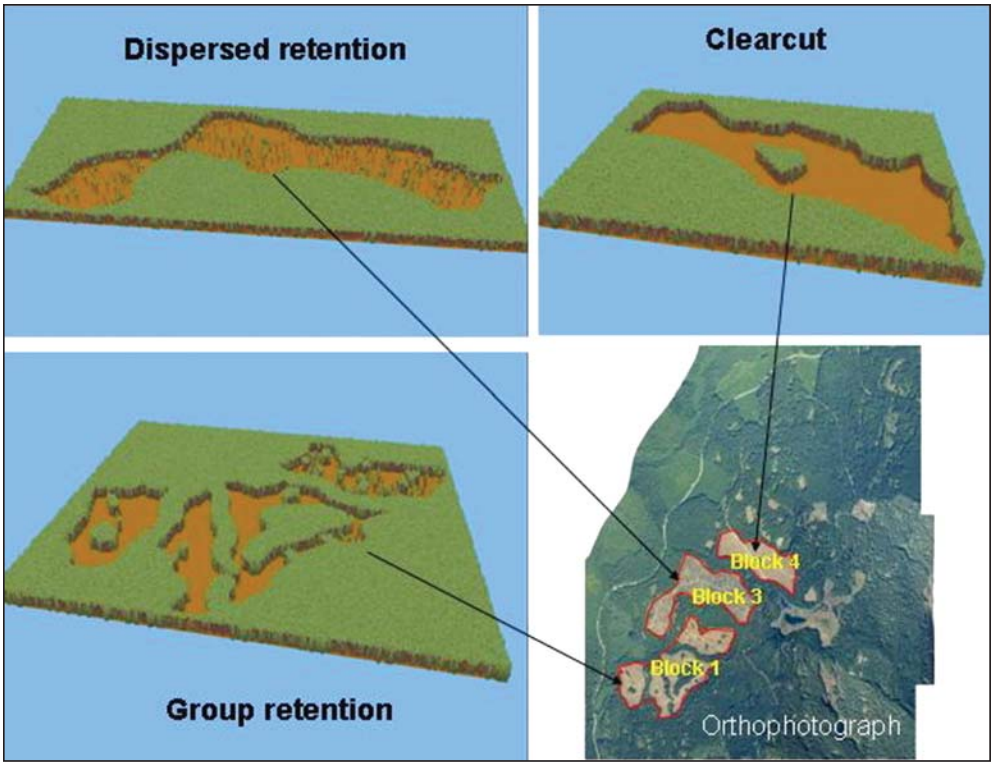

Figure 9—Orthophotograph of the STEMS experiment and TASS depictions of the aggregated retention (block 1), dispersed retention (block 3) and clearcut (block 4).

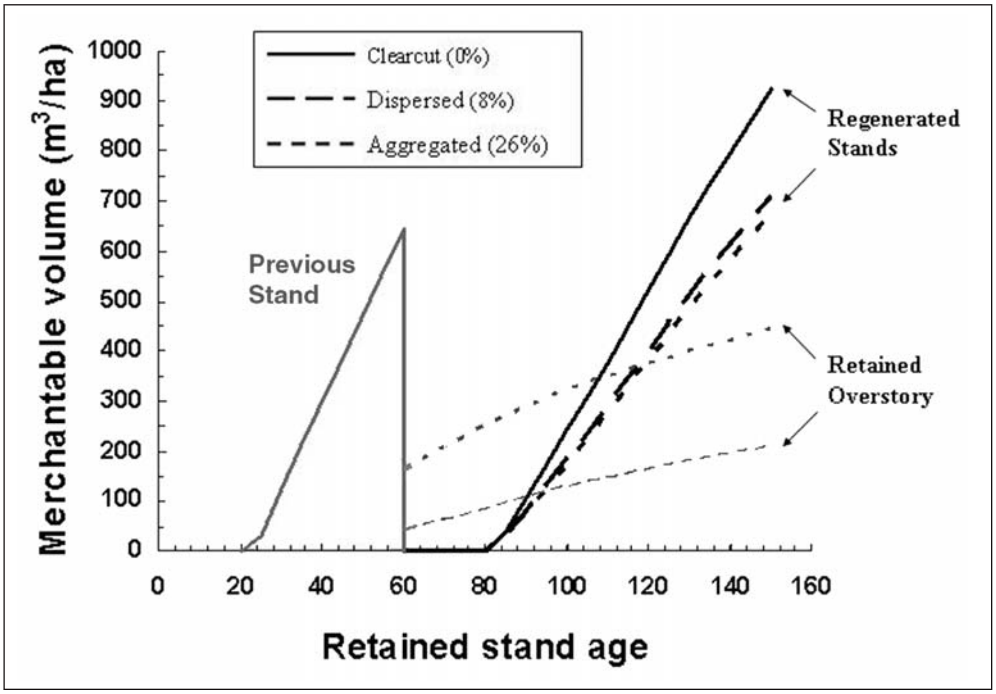

Figure 10—Simulated merchantable volume production (all trees 12.5cm+ diameter at breast height) before and after harvesting three blocks in the STEMS field experiment. Percentages refer to level of retention by ground area.

regenerated yields more than aggregated groups because a structure with greater length of open crown edge in the overstory is more efficient at occupying growing space. This type of information will be useful in designing the two future repetitions of the experiment.

Realistic simulated scenarios in a spatial model can also help design sampling protocols for monitoring growth and yield. Blocks in most silviculture system trials are so large that a systematic grid of plots must be established and monitored over time (e.g., de Montigny 2004). A sampling simulation program and simulated plots could ensure that the size and number of plots established will achieve sampling targets now and into the future.

## FUTURE DIRECTIONS

Modelers have to extend their research to meet current and future needs of forest researchers and practitioners involved in ecosystem management. In British Columbia, the highest priorities are clearly predictions of growth and yield and habitat features to ensure sustainability. Although one model cannot answer all questions, model fidelity can be increased by

- Measuring and modeling biological components of trees such as foliage and roots,
- Explicitly modeling agents of mortality (e.g., beetles, mistletoe, windthrow, root rot),
- Quantifying regeneration and understory growth,
- Developing new measures of structure, and
- Understanding ecosystem processes (light, moisture, competition).

Modelers also need to increase cooperation with those involved in ecosystem management by

- Participating in cooperative teams,
- Developing common terminology,
- Developing new measures for ecosystem values, and
- Sharing data and, when possible, exchanging model components.

## SUMMARY

Computer models that are biologically realistic and spatially explicit can help design field installations (both traditional and innovative). Such models can

- Clarify the objectives of the project,
- Provide an explicit range of conditions to include in both new experiments and future replications of existing experiments,
- Test sampling schemes for large treatment blocks.
- Establish meaningful quantitative field measures, and
- Visualize future stand structures.

When applied correctly, computer models also help land managers in developing rational operational guidelines and policy for both timber and nontimber resources. Models can predict tree and stand conditions not available from long-term data, and provide information in support of sustainability (e.g., measures of habitat and timber).

## REFERENCES

Brunner, A. 1998. A light model for spatially explicit forest stand models. Forest Ecology and Management. 107: 19-46.

Campbell, J.; Coxson, D.S. 2001. Canopy microcliamete and arboreal lichen loading in subalpine spruce-fir forests. Canadian Journal of Botany. 79: 537-555.

Canham, C.D. 1988. An index for understory light levels in and around canopy gaps. Ecology. 69: 1634-1638.

Clayoquot Scientific Panel. 1995. Scientific panel for sustainable forest practices in Clayoquot Sound. Report 5. Sustainable ecosystem management in Clayoquot Sound: planning and practices. Victoria, BC. 296 p.

Coates, K.D.; Canham, C.D.; Beaudet, M.; Sachs, D.L.; Messier, C. 2003. Use of a spatially explicit individual-tree model (SORTIE/BC) to explore the implications of patchiness in structurally complex forests. Forest Ecology and Management. 186(1-3): 297-310.

Curtis, R.O.; Marshall, D.D.; Bell, D.S. 2004. Silvicultural options for young-growth Douglas-fir forests: the capitol forest study—establishment and first results. Gen. Tech. Rep. PNW-GTR-598. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 110 p.

de Montigny, L. 2004. Silviculture treatments for ecosystem management in the Sayward (STEMS): Establishment report for STEMS 1, Snowden Demonstration Forest. Tech. Rep. 017. Victoria, BC: B.C. Ministry of Forests, Research Branch. 71 p.

de Montigny, L. 2005. Silviculture treatments for ecosystem management in the Sayward: the STEMS experiment. In: Peterson, C.E.; Maguire, D., eds. Balancing ecosystem values: innovative experiments for sustainable forestry, proceedings. Gen. Tech. Rep. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Di Lucca, C.M.; Goudie, J.W.; Stearns-Smith, S.C. 2004. Variable retention yield adjustment factors for TIPSY. Ext. Note 69. Victoria, BC: B.C. Ministry of Forestry, Research Program. 4 p.

Goudie, J.W. 1998. Model validation: A search for the magic grove or the magic model. p. 45-58. In: Bamsey, C. R., ed. Stand density management: planning and implementation, Edmonton, AB. Edmonton, AB: Clear Lake Ltd. 172 p.

Goward, T. 1998. Observations on the ecology of the lichen genus Bryoria in high elevation conifer forests. Canadian Field-Naturalist. 112: 496-501.

Greenough, J.A.; Kurz, W.A.; Murray, C.L. 1996. The environmental impacts of incremental silviculture. Prepared by ESSA Technologies Ltd., for B.C. Vancouver, BC: Ministry of Forestry, Silviculture Branch. 56 p.

Hatter, I.W.; Kinley, T. 1999. Mountain caribou: a species at risk. Cordillera. 5: 9-11.

Lewis, D.W. 2004. Arboreal lichens in natural and man aged high elevation spruce-fir forests of the north Thompson Valley, British Columbia. Burnaby, BC: Simon Fraser University. 110 p. M.S. thesis.

Marshall, D.; Curtis, R.A. 2005. Evaluation of silvicultural options for harvesting Douglas-fir young growth production forests. In: Peterson, C.E.; Maguire, D., eds. Balancing ecosystem values: innovative experiments for sustainable forestry, proceedings. Gen. Tech. Rep. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Mitchell, K.J. 1969. Simulation of the growth of even-aged stands of white spruce. Yale University, School of Forestry Bull. No. 75. New Haven, CT: Yale University. 48 p.

Mitchell, K.J. 1975a. Dynamics and simulated yield of Douglas-fir. Forest Science Monographs. 17. 39 p.

Mitchell, K.J. 1975b. Stand description and growth simulation from low-level stereo photos of tree crowns. Journal of Forestry. 73(1): 12-16, 45.

Mitchell, K.J. 1995. Simulate the treatment before pruning the stand. In: Hanley, D.P.; Oliver, C.D.; Maguire, D.A.; Briggs, D.G.; Fight, R.D., eds. Forest pruning and wood quality of western North American conifers. Institute of Forest Resources Contribution No. 77. Seattle, WA: University of Washington, College of Forest Resources: 281-290.

Mitchell, K.J.; Cameron, I.R. 1985. Managed stand yield tables for coastal Douglas-fir: initial density and precommercial thinning. Rep. No. 31. Victoria, BC. B.C. Ministry of Forestry, Research Branch, Land Management. 69 p.

Mitchell, K.J.; Stone, M.; Grout, S.E.; Di Lucca, C.M.; Nigh, G.D.; Goudie, J.W.; Stone, J.N.; Nussbaum, A.J.; Yanchuk, A.; Stearns-Smith, S.; Brockley. R. 2000. TIPSY version 3.0. Victoria BC: Ministry of Forests, Research Branch. http://www.for.gov.bc.ca/hre/software/ (13 December 2004).

Pacala, S.W.; Canham, C.D.; Silander, J.A., Jr. 1993. Forest models defined by field measurements: the design of a northeastern forest simulator. Canadian Journal of Forest Research. 23: 1980-1988.

Pojar, J.; Klinka, K.; Meidinger, D.V. 1987. Biogeoclimatic ecosystem classification in British Columbia. Forest Ecology and Management. 22: 119-154.

Rominger, E.M.; Robbins, C.T.; Evans, M.A. 1996. Woodland foraging ecology of woodland caribou in experimentally manipulated habitats, northeastern Washington. Journal of Wildlife Management. 60: 719-728.

Stage, A.R. 1973. PROGNOSIS model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Forest and Range Experiment Station. 32 p.

Stevenson, S.K.; Armleder, H.M.; Jull, M.J.; King, D.G.; McLellan, B.N.; Coxson, D.S. 2001. Mountain caribou in managed forests. 2nd ed. B.C. Wildlife Working Rep. No. R-26. Victoria, BC. Ministry of the Environment, Lands and Parks, Wildlife Branch. 58 p.

Wykoff, W.R.; Crookston, C.L.; Stage, A.R. 1982. User's guide to the stand prognosis model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Forest & Range Experiment Station. 122 p.

Zumrawi, A.A.; Stage A.; Snowden, B. 2002. Stand level scaling of a single tree distance independent diameter growth model: interim calibration of Prognosis in the South-eastern interior of British Columbia. In: Crookston, N.L.; Havis, R.N., compilers. Proceedings of second Forest Vegetation Simulator (FVS) conference. RMRS-P-25. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 151-157.

# Scaling Up From Stands to Landscapes

Thomas A. Spies[1]

---

## ABSTRACT

Stand-level experiments are critical to understanding the effects of innovative silvicultural practices on biological diversity. However, stand-level information is not sufficient to understand how management practices influence ecological, economic, or social outputs and outcomes. Landscape and regional studies are also needed, but experimental approaches are difficult to impossible at broad spatial scales. Consequently, other research approaches are needed at this scale, including modeling, retrospective studies, and monitoring of natural experiments. In this paper I examine some lessons learned from landscape-scale modeling studies that incorporate stand-level information. In particular, I focus on what we have learned from the Coastal Landscape Analysis and Modeling Study (CLAMS) as it pertains to estimating the effects of different forest management practices on biological diversity and timber production across landscapes. The simulations indicate that ecological effects of stand-level practices at landscape scales are influenced by (1) area of treatment as proportion of total area; (2) environmental variation; (3) diversity of initial biotic conditions (including vegetation and animals); (4) species and ecosystem processes; (5) dispersal effects (6) rate of change and time frame of analysis; (7) stochastic processes, e.g., disturbance; and (8) management practices and patterns. Large multi-owner landscapes, where many of the above influences are important, pose significant technical and institutional challenges to implementing new approaches to balancing ecosystem values. Significant advances can be made if we can do a better job of coordinating and integrating different research approaches to address sustainability questions that span multiple spatial and temporal scales.

KEYWORDS: Forest biodiversity, multi-ownership landscapes, spatial simulation models, Pacific Northwest.

## INTRODUCTION

Issues of forest sustainability are inherently issues of scale (Spies and Johnson 2003). Forest structure and composition vary over a wide range of spatial and temporal scales. Likewise, forest goods and services vary with scale and with objectives and values of different forest owners. Many gaps in our understanding of sustainability problems have risen from the changing priorities of society for goods and services from forests. For example, the biodiversity and recreation values of forests have increased worldwide. Experimental approaches can be used to identify the most effective management practices to meet the new goals; however, classic experiments are difficult or impossible to implement at broad scales, where many ecological and social processes operate (fig. 1). Consequently, other scientific approaches such as historical studies, long-term monitoring, and simulation modeling are needed to address the multi-scale nature of forest sustainability problems.

Over the last several years, the Coastal Landscape Analysis and Modeling Study (CLAMS) conducted research on scaling problems and policy effects in the Oregon Coast Range (Spies et al. 2002) (see also www.fsl.orst.edu/clams). Based on this experience, I will briefly identify several influences that must be considered when scaling up stand-level information to landscape and regional scales.

---

[1] Research Forester, USDA, Forest Service, Pacific Northwest Research Station, 3200 Jefferson Way, Corvallis, OR 97331, USA. Email: tspies@fs.fed.us

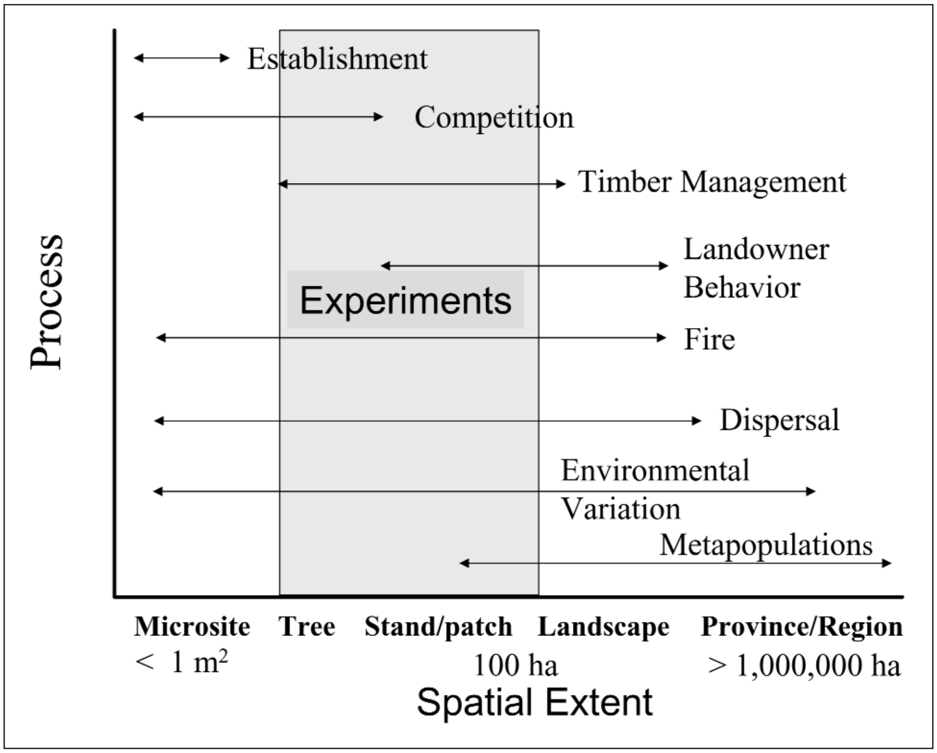

Figure 1—Spatial extent of management and natural processes and typical spatial extent of manipulative field experiments.

## INFLUENCES ON EFFECTS OF STAND-LEVEL PROCESSES AT LANDSCAPE SCALES

The following factors influence how stand-level processes and patterns affect processes and patterns at broader scales.

1. **Area of treatment as proportion of total area.** It is easy to forget that the landscape-scale effects of stand manipulations depend on the total area treated. For example, thinning thousands of hectares of young stands on federal lands in the Coast Range may sound like a lot, but when those hectares are a part of a 2.5 million hectare province, the effects of the treatments on habitat can be small at the scale of the province.
2. **Environmental variation.** Reactions of forest vegetation to human and natural disturbances will vary with site productivity, climate zone and topography (Wimberly and Spies 2001a). Most experimental studies can only capture a small portion of the environmental variability that occurs within a region. Consequently, one must exercise caution when extrapolating results to large, diverse landscapes and regions.
3. **Initial biotic conditions.** The response of plants and animals to silvicultural manipulations will depend on the organisms that are present on the site at the time of the treatment. Extrapolating treatment effects to large scales must take into account the diversity of stand conditions. New models such as Gradient Nearest Neighbor (Ohmann and Gregory 2002) that use remote sensing and geographic information systems provide a good way of retaining and spatially distributing the variation in vegetation that is found in a landscape.
4. **Variation in responses of species and ecosystems.** Again, it may seem obvious that not all species will respond to management practices and forest structure in the same way (Johnson and O'Neil 2001). However, this fundamental truth is often forgotten in debates about forest management impacts.
5. **Dispersal effects.** Most of the effects I have mentioned so far are simply additive effects—if one knows the areas of treatment and the species involved, it is possible to estimate effects with some certainty. In other words, knowledge of spatial arrangement of vegetation at landscape scales is not needed. When it comes to plant

establishment and animal colonization, however, it is important to know the landscape pattern of seed sources or source populations around a particular site. The patterns of seed sources in a landscape can affect the pattern of forest development even for such common species as western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) (Wimberly and Spies 2001b).

6. **Rate of change and time frame of analysis.** Most of our long-term studies of ecosystems are less than 25 years old, and few forestry and agricultural long-term studies are more than 100 years old. Ecologists are well aware that early responses to experimental treatments may change with time. New species may colonize a site and competitive interactions may cause some species to drop out and others to assume dominance. These patterns can take decades and centuries to play out. In the case of thinning to accelerate the development of old-growth forest structure, changes may take more than a century to appear (Garman et al. 2003).
7. **Stochastic processes.** Although growth patterns and species compositional changes resulting from physiological and competitive processes may be relatively easy to predict during stand development, it is far more difficult to predict disturbances or climate changes that can totally alter the course of development of a forest stand or landscape. We can try to estimate the probability of fire, insects, disease, and wind, but ultimately we really can not predict when and where these disturbances will occur. At landscape scales, these types of dynamics must be handled using probabilistic models and scenario analysis that identify alternative pathways.
8. **Management practices and patterns.** Multi-ownership landscapes pose special challenges for scaling up the effects of forest management. Management goals (Spies et al. 2002) and practices can differ widely among landowners. Policies and plans that owners operate under may look very different when implemented on the ground than they do on paper. Policy changes can occur for economic and political reasons that are impossible to predict. The effects of management practices may be a result of interactions between environment and forest conditions. Biophysical information needed to estimate management effects is typically not available in a uniform way in multi-ownership landscapes. Finally, simulation models that can integrate stand and landscape processes across large forests are only in the early stages of development.

## CONCLUSION

Scaling up from stands to landscapes and regions is not easy to do. Yet, we must undertake this task to more fully understand how forest management practices affect biodiversity and other values. The variety of influences on the expression of stand-level process and patterns at broad spatial and temporal scales argues strongly for using multiple research approaches to fill critical information gaps. Too often research approaches such as stand-level experiments, retrospective studies, and landscape simulation models are not carried out in a coordinated fashion. Information from one type of approach cannot be readily linked to another. This reduces the effectiveness of our efforts to understand how human activities influence species and ecosystems. Significant advances can be made if we can do a better job of coordinating and integrating different research approaches to address sustainability questions that span multiple spatial and temporal scales.

## ACKNOWLEDGMENTS

I would like to acknowledge the assistance of Rob Pabst in preparation and review of this paper.

## REFERENCES

Garman, S.L.; Cissel, J.H.; Mayo, J.H. 2003. Accelerating development of late-successional conditions in young managed Douglas-fir stands: a simulation study. Gen. Tech. Rep. PNW-GTR-557. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 57 p.

Johnson, D.H.; O'Neil, T.A., eds. 2001. Wildlife habitat relationships in Oregon and Washington. Corvallis, OR: Oregon State University Press.

Ohmann, J.L.; Gregory, M.J. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest neighbor imputation in coastal Oregon, USA. Canadian Journal of Forest Research. 32: 725-741.

Spies, T.A.; Johnson, K.N. 2003. The importance of scale in assessing the compatibility of forest commodities and biodiversity. In: Monserud, R.A.; Haynes, R.W.; Johnson, A.C., eds. Compatible forest management. Dordrecht, The Netherlands: Kluwer Academic Publishers: 211-235.

Spies, T.A.; Reeves, G.H.; Burnett, K.M.; McComb, W.C.; Johnson, K.N.; Grant, G.; Ohmann, J.L.; Garman, S.L.; Bettinger, P.S. 2002. Assessing the ecological consequences of forest policies in a multi-ownership province in Oregon. In: Liu, J.; Taylor, W.W., eds. Integrating landscape ecology into natural resource management. Cambridge, United Kingdom: Cambridge University Press: 179-207.

Wimberly, M.C.; Spies, T.A. 2001a. Influences of environment and disturbance on forest patterns in coastal Oregon watersheds. Ecology. 82: 1443-1459.

Wimberly, M.C.; Spies, T.A. 2001b. Modeling landscape patterns of understory tree regeneration in the Pacific Northwest, USA. Applied Vegetation Science. 4: 277-286.

# Simulating Structural Development and Fire Resistance of Second-Growth Ponderosa Pine Stands for Two Contrasting Stand Treatments

Stephen Fitzgerald,[1] Douglas A. Maguire,[2] and Ryan Singleton[3]

---

## ABSTRACT

We simulated the growth, development, and fire-resistant of 80-year-old second-growth ponderosa pine (*Pinus ponderosa* P.&C. Lawson) stands in central Oregon for two contrasting treatments: heavy, low thinning and single-tree selection. Our analysis shows that heavy, low thinning that leaves codomiant and dominant trees improved fire resistance. Single-tree selection, with the goal of producing stands uneven-sized distribution decreases fire resistance over the long run.

KEYWORDS: Ponderosa pine, fire resistance, stand structure.

## INTRODUCTION

The typical presettlement ponderosa pine (*Pinus ponderosa* P.&C. Lawson) forest consisted of open stands, dominated by a few large trees often in groups, with little understory vegetation and maintained by frequent low-intensity fires (Bork 1984, Weaver 1943, Youngblood et al. 2004) (fig. 1). Historically, tree density in old-growth ponderosa pine stands in Oregon varied from 12 to 40 trees per acre (Munger 1917). However, the structural development of ponderosa pine forests in Oregon has changed significantly over the past century because of disruptions to the natural fire regime and changes in stand and landscape structure from timber harvesting, grazing, and other land use (Hessburg and Agee 2003). Recent landscape-scale assessments have shown that stand density and fuel accumulation have increased significantly compared to historical conditions, and current conditions could potentially support wildfires that are lethal to trees and other vegetation (Gast et al. 1991, Quigley and Cole 1997, Schmidt et al. 2002).

In central Oregon, a significant portion of the old-growth ponderosa pine forest was heavily logged 80 years ago. The landscape was left to naturally regenerate, resulting in dense, even-aged stands which today are increasingly susceptible to insect and disease outbreaks and stand replacement fire. These stands differ dramatically from historical conditions, so their future structural development is largely unknown. Silvicultural intervention, however, provides an opportunity to influence that development for various objectives, including improving stand and landscape resistance to wildfire. Forest structure is an important aspect of stand and landscape resistance to wildfire (Graham et al. 2004). Various stand and fuel attributes have been summarized by Agee (2002) into "guiding principles" for creating forests that are more fire resistant (table 1). Managers can use these guidelines for developing prescriptions for stands where increasing fire resistance is a primary objective, such as within the wildland-urban interface.

## STUDY AND SITE DESCRIPTION

The fire-resistance analysis presented in this paper is part of a larger study we installed in 2002 to explore silvicultural treatments that advance second-growth ponderosa pine forests toward a more sustainable and biologically diverse condition.

The study was installed in pure ponderosa pine forests of central Oregon within the pumice soil zone. Soils are

---

[1] Extension Silviculture and Wildland Fire Specialist, Department of Forest Resources, Oregon State University, Corvallis, OR 97331, USA.
Email: stephen.fitzgerald@oregonstate.edu

[2] Extension Silvicultural Specialist and [3] Research Assistant, Department of Forest Science, Oregon State University, Corvallis, OR 97331, USA

Figure 1—Harold Weaver (1930s) in a typical old-growth ponderosa pine forest on the Klamath Indian Reservation circa 1930s. *(Photo courtesy of Bureau of Indian Affairs)*

coarse textured with high infiltration rates and low fertility. The soil is the result of volcanic deposition from Mount Mazama 7,700 years ago and from other volcanic events in the Cascade Range. Precipitation is approximately 46 to 51 cm. Site quality, as measured by Barrett's (1978) site index, is 80-90. The study site is on a ponderosa pine/bitterbrush/ Idaho fescue plant association (Volland 1985) at approximately 1280 m in elevation.

Our objective was to test differences in stand structural development over time using four silvicultural alternatives in second-growth, even-aged ponderosa pine stands: (1) no treatment; (2) group selection, cutting 1 to 2-ha openings (10 to 20 percent of area in openings) and with low thinning of matrix area between openings (SDI 272 to 346/ha (110 to 140/ac)); (3) heavy low thinning (SDI 146 to 222/ha (60 to 90/ac)) leaving the "best" dominant and codominant trees at relatively low stand densities; and (4) single-tree selection removing trees evenly across all diameter classes (SDI 185 to 272/ha (75 to 100/ac)) by using a combination of high and low thinning methods to thin evenly across all crown classes, leaving the most vigorous trees, and creating a stand that was uneven-sized with the goal of producing an uneven-aged stand. Low thinning primarily removes trees in the suppressed, intermediate, and codominant crown classes, leaving the more vigorous codominant and dominant trees. High thinning removes a small percentage of trees in the codominant and dominant crown classes freeing up site resources and releasing other healthy intermediate, codominant, and dominant trees.

**Table 1—Guiding principles for creating fire-resistant forests**

| Principle | Effect | Advantage | Concerns |
|---|---|---|---|
| Reduce surface fuels | Reduces potential flame length | Control easier, less torching | Surface disturbance, less with fire than other techniques |
| Increase height to live crown | Requires longer flame length to begin torching | Less torching | Opens understory, may allow surface wind to increase |
| Decrease crown density | Makes tree-to-tree crown fire less probable | Reduces crown fire potential | Surface wind may increase and surface fuels may be drier |
| Keep larger trees | Thicker bark and taller crowns | Increases survivability of trees | Removing smaller trees is economically less profitable |

Adapted from Agee 2002.

Treatments were randomly assigned in each of three blocks across the central Oregon region (3 blocks x 4 treatments) for a total of 12 treatment units. Pretreatment data was collected during the summers of 2002 and 2003. The entire study encompasses over 244 ha. Treatment units varied in size from 16.1 to 40.5 ha. Two hundred and forty five 0.081-ha plots were established across the entire study area to obtain uniform coverage, with 16 to 25 plots in each treatment unit depending on unit size. On each plot, trees per hectare, tree diameter, crown class, mistletoe rating, and damage or defect and whether the tree was marked for retention or to cut were recorded for each tree. Tree heights and tree crown dimensions (width, length, crown base height (CBHt)) were recorded for three trees per plot (suppressed, codominant, and dominant). Canopy bulk density (CBD) is defined as the amount of foliage (including small twigs and branches) in kilograms for a given volume of crown. The CBD was not directly measured on our study plots, but was calculated by the Fire and Fuels Extension Model to the Forest Vegetation Simulator (refer to next section for model descriptions). Also, all snags and their attributes (diameter, height, and decay class) were measured. On all other plots, downed wood piece size (diameter and length) and decay class were measured. The percentage of vegetative understory (forbs, grasses, and shrubs) and the number of tree seedlings below breast height were inventoried on two 0.004-ha subplots. Trees in each treatment unit were either marked for retention or to cut according to predetermined prescriptions and density targets. Treatment units will be harvested in 2005.

## TREATMENT SIMULATION OBJECTIVES AND PARAMETERS

To simplify our analysis, we evaluated the fire resistance of stands managed for two contrasting treatments: heavy, low thinning and single-tree selection using high and low thinning to achieve an uneven diameter distribution. We did not simulate the growth and development of stands in the control and group selection treatments.

A stand's resistance to fire is dependent on the amount of surface (i.e., needles and branches), ladder, and canopy fuels, as well as various stand attributes including stand density, average diameter, height to the base of the canopy and canopy bulk density (Agee et al. 2000, Graham et al. 2004). Ladder fuels are often comprised of shrubs and small to medium size trees which can convey a surface fire up into the overstory canopy.

We input our pretreatment plot data and simulated the growth and development of these stands using the Forest Vegetation Simulator (FVS) (Stage 1973, Wycoff et al. 1982). Stands were projected 40 years in the future. The Fire and Fuels Extension Model to FVS was used to simulate fuel dynamics and potential fire behavior attributes over time (Reinhardt and Crookston 2003) including flame length under severe and moderate fuel moisture and weather conditions, and torching and crowning indices. Flame lengths under severe and moderate conditions (temperature, wind

**Table 2—Simulated stand attributes for the 40-year projection period for heavy, low thinning and single-tree selection treatments**

| | Heavy, low thin | | | | Single-tree selection | | | |
|---|---|---|---|---|---|---|---|---|
| Year | T/ha | D.B.H. | CBHt | CBD | T/ha | D.B.H. | CBHt | CBD |
| 2002 | 366 | 27.2 | 8.5 | 0.042 | 501 | 23.9 | 6.4 | 0.043 |
| 2005 | 107 | 39.1 | 12.5 | .019 | 215 | 25.9 | 8.8 | .022 |
| 2012 | 106 | 41.4 | 12.5 | .019 | 210 | 28.2 | 8.8 | .024 |
| 2022 | 104 | 44.5 | 12.8 | .019 | 207 | 30.9 | 8.5 | .027 |
| 2032 | 101 | 47.5 | 12.8 | .019 | 200 | 34.0 | 6.4 | .029 |
| 2042 | 99 | 50.3 | 12.8 | .019 | 195 | 37.1 | 6.5 | .029 |

T/ha = Trees per hectare
D.B.H. = Quadratic mean diameter at breast height in centimeters
CBHt = Crown base height in meters
CBH = Canopy bulk density in kilograms per cubic meter

speed, fuel moistures) are defined as follows and are default values in the model:

| Condition | Temp.° (Celsius) | Wind Speed (km/hr) | Fuel Moisture[4] |
|---|---|---|---|
| Severe | 21.1 | 32.2 | Very dry |
| Moderate | 21.1 | 9.7 | Moist |

The torching index is the 6.1-meter wind speed at which torching of the lower tree canopy would be initiated. Similarly, crowning index is the 6.1-meter wind speed required to initiate an active crown fire.

Thinning treatments were simulated by instructing the model to remove trees that were marked for removal on study plots. Because trees less than 13 cm were not operationally marked in the study, we instructed the model to remove all trees less than 13 cm for the wide thinning treatment and to remove 50 percent of the trees less than 13 cm for the single-tree selection treatment. The goal for the single-tree selection treatment was to create a more open but uneven-sized stand by keeping some of the viable saplings and regeneration and maintaining healthy and vigorous trees across all diameter classes.

Because thinning activities creates slash (surface fuels) and, therefore, can affect fire behavior by increasing flame length and decreasing torching and crowning indices (Graham et al. 2004), we simulated a pile-and-burn treatment (in the 2004 simulation year) to reduce these understory fuels following thinning.

Stand structural differences and fire resistance were evaluated immediately before (2002 simulation year) and after thinning and pile-and-burn treatments (2005 simulation year) and after 10, 20, 30 and 40 years of simulation.

## RESULTS AND DISCUSSION

### Stand Structural Attributes

Table 2 displays stand structural attributes for the simulation period. The heavy low thinning treatment dramatically reduced trees per hectare (t/ha) from 366 to 107 and increased quadratic mean diameter (d.b.h.) from 27.2 to 39.1 cm. After 40 years, quadratic mean diameter increased to 50.3 cm, which is close to the diameter of old-growth ponderosa trees for this site (figs. 2a,b,c). In contrast, the combination of high and low thinning in the single-tree selection treatment increased average stand diameter only slightly from 23.9 to 25.9 cm because some of the larger trees were removed and some smaller trees retained, including regeneration, which tends to lower average tree size (figs. 3a,b,c). After 40 years the average tree diameter increased to 37.1 cm. As expected, heavy, low thinning left fewer trees per hectare than the single-tree selection treatment (107 vs 501, respectively). After 40 years, trees in the heavy, low thinning treatment averaged 13.2 cm larger than those in the single-tree selection treatment.

---

[4] See Reinhardt and Crookston (2003) for the 1-, 10-, 100-, and 1000-hour fuel moisture content under very dry and moist conditions.

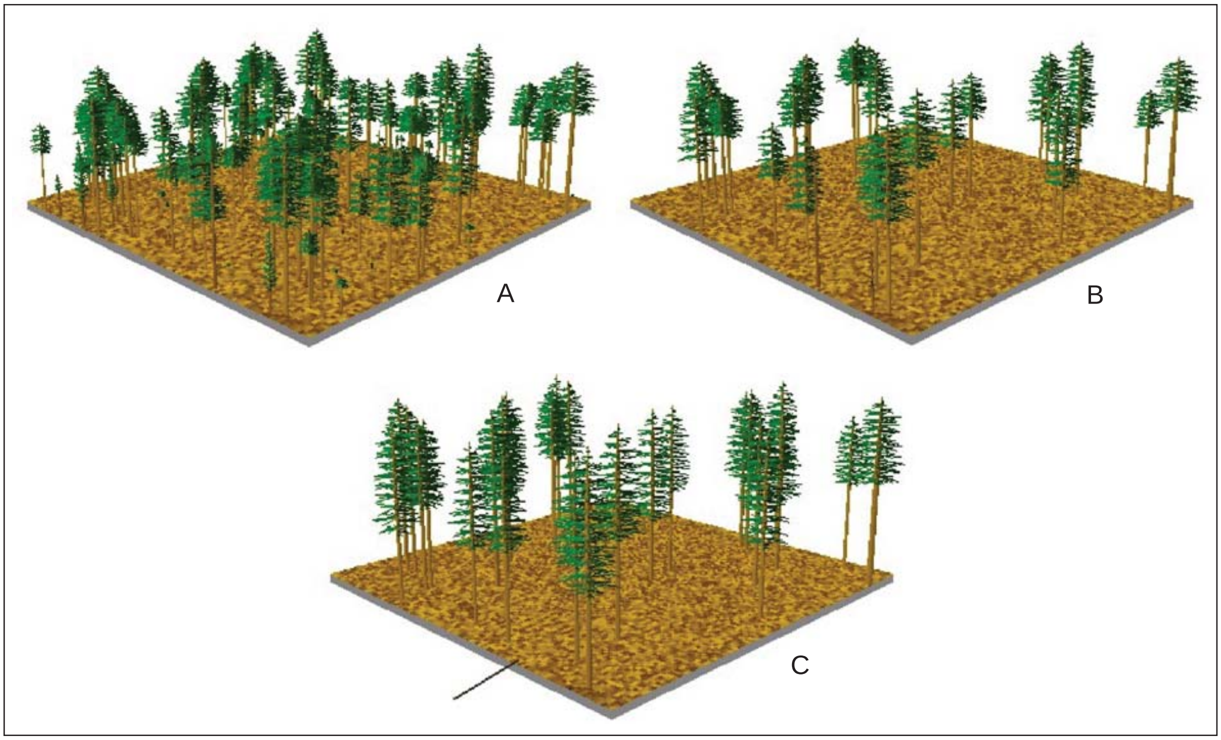

Figure 2—Heavy, low thinning treatment: (A) Pretreatment stand structure; (B) Post-thinning stand structure; (C) Stand structure after 40-year simulation period.

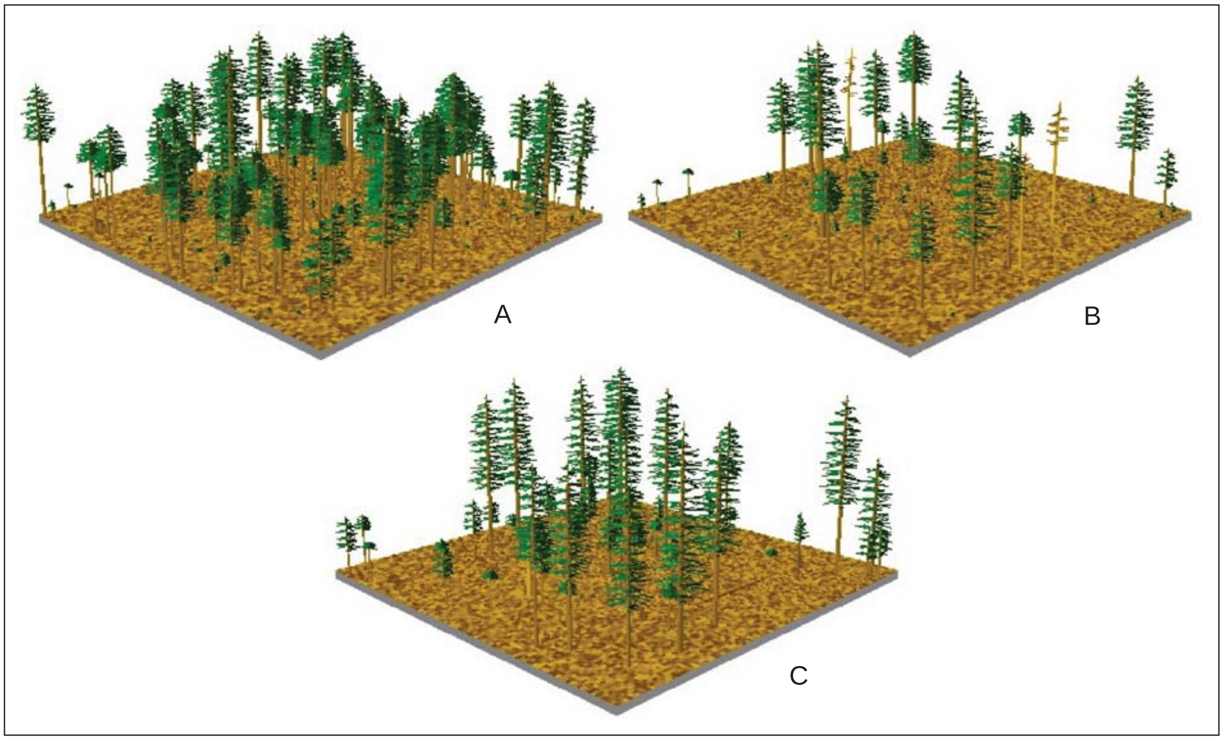

Figure 3—Single-tree selection treatment: (A) Pretreatment stand structure; (B) Post-thinning stand structure; (C) Stand structure after 40-year simulation period.

**Table 3—Simulated fire behavior attributes for heavy, low thinning and single-tree selection treatments**

|  | Heavy, low thin |  |  |  | Single-tree selection |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | Flame length[a] |  |  |  | Flame length |  |  |  |
| Year | Severe | Moderate | Torch index[b] | Crown index | Severe | Moderate | Torch index | Crown index |
| 2002 | 3.3 | 0.9 | 31.9 | 69.7 | 4.6 | 0.9 | 21.7 | 69.7 |
| 2005 | 4.4 | .8 | 25.1 | 124.3 | 5.0 | .8 | 19.2 | 112.1 |
| 2012 | 3.2 | 1.1 | 30.3 | 122.0 | .8 | 1.0 | 21.9 | 103.2 |
| 2022 | 3.1 | 1.1 | 31.7 | 120.9 | 3.8 | 1.0 | 22.2 | 95.0 |
| 2032 | 3.0 | 1.1 | 32.0 | 120.8 | 4.3 | 1.0 | 16.6 | 91.0 |
| 2042 | 3.0 | 1.1 | 32.0 | 120.8 | 4.3 | 1.0 | 16.6 | 91.0 |

[a] Flame lengths are in meters.

[b] Torching and crowning indices are in kilometers per hour.

Heavy, low thinning increased the height to the base of the crown (CBHt) from 8.5 to 12.5 m because larger codominant and dominant trees were left, and CBHt did not increase much after that over the 40-year simulation period. For the single-tree selection treatment, crown base height increased moderately from 6.4 to 8.8 meters, but decreased, as expected, over time to 6.4 m because of the presence of regeneration (i.e., ladder fuels) that grew into the lower canopy.

Canopy fuel, as measured by canopy bulk density (CBD), was reduced by half in both stand treatments, and it remained constant for the wide thinning treatment, but increased in the single-tree selection over the 40-year simulation period.

### Fire Behavior Attributes

Table 3 displays fire behavior attributes over the 40-year simulation period. Flame length is a predictor of fireline intensity, or the amount of heat released per unit area (Rothermal and Deeming 1980). Longer flame lengths indicate higher intensity, which are often more lethal to trees and other vegetation.

For both treatments, flame length under severe conditions increased immediately after treatment. This reflects increased wind speed and more thorough drying of surface fuels following thinning, which opens up canopy. Over time, flame lengths decrease, but flame lengths in the heavy, low thinning tend to be shorter than in the single-tree selection treatment. Flame lengths under moderate fuel moisture and weather conditions were similar for both treatments.

The torching index decreased immediately after thinning for both treatments due to the more open stand conditions. Over time, the torching index increases, but increases to a greater degree in the heavy, low thinning (32 km/hr at year 40). This indicates reduced potential for torching in the heavy, low thinning compared to the single-tree selection treatment (16.6 km/hr at year 40).

The crowing index increased immediately after thinning for both treatments and then decreases moderately over the 40-year simulation period. However, the crowning index is significantly higher in the heavy, low thinning treatment (120.8 km/hr at year 40) over the simulation period, indicating a much greater resistance to active crown fire behavior compared to the single-tree selection (91.0 km/hr at year 40). This is due to the lower canopy height from the presence of smaller trees and to the higher stand density and canopy fuels in the single-tree selection treatment.

In the single-tree selection treatment, we simulated only one thinning entry. The purpose of this treatment is to eventually produce an uneven-aged stand. In practice, uneven-aged management would entail multiple thinning entries every 10 to 20 years to remove trees across the entire diameter distribution and to create openings for additional regeneration (a new age class of trees). Continued thinning to create a more balanced uneven-aged stand would most likely lead to lower fire-resistance as additional regeneration is recruited and fuel ladders are created.

## CONCLUSIONS

Our simulation results show that thinning methods can significantly affect stand structural attributes, which in turn affect resistance to wildfire. Low thinning to a wide spacing increased overall resistance to wildfire by decreasing flame lengths under severe conditions, and increasing torching and crowning indices compared to the single-tree selection treatment. Treatments that retain the largest trees, increase canopy height by reducing ladder fuels, and reduce canopy fuels will improve resistance to wildfire (Agee 2002). Also, retaining the larger trees will improve their survival because they have thicker bark.

The results from this analysis are preliminary and are based on simulation results only. Although the structural attributes of stands can affect fire resistance, other landscape and site factors, such as overall fuel loading in the surrounding landscape, extreme weather conditions, and site factors such as slope, aspect and elevation can also affect fire behavior and tree and stand survivability.

## REFERENCES

Agee, J.K. 2002. Fire behavior and fire-resilient forests. Pages. In: Fitzgerald, S.A., ed. Fire in Oregon's forests: risk, effects, and treatment options. A synthesis of current issues and scientific literature. Special report. Portland, OR: Oregon Forest Resources Institute. 119-126.

Agee, J.K.; Bahro, B.; Finney, M.A.; Omi, P.N.; Sapsis, D.B.; Skinner, C.N.; vanWagtendonk, J.W.; Weatherspoon, C.P. 2000. The use of shaded fuelbreaks in landscape fire management. Forest Ecology and Management. 127: 55-66.

Barrett, J.W. 1978. Height growth and site index curves for managed, even-aged stands of ponderosa pine in the Pacific Northwest. Res. Pap. PNW-RP-232. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 14 p.

Bork, J.L. 1984. Fire history in three vegetation types on the east side of the Oregon Cascades. Corvallis, OR; Oregon State University. 94 p. Ph.D. dissertation.

Gast, W.R.; Scott, D.W.; Schmitt, C.; Clemens, D.; Howes, S.; Johnson, C.G.; Mason, R.; Mohr, F.; Clapp, R.A. 1991. Blue Mountains forest health report: new perspectives in forest health. Pacific Northwest Region, Malheur, Umatilla, and Wallowa-Whittman National Forests. 191 p.

Graham, R.T.; McCaffrey, S.; Jain, T.B., tech. eds. 2004. Science basis for changing forest structure to modify wildfire behavior and severity. Gen. Tech. Rep. RMRS-GTR-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 43 p.

Hessburg, P.F.; Agee, J.K. 2003. An environmental narrative of Inland Northwest United States forests. Forest Ecology and Management. 178: 23-59.

Munger, T.T. 1917. Western yellow pine in Oregon. USDA Bulletin 417. Washington, DC: Goverment Printing Office. 48 p.

Quigley, T.M.; Cole, H.B. 1997. Highlighted scientific findings of the interior Columbia Basin ecosystem management project. Gen. Tech. Rep. PNW-GTR-404. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 34 p.

Reinhardt, E.D.; Crookston, N.L. 2003. The fire and fuels extension to the Forest Vegetation Simulator. Gen. Tech. Rep. RMRS-GTR-116. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 209 p.

Rothermel, R.C.; Deeming, J.E. 1980. Measuring and interpreting fire behavior for correlation with fire effects. Gen. Tech. Rep. INT-GTR-93. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 4 p.

Schmidt, K.M.; Menakis, J.P.; Hardy, C.C.; Hann, W.J.; Bunnell. D.L. 2002. Development of coarse-scale spatial data for wildland fire and fuel management. Gen. Tech. Rep. RMRS-87. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Experiment Station. 41 p. +CD.

Stage, A.R. 1973. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Volland, L.A. 1985. Plant associations of the central Oregon pumice zone. R6-ECOL-104-1985. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 138 p.

Weaver, H. 1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific slope. Journal of Forestry. 41(1): 7-15.

Wycoff, W.R.; Crookston; N.L.; Stage, A.R. 1983. User's guide to the stand prognosis model. Gen. Tech. Rep. INT-GTR-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 112 p.

Youngbood, A.; Max,T.; Coe, K. 2004. Stand structure in eastside old-growth ponderosa pine forests of Oregon and northern California. Forest Ecology and Management. 199: 191-217.

# Predicting the Cumulative Effects of Forest Management in a Multi-Ownership Forest Landscape

David Lytle[1]

Land management agencies are often asked to consider how their management activities interact with those of neighboring landowners to affect the ecological attributes of forest landscapes. However, predicting the responses of multi-ownership forest landscapes to management is difficult. As a result, analyses of the cumulative effects of management are often informal, and future landscape conditions are poorly understood. Managers from public land management agencies in Minnesota and Ontario, Canada, are using an integrated framework to achieve common goals and better coordinate where goals differ. To support this framework, I have used LANDIS, a landscape-scale, forest dynamics model, to evaluate the cumulative effects of forest management in a 230 000 ha landscape managed for wilderness, timber, and recreation. Scenarios developed from current and proposed management plans were used to project the effects of 100 years of management on key forest attributes. These scenarios also contrast the current fire suppression policy with options that include prescribed and natural fire use. Compared to scenarios without harvest or fire, the current plans yield lower fuel loads and fire risk as a result of reduced stand ages and lower abundances of conifer fuel ladders. Scenarios with extended harvest rotations yield greater fire risk when compared to current plans, although prescribed fire use offsets these differences. Management of wilderness areas has a large impact on the landscape. The current fire suppression policy produces high fire risk within the wilderness, and results in the loss of early successional species; increased use of prescribed and natural fire reverses these trends.

---

[1] U.S. Department of Agriculture, Forest Service, North Central Research Station, 1831 Hwy. 169 E., Grand Rapids, MN 55744, USA.
Email: dlytle@fs.fed.us

# Projections of Future Overstory Stand Structure and Composition Following Variable-Retention Harvests in the Northwestern United States

Paul Schwarz,[1] Douglas A. Maguire,[2] and Doug Mainwaring[3]

## ABSTRACT

Among the motivations behind the 1994 Northwest Forest Plan was a growing awareness that the Pacific Northwestern landscape was becoming a patchwork of clearcuts and even-aged forest plantations, the latter with diminished structural diversity relative to presettlement forests. Potential deleterious effects of this patchwork landscape on wildlife populations and general biodiversity led to a mandate for minimum levels of green-tree retention within harvest units, in both dispersed and aggregated patterns. The Demonstration of Ecosystem Management Options (DEMO) study was initiated to address the lack of information on the efficacy of variable-retention harvests in providing habitat for target species. The DEMO study incorporated six different treatments in six blocks throughout Oregon and Washington. The following six treatments were specified by percentage of retained basal area and were implemented on 13-ha treatment units: (1) 100 percent; (2) 75-percent aggregated (three 1-ha cut patches); (3) 40-percent dispersed; (4) 40-percent aggregated (five 1-ha residual patches); (5) 15-percent dispersed; and (6) 15-percent aggregated (two 1-ha residual patches). All treatments except the control (100-precent retention) were planted in the harvested portions, so a new cohort of planted stock and natural regeneration will rapidly dominate harvested areas. The future structure of each of the 36 stands was projected with the ORGANON growth and yield model, assuming various management regimes. Visual representation of future stand structure was done with Envision software to facilitate communication among the scientists and managers comprising the multi-disciplinary DEMO team. These projections and visual representation of the stands will help the DEMO team design the next set of treatments that were intentionally left undefined at the inception of the study.

KEYWORDS: Variable retention, stand projection, growth model, simulation, visualization, yield.

## INTRODUCTION

Forest management on federally owned land in the northwestern United States has changed significantly since the adoption of the Northwest Forest Plan in 1994. Prior to implementation of this plan, the dominant management regime in the Douglas-fir dominated forests (*Pseudotsuga menziesii* (Mirb.) Franco) of the Oregon and Washington Cascades was clearcutting followed by planting. Fast-growing plantations successfully fulfilled the timber management goal mandated by previous federal legislation. As these stand conversions grew in number and dominated a larger portion of the landscape, the long-term effects on other ecosystem components came into question (Christensen et al. 1996). The northern spotted owl (*Strix occidentalis caurina*) was eventually listed as a threatened species due to the loss of habitat resulting from these stand conversions (Thomas et al. 1990).

Shortly thereafter, all federal lands within the Douglas-fir region were placed under management guidelines specified in the 1994 Northwest Forest Plan (Tuchmann et al. 1996). Emphasizing ecosystem management, this plan halted all clearcutting in harvest units within the owl's range, calling instead for variable retention harvests. According to the plan, at least 15 percent of the area in each harvest unit must be made up of retained green trees. In addition, 70 percent of this retention must be in aggregates 0.2–1.0 ha or larger,

---

[1] Research Associate, [2] Hayes Professor of Silviculture and Forest Biometrics, and [3] Research Assistant, Department of Forest Science, Oregon State University, Corvallis, OR 97331, USA. Email of corresponding author: doug.mainwaring@oregonstate.edu

with the remainder dispersed either as single trees or in small clumps <0.2 ha in size. Moreover, to the extent possible, retention should include the largest and oldest live, decadent or leaning trees, and hard snags. The intent was to retain residual trees indefinitely (Tuchmann et al. 1996).

Although the retention standards of this plan were based on the best information available at the time, no experiment or observational study had ever determined whether this level of retention provided meaningful or sufficient habitat necessary to preserve the organisms and ecological processes for which they were designed. As a starting point for addressing this question, the Demonstration of Ecosystem Management Options (DEMO) study was initiated (Franklin et al. 1999). Replicated at six locations throughout the Douglas-fir region (i.e., Oregon, Washington) (fig. 1), this interdisciplinary study was designed to test whether it is possible to balance timber production with maintenance of biodiversity in mature Douglas-fir forests. The primary objective of the study was to determine the response of vegetation, ectomycorrhizal fungi, canopy arthropods, small mammals, salamanders, and birds to different levels and patterns of retention, and to assess human perception of their visual quality. DEMO also has a long-term objective to determine what effect subsequent stand development has on these responses over time (Aubry et al. 1999, Halpern and Raphael 1999).

Each replication of this study included the same six treatments on 13-ha units: (1) an unharvested control; (2) 75-percent retention with the harvested area distributed among three 1-ha patch cuts (Retained trees were aggregated in the matrix surround the patch cuts.); (3) 40-percent dispersed retention; (4) 40-percent retention with retained trees distributed among five equally spaced 1-ha aggregates; (5) 15-percent dispersed retention; 6) 15-percent retention with retained trees distributed between two equally spaced 1-ha aggregates (fig. 2). On dispersed retention units, residual trees were evenly distributed. These treatments were harvested in 1997 and 1998, and harvested areas were replanted with a uniform mix of species prescribed for each block.

The planting density, generally between 500 and 750 trees per hectare, was consistent with the stated goal of balancing timber production with maintenance of biodiversity. However, timber harvests in these units were intended as an initial set of alternative silvicultural treatments, and no attempt was made to specify a full silvicultural regime or system. In this approach, further treatments could benefit from initial responses to harvest, changing scientific perspective, and changing public perceptions. Unknowable responses to the initial treatments and the long-term nature of this type of study require flexibility in design of a treatment regime. However, the new cohort in these forests will develop quickly to create a relatively closed canopy in 15 to 25 years, potentially causing a drastic change in ground vegetation and the many organisms that rely on the understory for food or shelter (e.g., Alaback 1982). The ability to predict future stand structures will aid decisionmaking about what future management actions, if any, should be taken in these treatment units. This peek into the future is especially important in a long-term, multidisciplinary study, where competing research objectives, multi-institutional involvement, and personnel turnover make quick action difficult (Franklin et al. 1999).

Figure 1—Locations of the six DEMO blocks. CF: Capitol Forest; BU: Butte; PH: Paradise Hills; LW: Little White Salmon; WF: Watson Falls; DP: Dog Prairie.

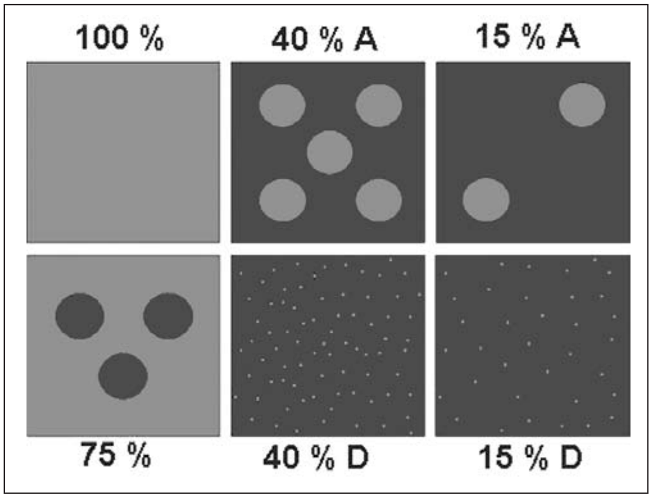

Figure 2—Retention levels and patterns of the six DEMO treatments. Gray coloration represents retained trees; black denotes harvested areas.

Given the generally accepted influence of forest structure on dependent biotic communities, predicting the likely effects of any silvicultural regime requires predicting the subsequent structure and dynamics of the vegetation. Although quantitative descriptors may be sufficient for some foresters and forest ecologists, they are less useful for managers and scientists working with other organisms. Stand and landscape visualization software was developed to surmount this communication challenge. Because visualization software converts stand variables and tree dimensions into a three-dimensional visualization, it provides a means by which forest structure can be inferred from very detailed, quantitative description that would otherwise be difficult to interpret (McGaughey 1997). Coupled with an appropriate growth model, three-dimensional depictions of future stand structure provide insight into the ramifications of alternative silvicultural treatments. The objectives of this paper are to (1) link the tools necessary for projecting the future structure of DEMO treatments units, (2) produce visualizations of future structures of each unit, (3) evaluate alternative treatment regimes, (4) facilitate planning by the multidisciplinary DEMO team, and (5) begin discussion on specifications for variable-retention silvicultural systems.

## METHODS

### Data Collection

Data on tree species composition and stand structure were collected from 0.04-ha circular plots on a 40-m sampling grid within each treatment unit (Aubry et al. 1999). Diameter at breast height (1.3 m, d.b.h.) was measured on all trees, and height and height to crown base were measured on up to 40 trees per species per treatment unit. Trees chosen for this subsample were distributed evenly across the diameter distribution of each treatment. Missing heights and heights to crown base were estimated by regression equations developed for each treatment unit and using d.b.h. as the predictor.

Stand age was estimated by counting rings on tree stumps. Once adjusted for stump height (Omule and Kozak 1989), combination of an age-d.b.h. relationship with height-diameter curves allowed estimation of site index for each treatment unit (Bruce 1981, Hann and Scrivani 1987).

Information on average planted tree density at each of the treatment units was obtained from post-harvest planting records. The amount and composition of competing understory vegetation, used in simulating young stand growth, was estimated from ground surveys on each subplot.

### Simulations

Individual tree measurements were read into ORGANON, an empirical growth and yield model developed for mixed conifer forests of southwestern Oregon and Douglas-fir/hemlock forests of western Oregon and Washington (Hann et al. 1993). The southwest Oregon variant of ORGANON (SWO) was used for all of the simulations. When necessary, tree species present in the field plot but not supported in the SWO variant were replaced with ecologically similar species.

All treatment units were simulated for 100 years, or twenty 5-year growth cycles. For the treatment units with planted seedlings, the first 15 years of seedling growth were simulated using the SYSTUM-1 young stand simulator (Ritchie et al.1993). Output from this model was then merged with the tree lists of the measured overstory trees, similarly grown 15 years. The merged tree lists were then simulated another 85 years using ORGANON. On plots with aggregated retention, separate runs were used for the aggregates and the cut portion containing young trees; i.e., they were simulated as two separate stands with no competitive effects on each other.

Images of the projected stands were rendered with the Envision Environmental Visualization System developed by the USDA Forest Service, Pacific Northwestern Research Station (http://forsys.cfr.washington.edu/envision.html). Envision is a stand and landscape level visualization system that incorporates a digital terrain model, thereby placing stands in a geographic context and providing topographic relief.

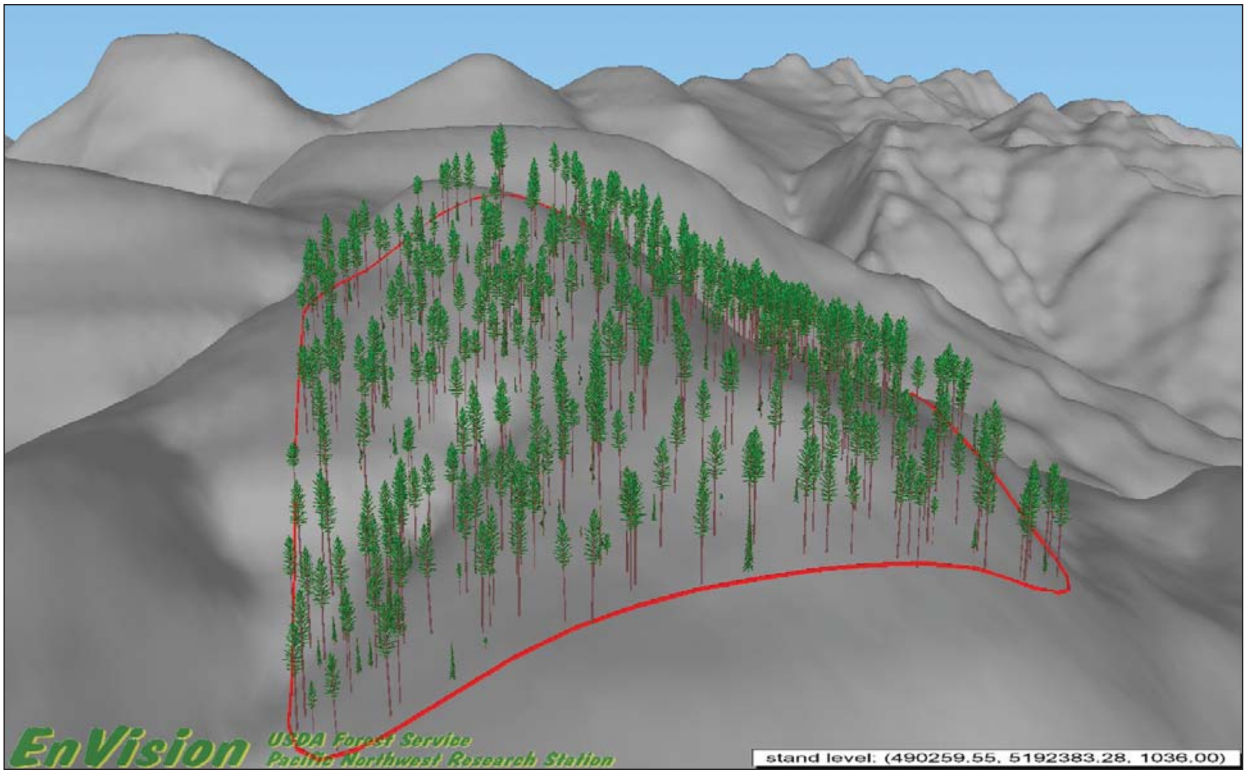

Figure 3—Capitol Forest treatment 15-percent dispersed, year 0, stand-level view.

To evaluate treatments for possible follow-up harvests, alternative management scenarios were explored at Paradise Hills, a Site IV, high elevation site in the Cascade Range. Four scenarios were simulated: (1) BL—a baseline scenario, involving no additional management activities; (2) UN—understory management scenario, in which stands were grown for 50 years and then 50 percent of the young trees were removed; (3) UNOV—understory and overstory management scenario, in which the stands were thinned proportionally (thinned trees were distributed across the diameter distribution) to a relative density of 35 whenever they reach a relative density of 55 (Reineke 1933); and (4) TFB—thinning-from-below scenario, in which thinned trees were taken from the low end of the diameter distribution. Stands were thinned from below to a relative density of 35 whenever they reached a relative density of 55.

## RESULTS AND DISCUSSION

Figures 3 through 8 present stand-level and close-up views of Capitol Forest treatment 15-percent dispersed retention at years 0, 15, and 100 for the baseline management scenario (BL, no future treatment). At year 15, the understory simulated with SYSTUM-1 is first available for incorporation into ORGANON and visualization with Envision. Although this stand is two-storied at year 100, its canopy appears closed. Any positive effect of the original harvest on understory development can be expected to reverse as both the overstory and understory grow. The rate at which this occurs depends on the level and pattern of retention, the productive capacity of the site, and the species planted in the understory. Because visualizations can be produced at each growth interval of the growth model, output from both, used in concert, make it possible to rapidly assess canopy closure. Output from all treatments on all blocks reinforces expectation: without further treatment, closed canopies can be expected long before 100 years, even where retaining only 15 percent of the original basal area.

Closed canopies within treatment units are unsuitable for some forest biota but suitable for others. Therefore, structures can be maintained over time to meet habitat requirements of specific species targeted for management. In the broader context, however, it is likely that a higher diversity of taxa would be favored by keeping stand density at a level that promotes ground vegetation (North et al. 1996, Thomas et al. 1999). It is also important from a management perspective to consider the diversity of structures and development stages across the landscape. Variable-retention harvests distributed spatially and temporally across the

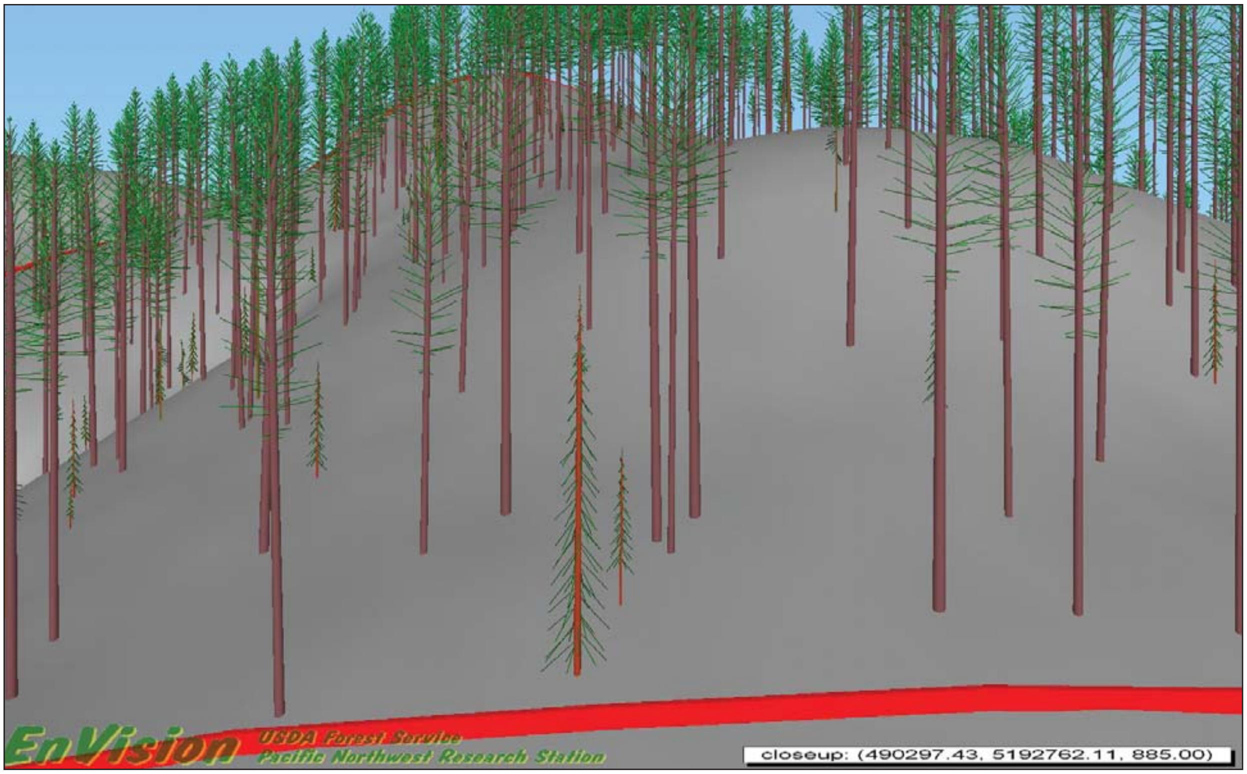

Figure 4—Capitol Forest treatment 15-percent dispersed, year 0, close-up view.

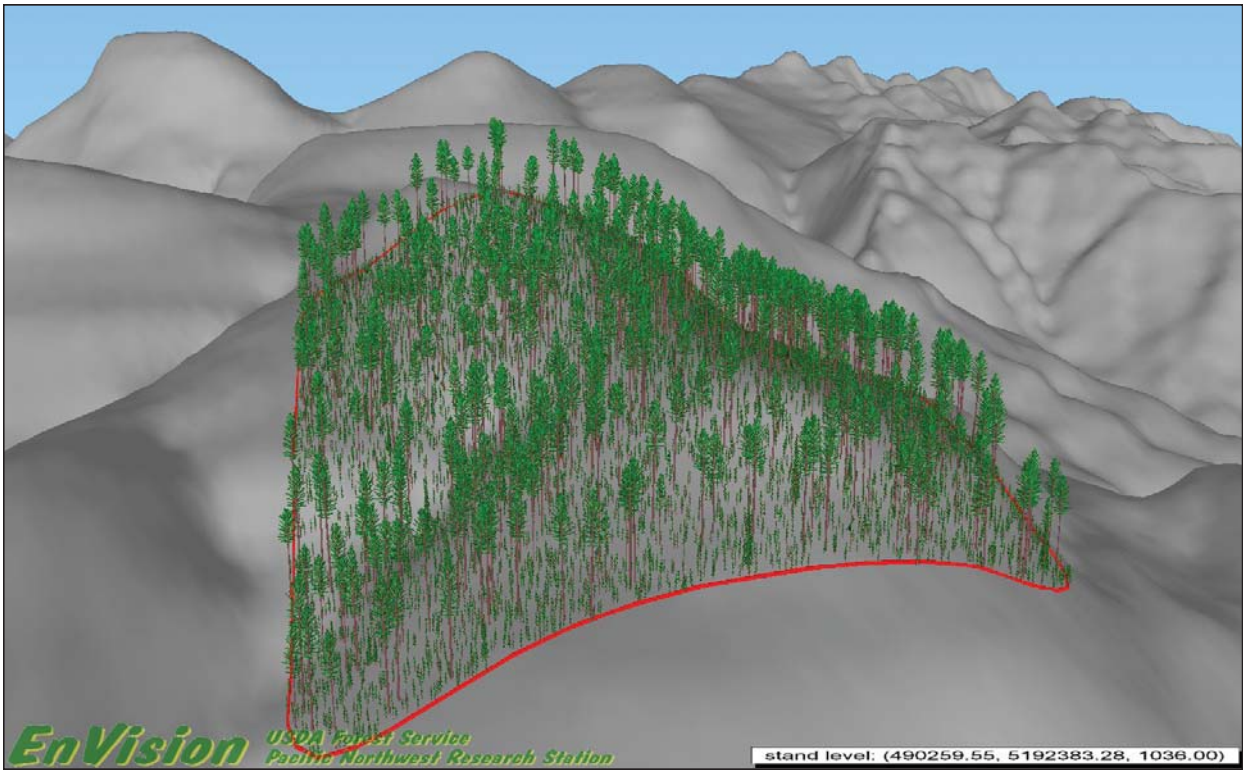

Figure 5—Capitol Forest treatment 15-percent dispersed, year 15, stand-level view.

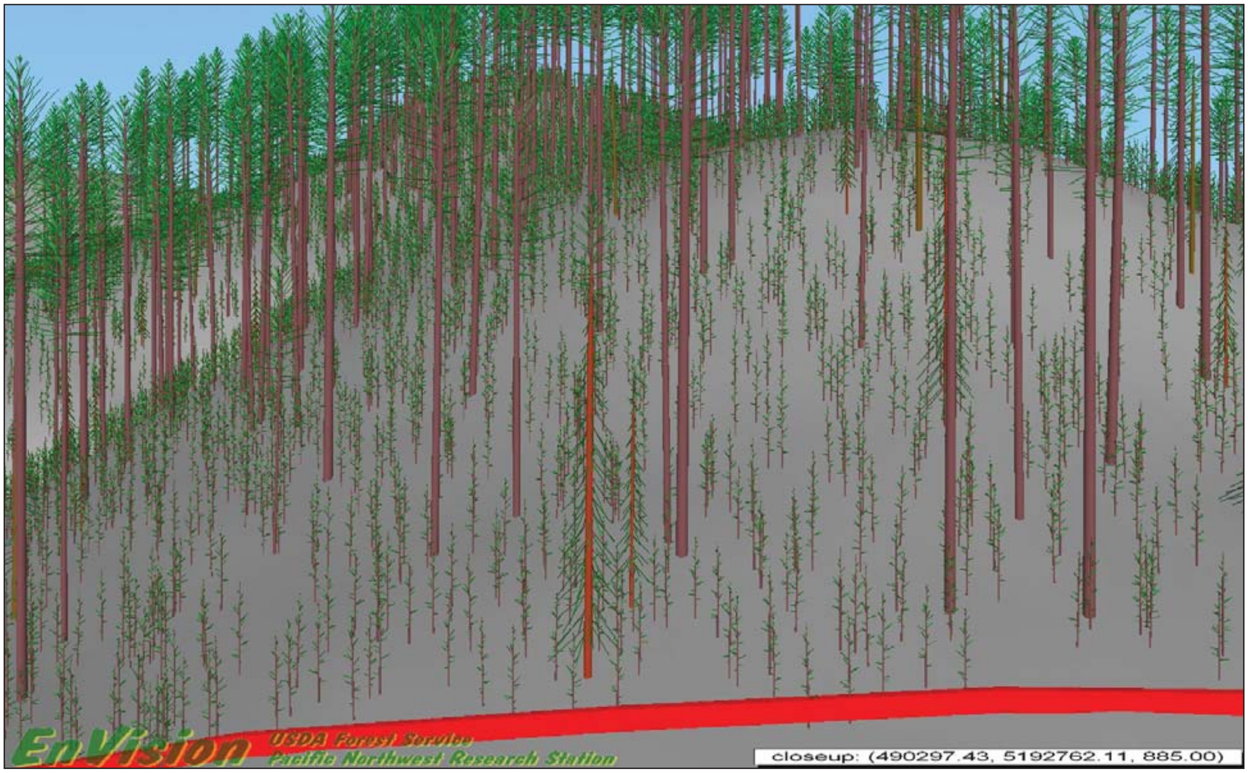

Figure 6—Capitol Forest, treatment 15-percent dispersed, year 15, close-up view.

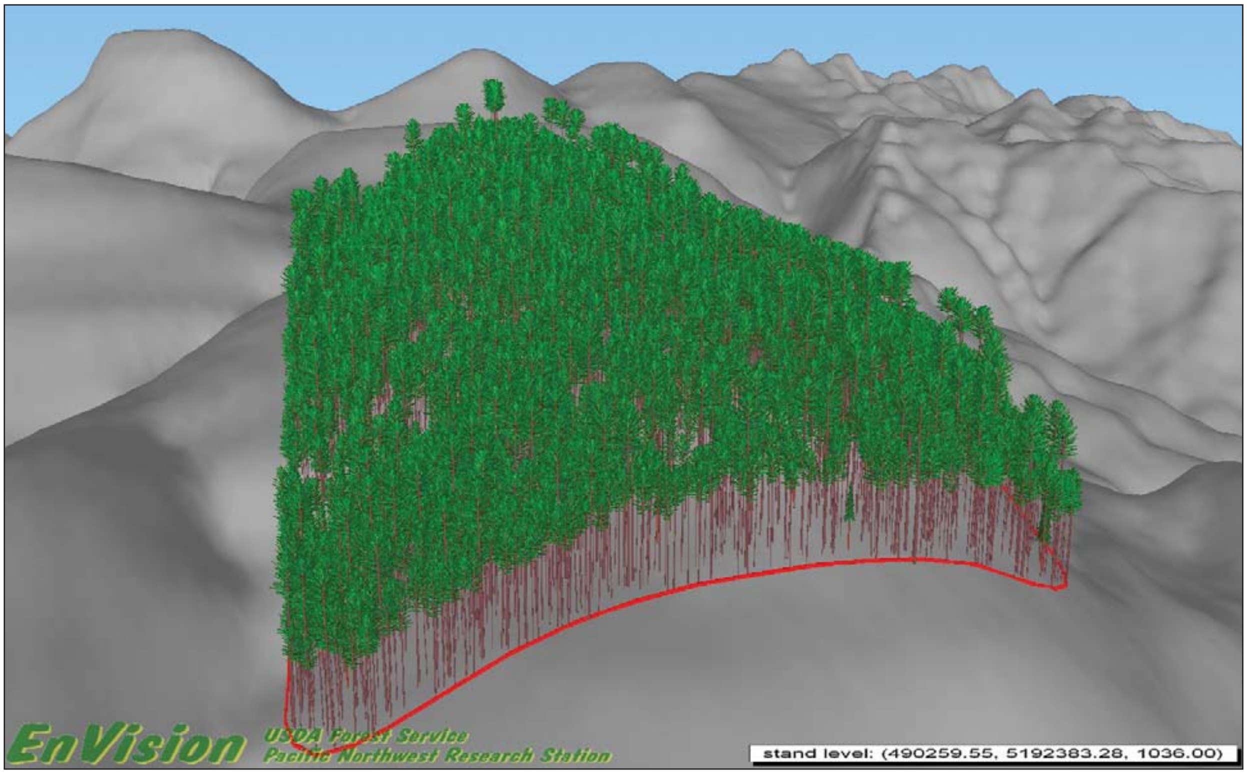

Figure 7—Capitol Forest, treatment 15-percent dispersed, year 100, stand-level view.

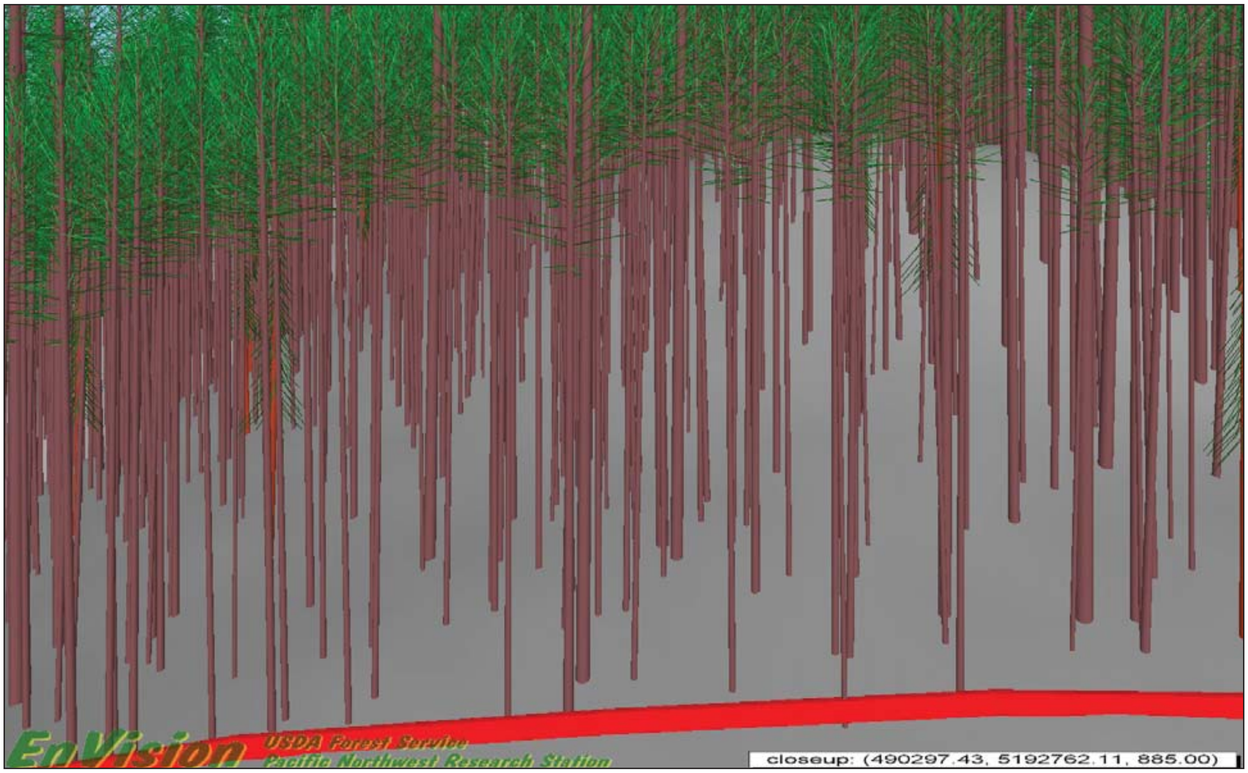

Figure 8—Capitol Forest, treatment 15-percent dispersed, year 100, close-up view.

landscape would provide a range in stand density and, thereby, create a range in habitat conditions that any one stand would not provide continuously. However, because federal forest managers face difficulty in implementing harvests, future harvests are unlikely to be distributed across the landscape to compensate for many stands entering the stem-exclusion stage of development (Oliver and Larsen 1996). Variable-retention treatments would also retain more large trees, in contrast to the plantations produced over the last several decades. One question remains however: Does the presence of large trees, with a solid lower canopy and diminishing understory, continue to provide sufficient habitat for organisms of interest?

Output from the four management scenarios applied at Paradise Hills is shown in figures 9 through 17. Basal area responses indicate that the understory scenario (UN) accrues more basal area than either the understory/overstory (UNOV) or thin-from-below (TFB) scenarios, but less than the baseline (BL) (fig. 9). Furthermore, the UNOV and TFB scenarios have approximately similar basal areas throughout the 100-year simulation. The differences between the baseline (BL) and reharvesting scenarios are also apparent visually, as are the differences among the reharvesting scenarios themselves (figs. 10 through 17). For example, the density of young trees in the TFB scenario (fig. 17) is noticeably lower than density in the UNOV scenario (fig. 15).

Patterns in total volume production differ by variable-retention treatment, management scenario, and cohort (fig. 18), largely because differences in overstory structure affect growth and development of the understory. At a 40-percent retention level, although overstory production for the 100-year period is comparable between the aggregated and dispersed retention, the well-distributed shade of dispersed trees limits growth and development of the understory cohort compared to uncut aggregates of the same basal area. In contrast, at 15-percent retention, understory production is roughly equivalent for both aggregated and dispersed retention. However, with the significant spacing given to overstory trees in the dispersed pattern, overstory production is more than twice the amount observed in the aggregated pattern.

In general, total volume production at Paradise Hills decreased as harvest intensity increased from BL to UN to UNOV and TFB. In addition to its effect on total volume production, removing growing stock has a significant effect on three-dimensional stand structure, an effect that is less interpretable with bar charts and columns of numbers.

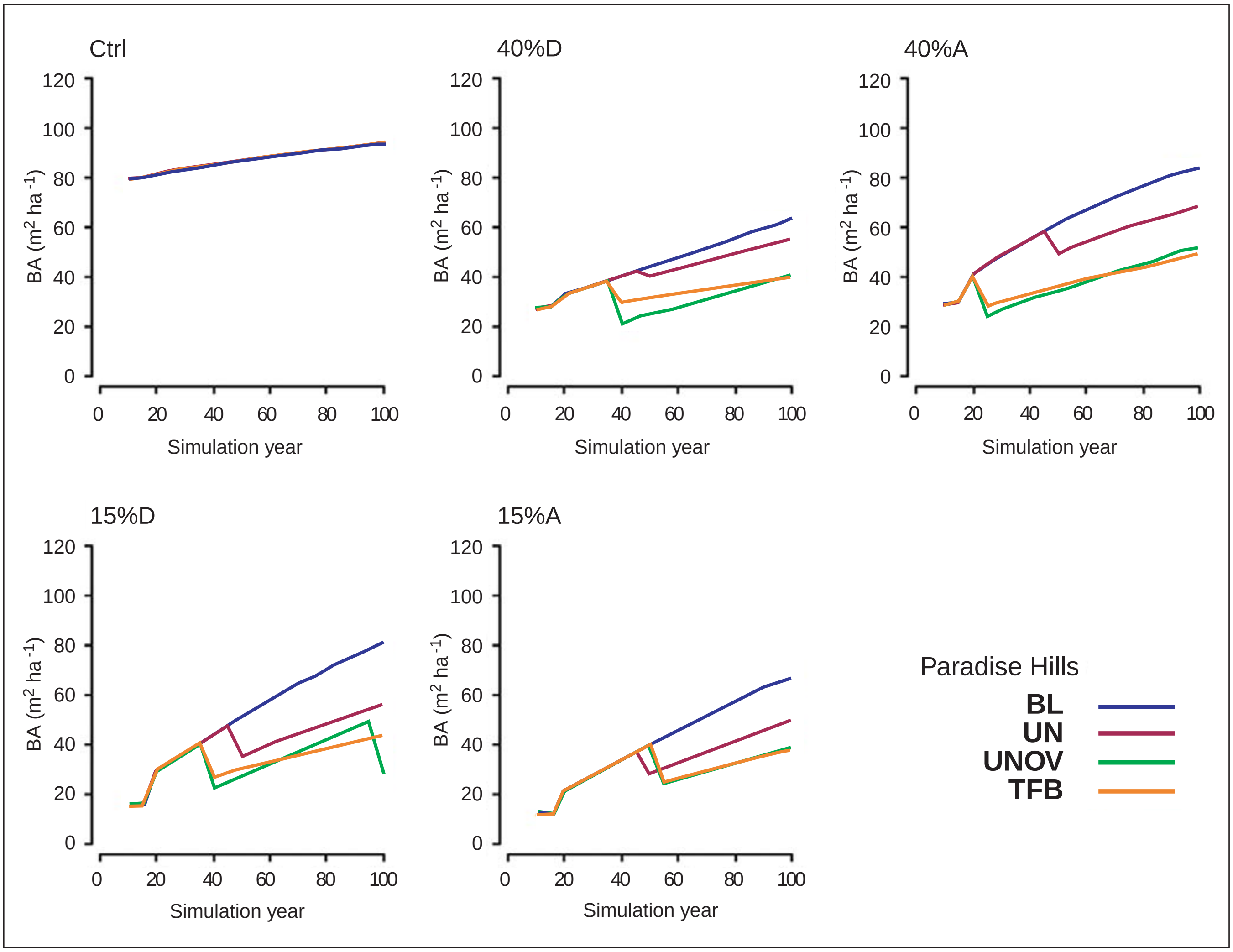

Figure 9—Stand basal area over time for four different management scenarios at Paradise Hills.

Output from visualization software allows rapid assessment of stand structural differences and facilitates communication about the effects of silvicultural treatments on structural aspects relevant to both timber production and biodiversity.

## CONCLUSIONS

Federal land management in the United States requires trade-offs and balances among competing demands by various publics. This process is the quintessence of multiresource management and, hence, requires a multidisciplinary approach to developing silvicultural systems to achieve complex objectives. Output from DEMO research, therefore, must be readily interpretable by many people and groups with little or no silvicultural expertise. Coupling growth models like SYSTUM-1 and ORGANON with a visualization system like Envision can portray aspects of stand structure that are relevant to all interested parties, and thereby facilitate management planning by multidisciplinary teams and multiple publics.

## ACKNOWLEDGMENTS

This research is a component of the Demonstration of Ecosystem Management Options (DEMO) study. Funds were provided by the USDA Forest Service, PNW Research Station to Oregon State University and to the University of Washington.

## REFERENCES

Alaback, P.B. 1982. Dynamics of understory biomass in Sitka spruce-western hemlock forests of Southeast Alaska. Ecology. 63: 1932-1948.

*(text continues on p. 213)*

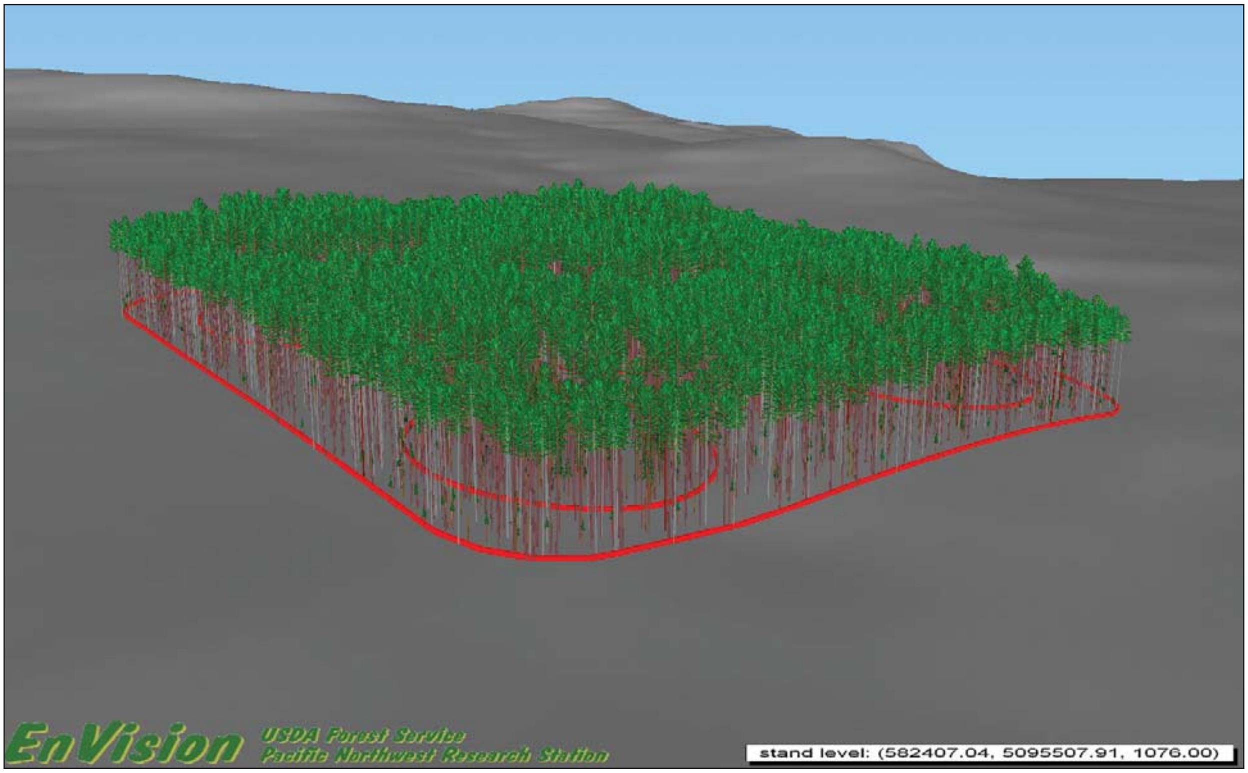

Figure 10—Paradise Hills, treatment 40-percent aggregate, baseline, year 100, stand-level view.

Figure 11—Paradise Hills, treatment 40-percent aggregate, baseline, year 100, close-up view.

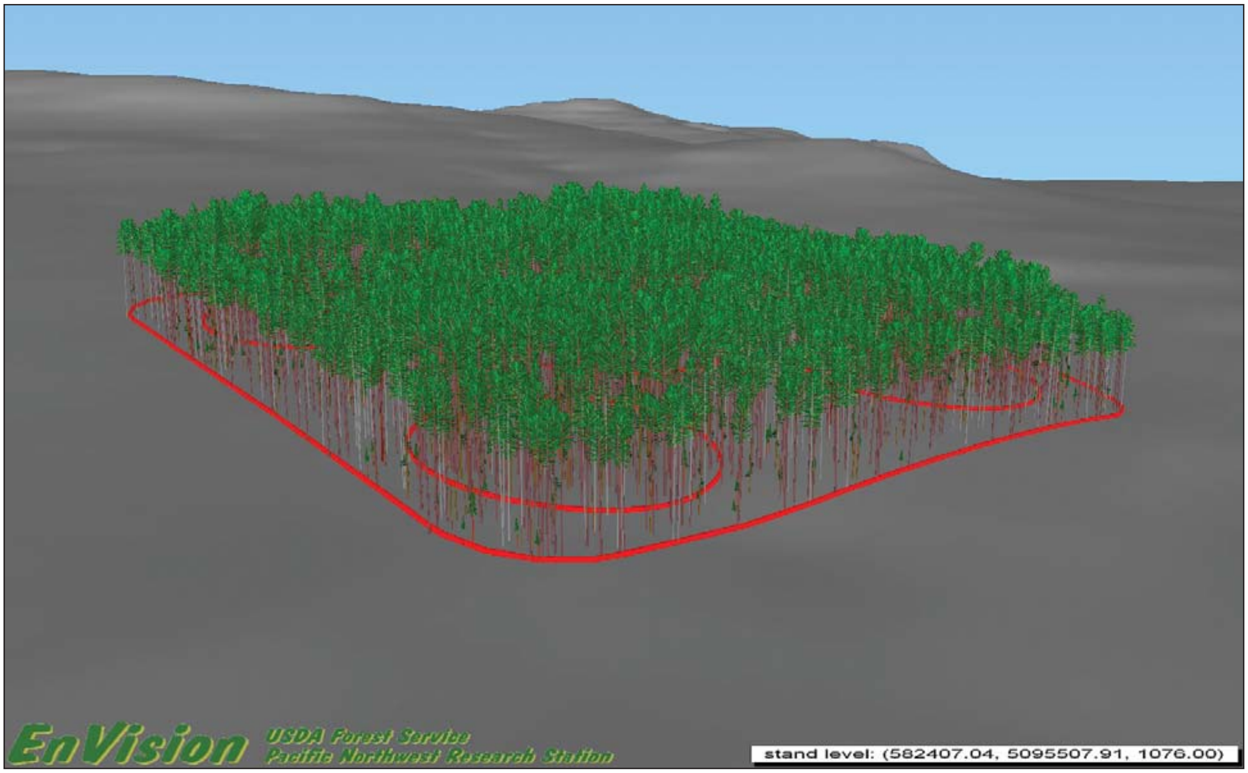

Figure 12—Paradise Hills, treatment 40-percent aggregate, understory scenario, year 100, stand-level view.

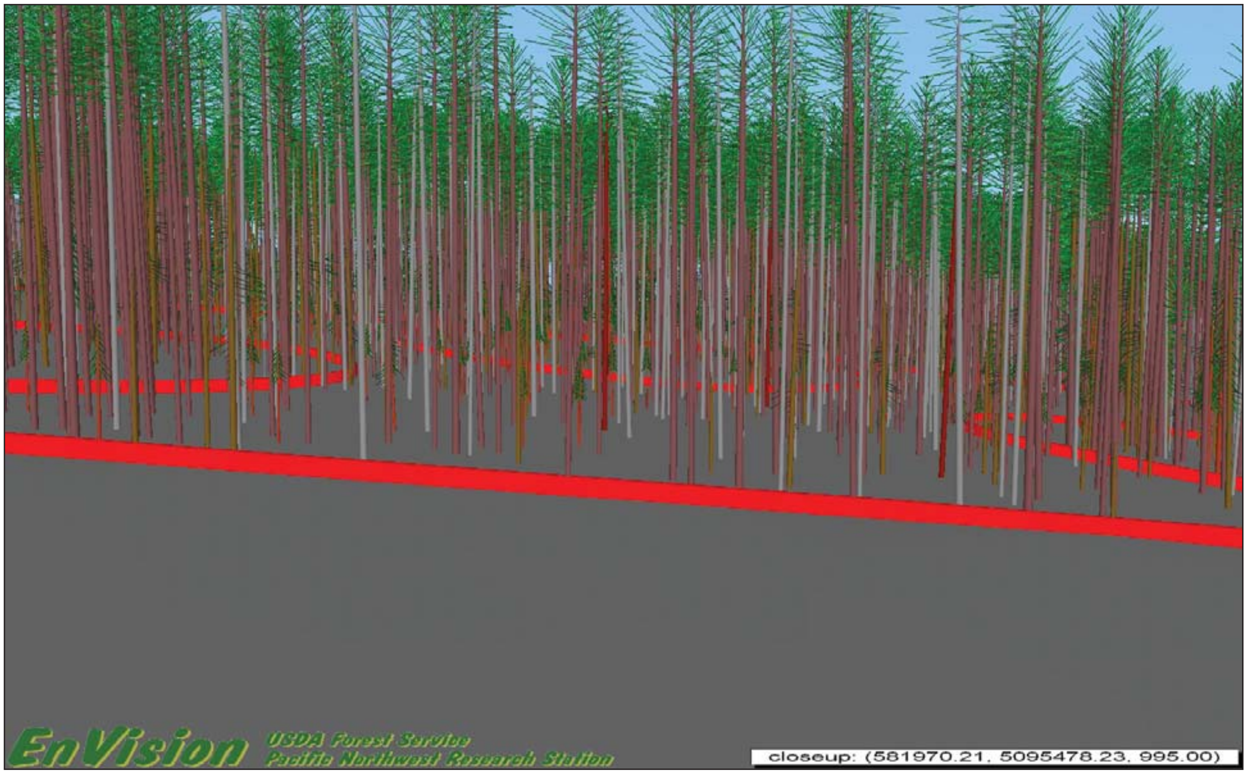

Figure 13—Paradise Hills, treatment 40-percent aggregate, understory scenario, year 100, close-up view.

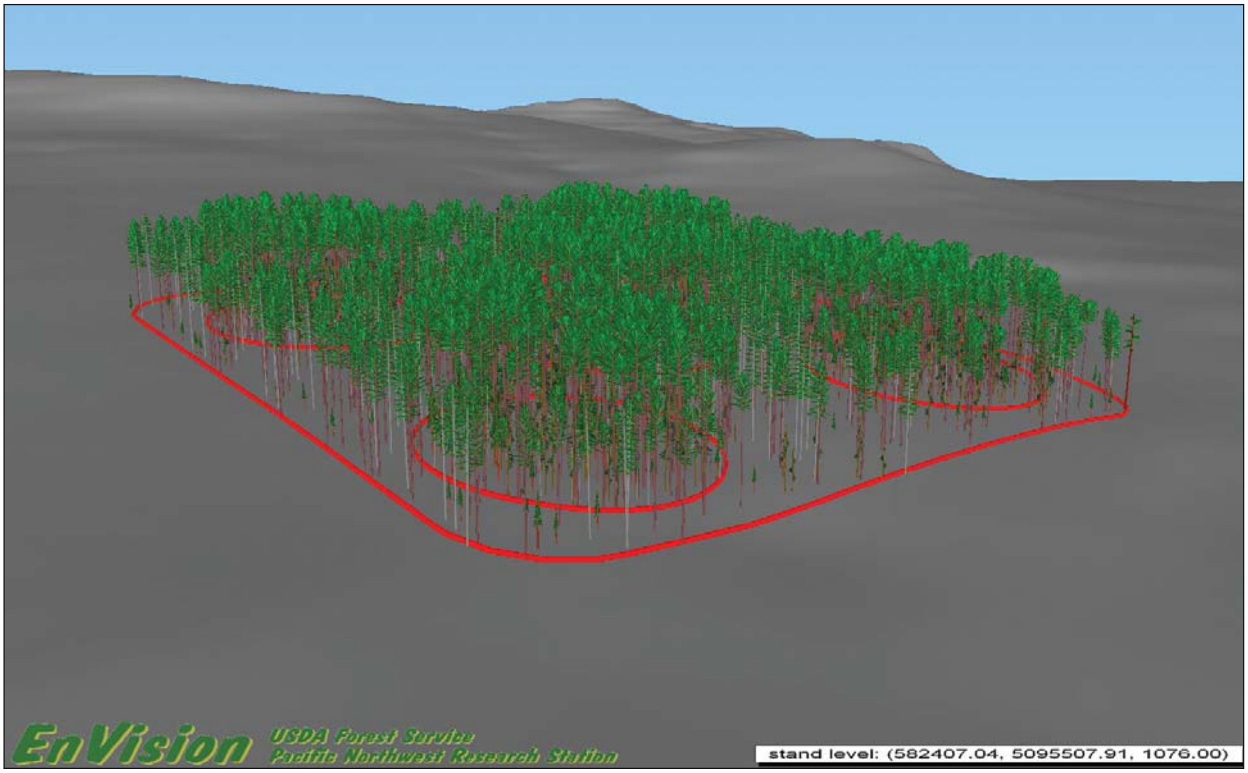

Figure 14—Paradise Hills, treatment 40-percent aggregate, understory/overstory scenario, year 100, stand-level view.

Figure 15—Paradise Hills, treatment 40-percent aggregate, understory/overstory scenario, year 100, close-up view.

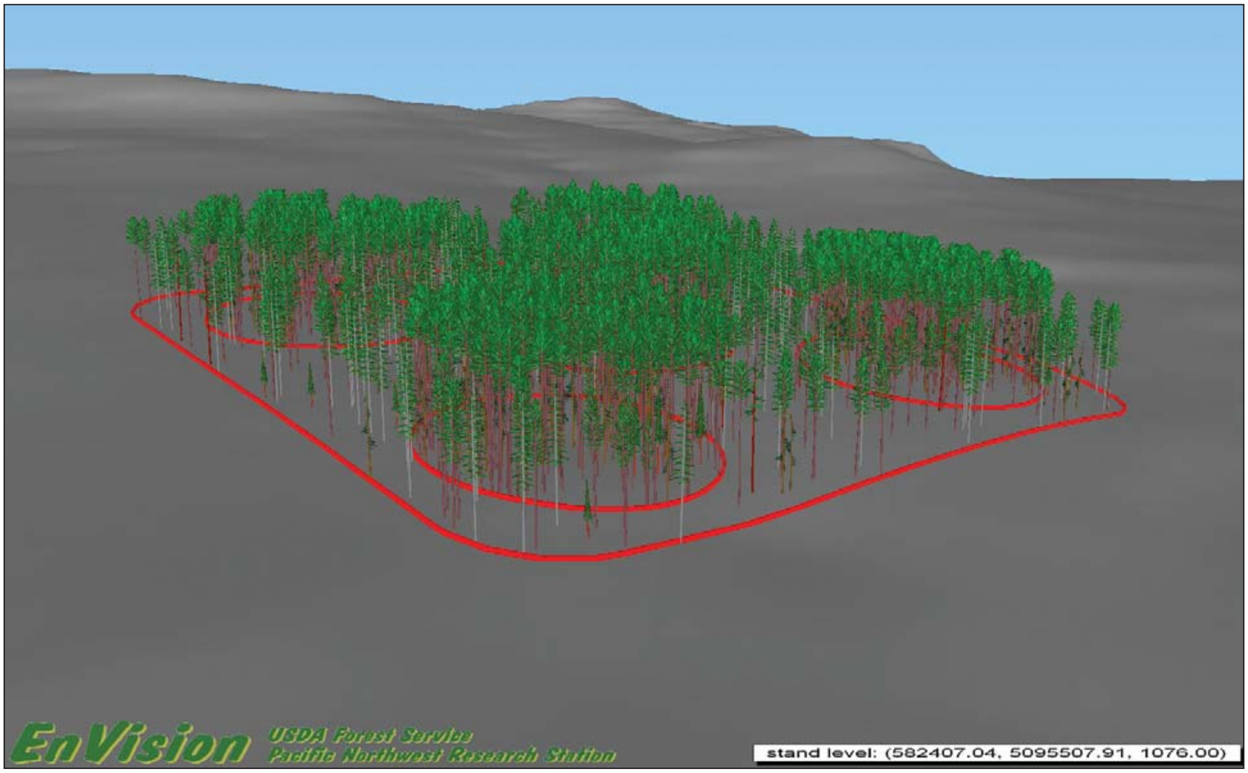

Figure 16—Paradise Hills, treatment 40-percent aggregate, thinning-from-below scenario, year 100, stand-level view.

Figure 17—Paradise Hills, treatment 40-percent aggregate, thinning-from-below scenario, year 100, close-up view.

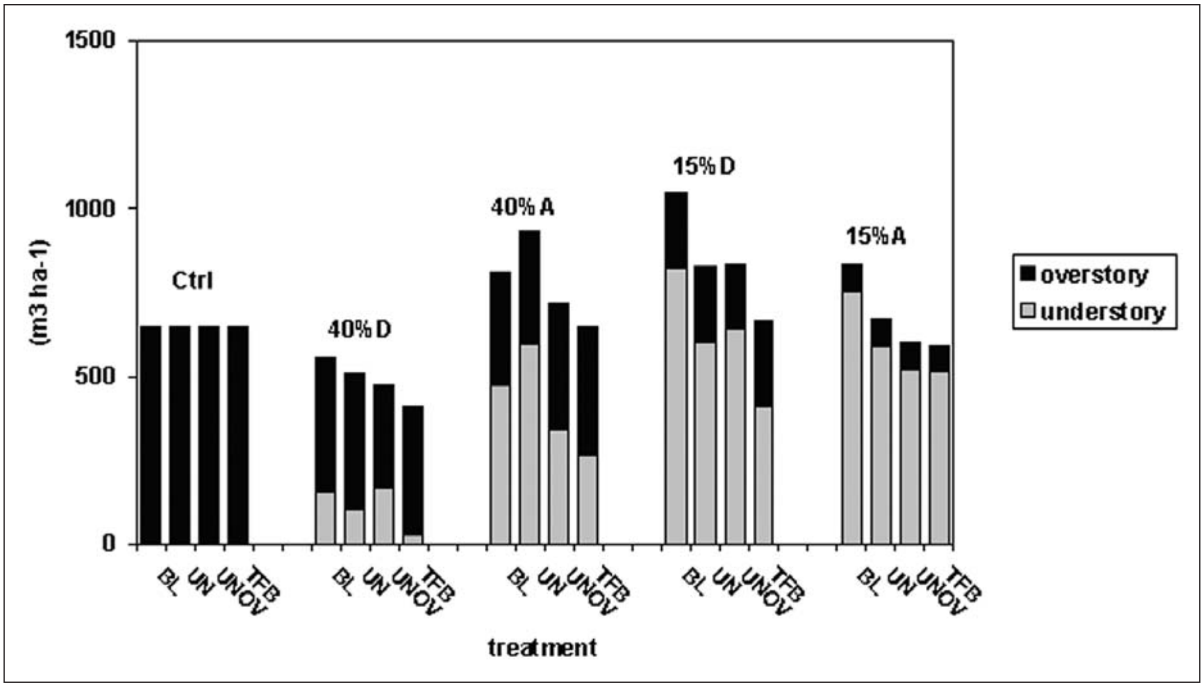

Figure 18—Overstory and understory volume production, Paradise Hills, by treatment and management scenario.

Aubry, K.B.; Amaranthus, M.P.; Halpern, C.B.; White, J.D.; Woodard, B.L.; Peterson, C.E.; Lagoudakis, C.A.; Horton, A.J. 1999. Evaluating the effects of varying levels and patterns of green-tree retention: experimental design of the DEMO study. Northwest Science. 73(special issue): 12-26.

Bruce, D. 1981. Consistent height-growth and growth-rate estimates for remeasured plots. Forest Science. 27: 711-725.

Christensen, N.L.; Bartuska, A.M.; Brown, J.H.; Carpenter, S.; D'Antonio, C.; Francis, R.; Franklin, J.F.; Macmahon, J.A.; Noss, R.F.; Parsons, D.J.; Peterson, C.H.; Turner, M.G.;Woodmansee, R.G. 1996. The report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. Ecological Applications. 6: 665–691.

Franklin, J.F.; Norris, L.A.; Berg, D.R.; Smith, G.R.; 1999. The history of an experiment in regeneration harvest of northwestern forest ecosystems. Northwest Science. 73(special issue): 3-11.

Halpern, C.B.; Raphael, M.G., eds. 1999. Retention harvests in northwestern forest ecosystems: the Demonstration of Ecosystem Management Options (DEMO) Study. Northwest Science. 73(special issue): 125 p.

Hann, D.W., Olsen, C.L., Hester, A.S. 1993. ORGANON user's manual. Corvallis, OR: Department of Forest Resources, Oregon State University. 113 p.

Hann, D.W.; Scrivani, J.A. 1987. Dominant-height-growth and site-index equations for Douglas-fir and ponderosa pine in southwest Oregon. Res. Bul. 59. Corvallis, OR: Oregon State University, Forest Research Laboratory. 36 p.

McGaughey, R.J. 1997. Visualizing forest stand dynamics using the stand visualization system. In: Proceedings of the 1997 ACSM/ASPRS Annual Convention and Exposition. Bethesda, MD: American Society of Photogrammetry and Remote Sensing. 4: 248-257.

North, M.; Chen, J.; Smith, G.; Krakowiak, L.; Franklin, J. 1996. Initial response of understory plant diversity and overstory diameter growth to a green tree retention harvest. Northwest Science. 70: 24-35.

Oliver, C.D.; Larsen, B.C. 1996. Forest Stand Dynamics. New York: John Wiley and Sons. 521 p.

Omule, S.A.Y.; Kozak, A. 1989. Stump and breast height diameter tables for BC tree species. FRDA Rep. No. 062. Victoria, BC: For. Can. and BC Ministry of Forests.

Reineke, L.H. 1933. Perfecting a stand density index for even-aged forests. Journal of Agricultural Research. 46: 627-638.

Ritchie, M.W.; Powers, R.F. 1993. User's guide for SYSTUM-1 (Version 2.0): a simulator of growth trends in young stands under management in California and Oregon. Gen. Tech. Rep. PSW-GTR-147. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 45 p.

Thomas, J.W.; Forsman, E.D.; Lint, J.B.; Meslow, E.C.; Noon, B.R.; Verner, J. 1990. A conservation strategy for the northern spotted owl: report of the Interagency Scientific Committee to Address the Conservation of the northern spotted owl. Portland, OR: U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management, Fish and Wildlife Service, and National Park Service. 427 p.

Thomas, S.C.; Halpern, C.B.; Falk, D.A.; Liguori, D.A.; Austin, K.A. 1999. Plant diversity in managed forests: understory responses to thinning and fertilization. Ecological Applications. 9: 864-879.

Tuchmann, E.T.; Connaughton, K.P.; Freedman, L.E.; Moriwaki, C.B. 1996. The Northwest Forest Plan: a report to the President and Congress. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 253 p.

# Effects of Different Levels of Canopy Tree Retention on Stocking and Yield of the Regeneration Cohort in the Southern Interior of British Columbia

Hailemariam Temesgen,[1] Pat J. Martin,[2] Douglas A. Maguire,[3] and John C. Tappeiner[4]

## ABSTRACT

Variable retention has become a prominent silvicultural strategy for meeting multiple resource management objectives. Under this strategy, retained trees contribute to the structural complexity of the subsequent stand, and provide habitat for wildlife and shelter for regeneration and understory vegetation. Retained trees, however, affect the stocking and yield of the young tree cohort to some degree. The effects of retained trees vary by the spatial arrangement of retention (group or dispersed), attributes of retained trees (type of species, condition, size and frequency), site, and other factors.

Under a variable-retention strategy, accurate growth and yield predictions for the resulting two-tiered stands are required. This paper outlines the effects of retained trees on understory tree development and compares various approaches that are used to model and simulate the effects of different levels of retention on yield at rotation. Specific simulations were conducted to quantify the effects of retained trees on seedling stocking and future yield for pure lodgepole pine (*Pinus contorta* Dougl. ex Loud.) and interior spruce (*Picea engelmannii x glauca*) stands in British Columbia. Compared to clearcut scenarios, retained trees reduced regeneration stocking by 0.3 to 6.5 percent on a stocked quadrat basis. The effects on the final yield of the understory cohort ranged from -8 to -32 percent, depending on the level of retention (2 to 12 $m^2$/ha).

KEYWORDS: Stocking, growth and yield models, variable-retention harvesting, mean stocked quadrat, partial cutting, understory development.

## BACKGROUND

Variable-retention harvesting (VRH), the practice of leaving live trees after regeneration harvests has become a tactic in ecosystem management. Retained trees carry over many structural features of the old stand into the new one, provide shelter for new regeneration (Franklin et al. 1997), and are thought to help conserve late-seral species. In the Pacific Northwest of the United States and Canada, most forest management plans for public lands prescribe some degree of VRH. Although many potential benefits of VRH have been hypothesized, the actual effects of VRH on future yield and stocking are unknown for most forest types (Zenner et al. 1998). Recent studies, however, have showed that VRH reduced the growth and future yield of regenerating cohorts (Acker et al. 1998, Birch and Johnson 1992, Hansen et al. 1995, Long and Roberts 1992, Rose and Muir 1997, Zenner et al. 1998). Variable-retention harvesting has also been shown to influence species composition (Rose and Muir 1997).

The influence of retained trees varies by the pattern of retention (group or dispersed), attributes of the retained trees (i.e., species, condition, size and frequency), and other factors (e.g., site quality, windthrow, etc). Future growth and yield is also affected by change in species composition. For coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), Rose and Muir (1997) asserted that, compared to clearcuts,

---

[1] Assistant Professor, Department of Forest Resources, Oregon State University, Corvallis, OR 97331, USA. Email: Hailemariam.Temesgen@oregonstate.edu

[2] Stand Development Specialist, BC Ministry of Forests, Forest Practices Branch, Victoria, BC, Canada

[3] Associate Professor, and [4] Professor, Department of Forest Sciences and Department of Forest Resources, Oregon State University; Corvallis, OR 97331, USA.

the understories of stands with a relatively large number of residual trees are dominated by higher relative densities of shade tolerant tree species such as western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western redcedar (*Thuja plicata* Donn) and lower relative density. The mix of species that successfully regenerates will affect future growth, yield and value.

This paper (1) reviews the impacts of VRH on stocking of regeneration and future yield of the understory cohort, (2) reviews the methods used to quantify these impacts, and (3) simulates the effect of overstory residual trees on understory yield (volume at rotation) and stocking in dispersed VRH. Throughout this paper, impact on yield refers to the impact of retained overstory trees on future yield of understory cohorts grown to rotation age beneath.

## IMPACTS OF VARIABLE-RETENTION HARVESTING ON YIELD AND STOCKING

Residual trees compete with understory cohorts for light, water, and nutrients. This competition is proportional to (1) area occupied by retained trees, and (2) size of retained trees, vigor, and the level and duration of retention.

Rose and Muir (1997) estimated that half of the yield reduction due to retained trees is due to their physical occupation of space. The remaining half results from other factors such as shading and competition for resources. Similarly, in examining competition among retained trees, Canham et al. (2004) concluded that crowding, which they defined as "belowground competition and physical, aboveground inhibition of crown development," had a larger influence on retained trees radial growth than shading.

The impact of retained trees on understory yield is a function of retained tree size and vigor (i.e., size of crown and rate of crown expansion). Retained trees with large crowns, and those that vigorously expand their crowns, more strongly suppress understory tree growth (Birch and Johnson 1992) than those with smaller crowns and less vigorous growth. As the amount of retention increases, understory growth declines (Birch and Johnson 1992, Long and Roberts 1992, Hansen et al. 1995, Rose and Muir 1997, Acker et al. 1998). Retention that is short-lived, or removed after a brief period, is less detrimental to understory tree growth.

Generally, impacts of retained trees on yield can be categorized in terms of effects on (1) mean annual increment (MAI), (2) basal area and volume, (3) harvest value, (4) individual tree attributes, and (5) stocking.

### Mean Annual Increment

Based on a field study, in the Willamette National Forest in Oregon, Acker et al. (1998) found that mean annual increment (MAI) of understory cohorts beneath retained trees decreased with an increase of retained trees basal area, and later estimated MAI of the lower canopy as a function of initial residual basal area. For $10m^2$/ha residual tree basal area, the authors predicted a 26-percent decline in the young cohort's MAI (with 95-percent confidence interval of -30 percent to -22 percent) in stands that ranged from 72 to 139 years old.

In simulations with ORGANON, Birch and Johnson (1992) found that compared to clear cutting, retention of 50 codominant overstory trees per hectare resulted in a 25.5 percent reduction in MAI of the young cohort. Leaving 20 to 50 trees per hectare also lengthened the time for a stand to reach culmination of MAI by approximately 10 years.

### Basal Area and Volume

Rose and Muir (1997) examined USDA Forest Service inventory plot data from 132 stands (Cascade Range and southwest area of Oregon) with and without residual trees at different levels of retention. The authors found that increased number and basal area of residual trees substantially reduced understory basal area. The relationship between understory basal area and the density of retained trees was sigmoidal. No significant decrease in understory basal area was detected up to 15 retained trees per hectare. At densities above 15 retained trees per hectare, understory basal area declined. High densities of retained trees showed a decreasing marginal effect on understory basal area. Acker et al. (1998), Hansen et al. (1995), and Birch and Johnson (1992) noted yield losses at levels as low as 5 retained trees per hectare.

In a paired plot study, Acker et al. (1998) examined 14 stands in the Willamette National Forest (Oregon) and estimated the effect of retained trees on forest structure and yield and found that basal area and volume per hectare decreased with an increase in residual basal area. At a residual leave tree basal area of $10m^2$/ha, volume in the younger cohort after 100 years was reduced by 23 percent.

Analyzing data from Acker et al. (1998), Zenner et al. (1998) found that leaving 5 to 50 trees per hectare (5 to 60 percent of total stand volume) reduced total volume by 22 to 45 percent, compared to zero retention. Using a paired plot study in Barenthoren forests in Germany, Assmann (1970) showed that the presence of 20 mature residual pine trees per hectare reduced the understory Scots pine (*Pinus* *sylvestris* L.) yield by 20 percent when compared to single-storied stands with no retained trees.

Andreassen (1994) compared the yield of 16 partially cut Norway spruce (*Picea abies*) stands (established between 1921 and 1939) to their respective even-aged yield tables and found a 20-percent yield reduction compared to even-aged stands. However, the accuracy of this reduction is dependent upon the exactness of the yield curves. Using the ZELIG forest-level model, Hansen et al. (1995) examined nine retention levels (0, 5, 10, 15, 20, 30, 50, 100, and 150 trees per hectare) at four rotations (40, 80, 120, and 240 years) in a hemlock-fir-redcedar forest in the Oregon Cascade Range. The results of this study indicated that, at a 120-years rotation, leaving 5 trees per hectare reduced final basal area by 18.5 percent and leaving 30 trees per hectare reduced basal area by 38.6 percent, when compared to basal area in stands regenerated after clear cutting (table 5 in Hansen et al. 1995).

In their simulation of the development of a well-stocked 80-year Douglas-fir stand on a median (site index of 33 m) site, Birch and Johnson (1992) mainly ascribed the high merchantable volume reduction in VRH to the influence of retained trees on the growth of the understory. In this study, they accounted for the blow down of retained trees. Based on the impact of a 30-year storm event, the authors assumed 10-percent blow down of retained trees over a rotation.

### Harvest Value

In their comprehensive analysis of alternative silvicultural systems, Hansen et al. (1995) concluded that retention level and rotation age strongly influenced ecological and economic responses in western Oregon forests. Hansen et al. (1995) noted that future yield decreased significantly with increasing retention level and rotation age, with a notable threshold between retention levels of 0 and 5 trees per hectare. The authors asserted, however, that the decrease in the net wood products value was not directly proportional to level of retention due to the high value of logs from retained trees (assuming the retained trees are harvested at the end of the rotation).

### Individual Tree Attributes

On national forest land in Oregon, Isaac (1956) reported that height growth of Douglas-fir saplings was reduced when the number of retained trees was as low as 26 trees per hectare. This finding was supported by Hoyer's (1991) findings that indicated significant height growth reduction even under only one retained tree.

Hansen et al. (1995) examined planted Douglas-fir near the Oregon coast at 20 m and greater distance from a 45-m tall southern intact stand boundary. After 10 to 11 years of growth, they found a 20-percent reduction in height and diameter at 20 m but no decrease at 40 m compared to growth in the open. Using data from 19 stands in western Washington, Hoyer (1991) found that a reduction in height growth was greatest immediately adjacent to an overstory tree, and decreased with distance from the tree, until at 20 m away, the reduction was no longer significant. Based on these findings, Acker et al. (1998) assumed that the effects of a residual tree on the young cohort were minimal at and beyond 18.3 m.

Wampler (1993) investigated the relationship between retained trees density and understory height growth of Douglas-fir trees in the Gifford Pinchot and Mount Baker-Snoqualmie National Forests. The author found that

1) The relationship between retained trees density and understory tree height growth changed over time;
2) On average, height growth was reduced by 15 percent, when compared to the clear cut scenario;
3) A positive correlation between height to diameter ratios (a measure of stability for a tree) and retained trees density existed in four of the seven stands considered in the study; and
4) Noticeable height growth reduction occurred even under few retained trees.

Retained trees shade seedlings and saplings growing near them. The growth rates of understory interior spruce (*Picea engelmannii x glauca*) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) have been related to understory light levels in many studies. Coates and Burton (1999) examined the height and radial growth of planted lodgepole pine and interior spruce growing under a wide range of light levels in a partial cutting experiment. They found that at 50 percent of open-sky light, lodgepole pine achieved 60 percent of height and 50 percent of diameter growth possible under full light. At 50 percent of full light, interior spruce achieved 57 percent of height and 54 percent of diameter growth observed under open-sky conditions. Over a number of climatic regions in British Columbia, Wright et al. (1998) studied the relationship of sapling height and radial growth to light level. In the western sub-boreal region at 50 percent light, lodgepole pine achieved 34 percent of the height increment and 24 percent of the radial increment observed at 100 percent light. At 50 percent light, interior spruce achieved 71 percent of height and 51 percent of radial growth potential. Shading also impacts other understory pine and spruce tree attributes such as live crown ratio, leader over lateral length ratio, number of branches per whorl, and root over shoot ratio (Messier et al. 1999, Williams et al. 1999). Though understory tree growth correlates well to understory light levels, retained trees may also reduce seedling growth by competing for soil moisture and nutrients or reducing soil temperature (Lajzerowicz et al. 2004).

### Stocking

Though the long-term impacts of retained trees on understory tree height and diameter growth are negative, retention may increase understory tree stocking over the short-term (Kobe and Coates 1996). Seed rain, germination and short-term survival may increase in the presence of retained trees. However, over the longer term at higher levels of retention, seedling and sapling mortality rates increase (Kobe and Coates 1996).

## METHODS TO QUANTIFY IMPACTS OF VARIABLE-RETENTION HARVESTING

Methods to quantify the impacts of different levels and patterns of retention on future yield include retrospective studies and model extrapolation and simulation techniques. Retrospective studies have been used to estimate the effects of overstory residual trees on regeneration yield (Acker et al. 1998, Assman 1970, Hansen et al. 1995, Rose and Muir 1997, Zenner et al. 1995). In these studies, paired plots (one with and the other without residual trees) are placed as close as possible to compare understory yield trajectories.

Assmann (1970: 408) noted that trees retained at the stand boundary might have lower effect on the growth of a young cohort than residual trees further in the stand. Other studies that reached similar conclusions include Hoyer (1991, 1993) and Wampler (1993). Several studies have assessed the influence of stand microclimate and edges adjacent to residual trees (e.g., Carter and Klinka 1992, Chen et al. 1993). However, most of these studies did not quantify the impact of residual trees on growth and yield of the future forest.

Most of the retrospective studies (e.g., paired plot comparisons or comparison to an existing yield curve) have little information on past stand history, making yield impact estimates inconclusive. Recognizing this, Acker et al. (1998) asserted that even though the results and comparisons made using retrospective studies are indicative only, these studies provide information quickly, facilitate understanding of stand dynamics, and are a useful complement to long-term field experiments.

### Model Extrapolation and Simulation Techniques

The Prognosis (Long and Roberts 1992) and ORGANON (Birch and Johnson 1992) growth and yield models have been used to quantify the yield impacts of retained trees. Other simulation techniques have also been used (Hansen et al. 1995). Using a variant of the Prognosis model, Long and Roberts (1992) simulated stand development under various levels of Douglas-fir retention. Retention of 12 to 86 trees per hectare for 100 years produced a 24- to 54-percent reduction in understory volume production.

Using the growth and yield model ORGANON, Birch and Johnson (1992) simulated the impact of leaving 5 to 50 Douglas-fir trees (from the upper half of the diameter distribution) per hectare in clumped and scattered arrangements for 60- and 90-year rotations. The retention of 5 to 50 trees per hectare (approximately 2 percent and 16 percent of initial stand volume, respectively) showed a 5 to 37 percent reduction in understory merchantable volume on a 60-year rotation, compared to no overstory retention (fig. 1, in Birch and Johnson 1992).

Our review of the literature suggests that, given the importance of the issue, information on effects of retained trees on yield and stocking remains inadequate. Few long-term data exist to quantify the impacts of retained trees on yield and stocking. Resource managers have no direct way of estimating the impact of retained trees on yield and future stand structure. In light of this, interim estimates quantifying the impacts of retained trees on yield and stocking are paramount. In this study, regeneration survey simulation was combined with stand-growth simulation to quantify the impacts of retained trees on yield and stocking of pure pine and spruce stands in the interior of British Columbia.

## METHODS

### Stand Survey and Simulation

To assess the effects of VRH on stocking of regeneration and yield of the understory, the Tree and Stand Simulator (TASS) (Mitchell 1975) was used to simulate the growth of 268 pure pine and interior spruce stands with differing establishment densities (both planted and natural), spatial distributions, and levels of retention (table 1).

TASS is an individual tree distance-dependent growth model that generates, spatial, stem-mapped data (Mitchell 1975), and it is widely used for timber supply analysis and adjusting the yield impacts of retained trees.

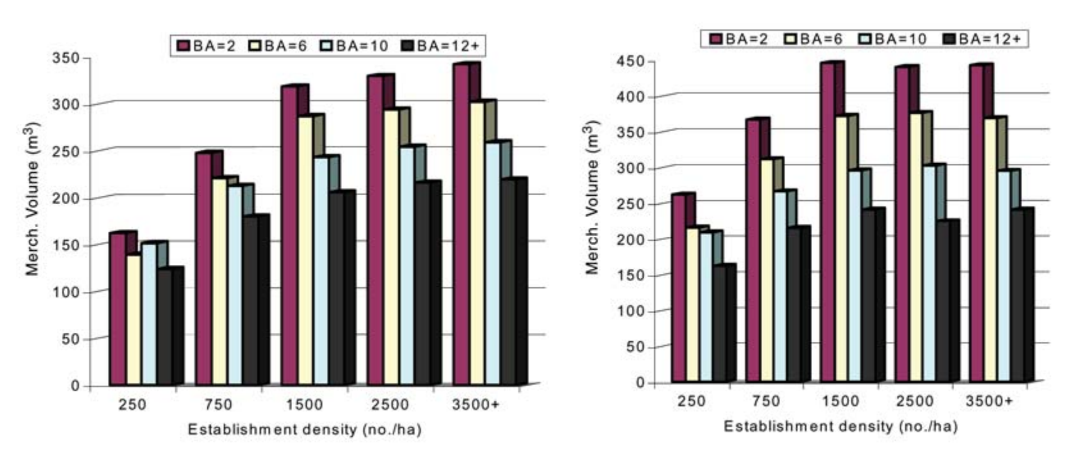

Figure 1—Merchantable volume of the understory stand 80 years after harvest over establishment density under different levels of retention (2 to 12+$m^2$/ha) of lodgepole pine (a) and spruce (b) trees.

**Table 1—Attributes in the matrix of TASS[a] runs used to examine the impact of retained trees on understory stocking and future yield in pure pine and spruce stands**

| Factor | Levels |
|---|---|
| Planting density (no./ha) | 0, 600, 1200 |
| Natural density | 0, 600, 1200, 3000, 4000 |
| No. of retained green trees/ha (retained trees) | 0, 12, 48, 96, and 144 trees/ha |
| Spatial distribution of naturals and retained trees | Random |
| Site index | 20 m |

[a] Tree and Stand Simulator (TASS) is an individual tree, distance-dependent growth model developed by Mitchell (1975).

Note: All possible combinations of the factors listed in table 1 were not simulated because of limitations with the current TASS version (Polsson 2003). However, the simulations above, done by Ken Polsson, BC Ministry of Forests, covered a wide range of established densities, basal area, and number of retained trees.

Simulations were used to study the effect of retained trees on regeneration stocking after 10 years of stand development and understory yield after 80 years of growth. Simulations were done for a 3-ha area. Regeneration surveys were simulated on the stem maps extracted from the stand growth simulator 10 years after harvest. In each stand, sample plots (50 $m^2$, 3.99 m radius) were established on randomly oriented 25-m grids resulting in approximately 48 plots for each simulated survey (a 25-m grid provides 16 plots per hectare). For each of the 268 simulated stands, 30 independent surveys were simulated, resulting in 8,040 simulated surveys.

Each 0.005-hectare circular plot was split into quarters (quadrants) along the north-south and east-west axes. The species and height of each tree in each quadrant was recorded. A quadrant was considered stocked if it contained at least one live tree. For each plot, the number of stocked quadrants was counted. For each survey, mean stocked quadrant (MSQ) was calculated (J.S. Thrower and Assoc. 2002, Martin et al. 2002) and later was compared to merchantable volume 80 years after harvest. In addition, relationships and associations between MSQ and merchantable volume 80 years after harvest were examined.

## RESULTS AND DISCUSSION

### Data Summary

In this study, the distributions of simulated stands by seedling establishment density and basal area of retained

**Table 2—Attributes of simulated test population (stands) 10 and 80 years after harvest for pure lodgepole pine and spruce stands**

| | | Lodgepole pine stands, n=134 | | | | Spruce stands, n=134 | | | |
|---|---|---|---|---|---|---|---|---|---|
| Scenario | Attribute | Min. | Mean | Max. | Std | Min. | Mean | Max. | Std |
| At start of simulation (attributes of retained trees (RT)) | Number of trees/ha | 0 | 61 | 144 | 54 | 0 | 61 | 144 | 54 |
| | Crown closure (percent) | 3.0 | 20.3 | 38.0 | 12.6 | 4.0 | 22.2 | 43.0 | 13.8 |
| | Basal area (m$^2$/ha) | 1.0 | 7.1 | 14.0 | 4.8 | 1.3 | 9.1 | 18.3 | 6.1 |
| | Merch. volume (m$^3$/ha) | 8.0 | 55.8 | 110.0 | 37.0 | 12.0 | 87.4 | 176.0 | 58.1 |
| | Average height (m) | 22.2 | 22.9 | 23.6 | 0.2 | 27.8 | 28.6 | 30.0 | 0.3 |
| | Average diameter (cm) | 32.6 | 34.2 | 36.3 | 0.5 | 35.3 | 38.0 | 40.6 | 0.8 |
| | Average crown width (m) | 5.5 | 5.7 | 6.1 | 0.1 | 5.7 | 5.9 | 6.5 | 0.2 |
| | Density of regen (tree/ha) | 274 | 1765 | 5063 | 1375 | 260 | 2032 | 5660 | 1450 |
| After 80 years (attributes of RT and regeneration cohort) | Number of trees/ha | 304 | 992 | 1382 | 298 | 283 | 894 | 1350 | 272 |
| | Crown closure (percent) | 54.0 | 97.1 | 100.0 | 8.5 | 64.0 | 98.0 | 100.0 | 6.3 |
| | Basal area (m$^2$/ha) | 9.8 | 35.9 | 48.8 | 8.7 | 11.7 | 40.3 | 58.3 | 11.2 |
| | Merch. volume (m$^3$/ha) | 67.0 | 259.6 | 353.0 | 67.2 | 102.0 | 335.2 | 474.0 | 94.0 |
| | Average height (m) | 17.2 | 32.8 | 25.9 | 0.5 | 19.4 | 27.6 | 35.0 | 1.1 |
| | Average diameter (cm) | 18.4 | 29.6 | 39.2 | 2.6 | 19.7 | 33.9 | 46.5 | 3.3 |
| | Average crown width (m) | 2.5 | 3.2 | 4.6 | 0.6 | 2.4 | 3.2 | 4.9 | 0.7 |
| | Basal area of retained trees (m$^2$/ha) | 0.0 | 6.7 | 16.3 | 6.0 | 0.0 | 9.2 | 22.7 | 8.2 |
| | Merch. volume of retained trees (m$^3$/ha) | 0.0 | 57.1 | 139.0 | 50.9 | 0.0 | 97.9 | 242.0 | 87.0 |

trees were similar for both lodgepole pine and spruce stands. A quarter of the simulated stands had establishment density of 1000 to 1750 seedlings per hectare. Similarly, for both species, 25 percent of the simulated stands were established with more than 3000 seedlings per hectare (table 2).

The average diameter at breast height (d.b.h.) and height of the retained trees were 34.2 cm and 22.9 m, respectively, for pine and 38.0 cm and 28.6 m, respectively, for spruce stands (table 2). Even though the retained trees did not differ much in size, the simulated stands covered a wide range of crown closure (3 to 43 percent) at the start of the simulation. At the time of survey simulation (10 years post-harvest), regeneration establishment density for the simulated stands ranged from 274 to 5063 trees per hectare. After 80 years, the simulated stands covered a wide range of conditions. For example, crown closure ranged from 54 to 100 percent, basal area ranged from 9.8 to 58.3 m$^2$/ha, and merchantable volume ranged from 67.0 to 474.0 m$^3$/ha (table 2).

For lodgepole pine, the average crown diameter of retained trees was 5.7 m (table 2), representing 25.5 m$^2$ in crown projection area. Hence a density of 12 retained trees per hectare represents 3 percent of the total area and 96 retained trees represents 24.5 percent of the total area. Negative correlations were observed between average crown width of retained trees and merchantable volume 80 years after harvest.

For the regeneration layer, there was strong relationship between establishment density and merchantable volume 80 years after harvest (fig. 1). Under different levels of retention, the future merchantable volume of the younger cohort increased rapidly with an increase of establishment density up to 1500 seedlings per hectare.

For both pine and spruce stands, the average number of mean stocked quadrants 10 years post-harvest decreased with an increase of number and basal area of retained trees. As expected, MSQ increased with an increase in regeneration density (table 3). The variability among estimated MSQ

**Table 3—Number of stands, minimum (min), mean, maximum (max), and standard deviation (Std) of mean number of stocked quadrants by number and basal area of retained trees, and regeneration density for pure pine and spruce stands. Mean number of stocked quadrants values were obtained from 30 simulated surveys 10 years after harvest.**

| Pure pine | | | | | | Pure spruce | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. of | | Mean no. of stocked quadrant | | | | | Mean no. of stocked quadrant | | | |
| retained trees/ha | stands | No. of Min | Mean | Max | Std | No of stands | Min | Mean | Max | Std |
| 0 | 26 | 2.16 | 3.68 | 3.89 | 0.39 | 26 | 2.09 | 3.68 | 3.87 | 0.40 |
| 12 | 27 | 1.06 | 3.58 | 3.89 | 0.63 | 27 | 2.12 | 3.66 | 3.88 | 0.41 |
| 48 | 27 | 1.20 | 3.57 | 3.90 | 0.61 | 27 | 1.00 | 3.44 | 3.90 | 0.81 |
| 96 | 27 | 1.38 | 3.55 | 3.87 | 0.58 | 27 | 1.00 | 3.47 | 3.85 | 0.64 |
| 144 | 27 | 1.42 | 3.52 | 3.86 | 0.55 | 27 | 1.00 | 3.41 | 3.84 | 0.62 |
| **Basal area class (m$^2$/ha)** | | | | | | **Basal area class (m$^2$/ha)** | | | | |
| 2 | 53 | 1.06 | 3.63 | 3.89 | 0.52 | 53 | 2.09 | 3.67 | 3.88 | 0.40 |
| 6 | 27 | 1.20 | 3.57 | 3.90 | 0.61 | 27 | 1.00 | 3.44 | 3.90 | 0.81 |
| 10 | 27 | 1.38 | 3.55 | 3.87 | 0.58 | 25 | 1.00 | 3.45 | 3.85 | 0.66 |
| 12+ | 27 | 1.42 | 3.52 | 3.86 | 0.55 | 29 | 1.00 | 3.44 | 3.84 | 0.61 |
| **Density class (no. reg/ha)** | | | | | | **Density class (no. reg/ha)** | | | | |
| 250 | 18 | 1.06 | 2.47 | 3.36 | 0.77 | 18 | 1.00 | 2.41 | 3.28 | 0.80 |
| 750 | 24 | 2.86 | 3.48 | 3.82 | 0.30 | 26 | 2.77 | 3.41 | 3.72 | 0.29 |
| 1500 | 36 | 3.58 | 3.80 | 3.88 | 0.07 | 34 | 1.00 | 3.69 | 3.87 | 0.48 |
| 2500 | 22 | 3.72 | 3.84 | 3.90 | 0.04 | 23 | 3.70 | 3.81 | 3.86 | 0.04 |
| 3500+ | 34 | 3.80 | 3.85 | 3.89 | 0.02 | 33 | 3.78 | 3.84 | 3.90 | 0.03 |

values increased with an increase in the number and basal area of retained trees and decreased with an increase in regeneration density (table 3).

For a given density class, MSQ decreased as basal area of the retained trees increased. Increasing the establishment density from 750 to 1500 seedlings per hectare increased the average mean number of stocked quadrants from 3.48 to 3.80 and from 3.41 to 3.69 for pine and spruce stands, respectively. An increase of retained trees from 12 to 48 retained trees per hectare decreased MSQ from 3.58 to 3.57 and from 3.66 to 3.44 in pine and spruce stands, respectively (table 3).

For each level of retention, there was strong and consistent evidence that understory merchantable volume 80 years after harvest increased with MSQ (figs. 2 and 3), reflecting the effects of retained trees on both stocking and growth of the understory component. The maximum merchantable volume achieved decreased with an increase in retained basal area (figs. 2 and 3).

The difference between predicted merchantable volume with and without retention increased with an increase in retained basal area. When basal area of the retained trees was less than 2 m$^2$/ha, however, most of the observed differences included zero within their 95-percent confidence intervals. There was strong association between the observed differences in merchantable volume and retained basal area, with a correlation coefficient of -0.817 and -0.90 for pure lodgepole pine and spruce stands, respectively.

## SUMMARY

Various methods are used to examine the impacts of retained trees on the growth of seedlings established around them. Over the long term, retained trees reduce understory tree height and diameter growth and increase mortality, resulting in reduced basal area per unit and reduced volume production by the young cohort.

Simulation results from this study demonstrate that the impacts of retained trees differ by species, retention level, and understory density for pure lodgepole pine and interior

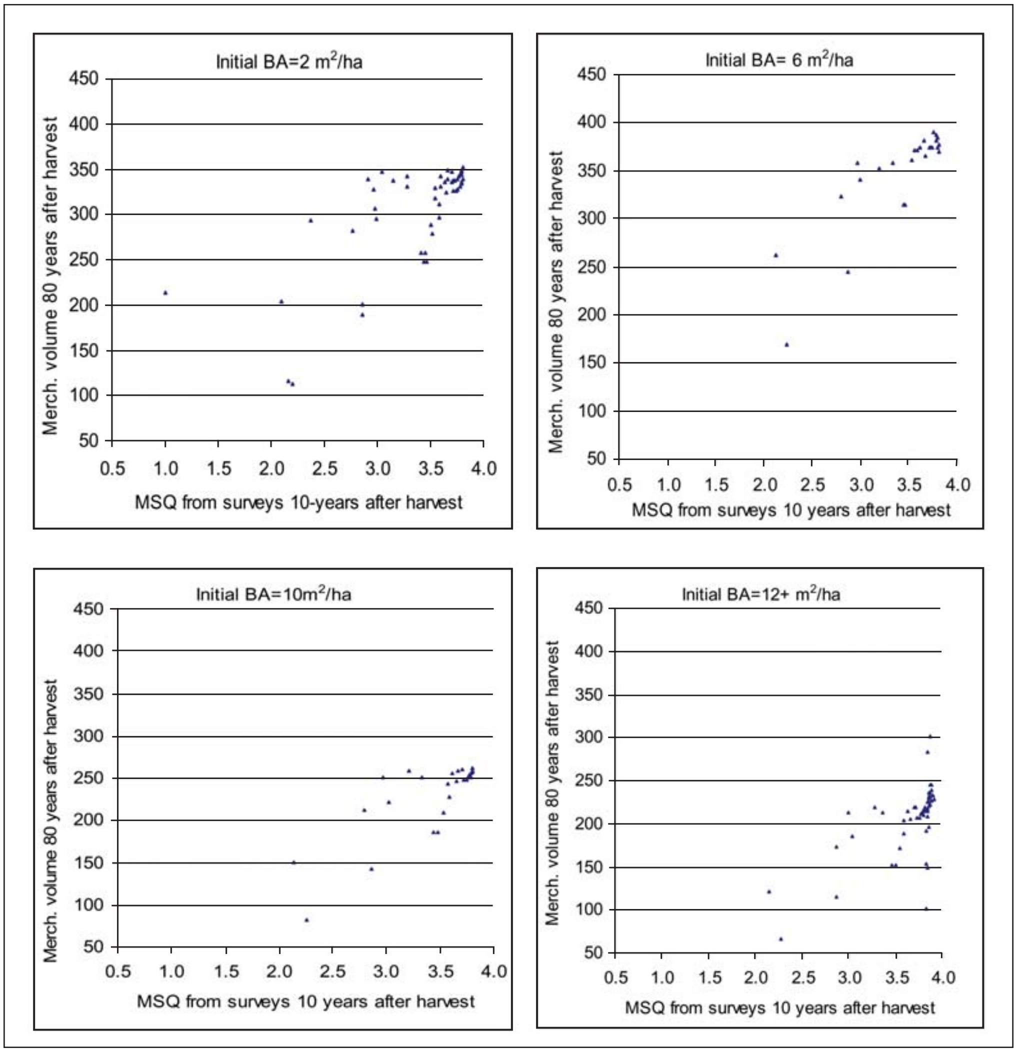

Figure 2—Merchantable volume 80 years after harvest versus mean stocked quadrants for the young cohort of pure lodgepole pine stands under four levels of retention. Mean number of stocked quadrants values were obtained from surveys completed 10 years after harvest.

spruce stands. Compared to clearcut scenarios, retained trees reduced regeneration stocking by 0.27 to 6.52 percent on a stocked quadrat basis. The effects on the future yield of the understory cohort ranged from -8 to -32 percent, depending on the level of retention (2 to 12 m$^2$/ha).

The greater the vertical complexity of the stand, the more important it will be to apply individual tree models for simulating specific stands. Likewise, the greater the horizontal complexity of the stand, the more important it will be to project future development with distance-dependent models. The general relationships that we have demonstrated between residual basal area, seedling stocking, and future understory yield provide useful insight into some of the impacts of retained overstory trees.

## ACKNOWLEDGMENTS

We thank Valerie LeMay, Peter Marshall, Steve Mitchell, Ken Day, (all at Faculty of Forestry, at the University of British Columbia), Bill Beese, (Weyerhaeuser Ltd. Canada), Kim Iles, (Iles & Assoc.), Rick Dawson, (Ministry of Forests, Cariboo Forest Region), and Jim Goudie, (Ministry of Forests, Research Branch) for their insights and advice on this project. This project was funded by Forest Innovation BC (and administered by Riverside Forests Products Ltd), and Department of Forest Resources at Oregon State University.

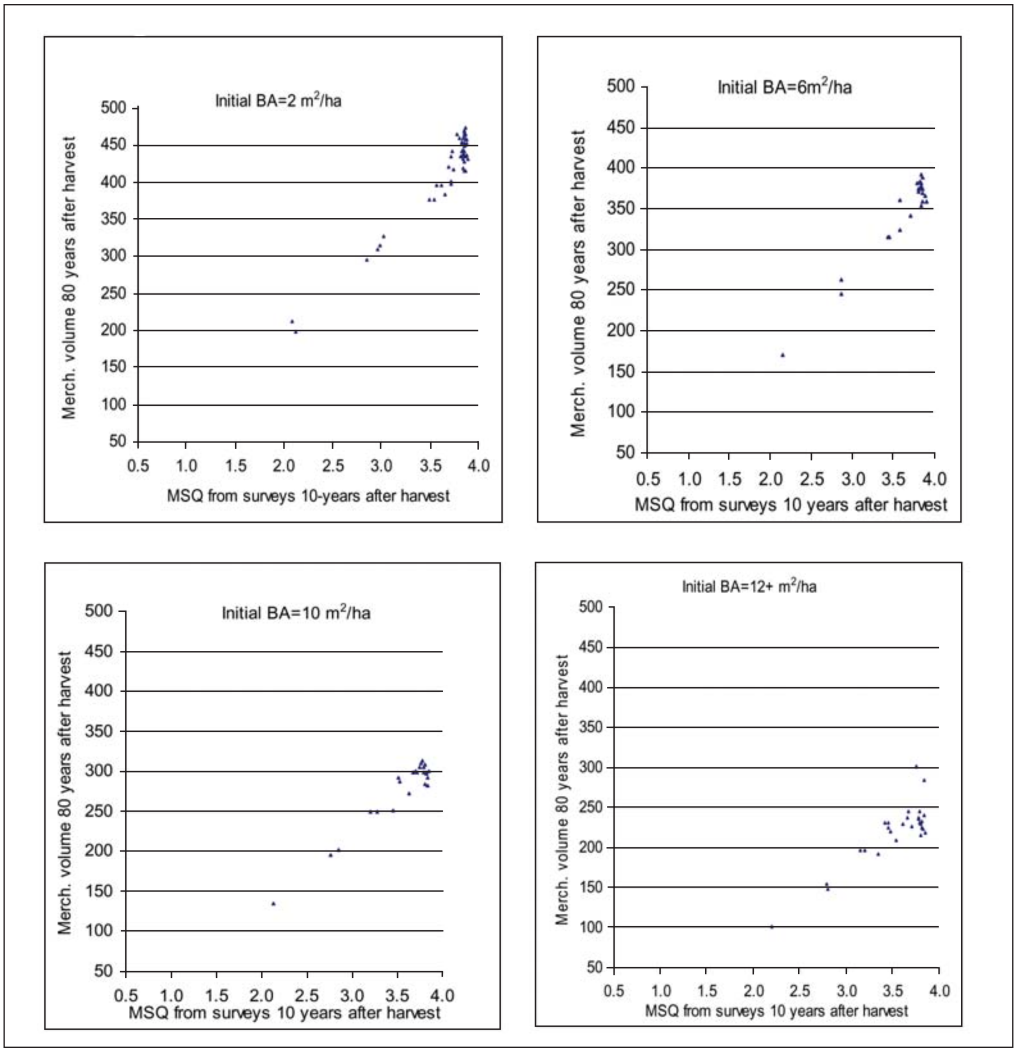

Figure 3—Merchantable volume 80 years after harvest versus mean stocked quadrants for the young cohort of pure interior spruce stands under four levels of retention. Mean number of stocked quadrants values were obtained from surveys completed 10 years after harvest.

## REFERENCES

Acker, S.A.; Zenner, E.K.; Emmingham, W.H. 1998. Structure and yield of two-aged stands on the Willamette National Forest, Oregon: implications for green tree retention. Canadian Journal of Forest Research. 28: 749-758.

Andreassen, K. 1994. Development and yield in selection forest. Medd. Skogforsk. 47(5): 1-37.

Assmann, E. 1970. The principles of forest yield studies. Oxford: Pergamon Press. 506 p.

Birch, K.R.; Johnson, K.N. 1992. Stand-level wood production costs of leaving live, mature trees at regeneration harvest in coastal Douglas-fir stands. Western Journal of Applied Forestry. 7: 65-68.

Canham, C.D., LePage, P.T.; Coates, K.D. 2004. A neighborhood analysis of canopy tree competition: effects of shading versus crowding. Canadian Journal of Forest Research. 34: 778-787.

Carter, R.E.; Klinka, K. 1992. Variation in shade tolerance of Douglas-fir, western hemlock and western red cedar in coastal British Columbia. Forest Ecology and Management. 55: 87-105.

Chen, J.; Franklin, J.F.; Spies, T.A. 1993. Contrasting microclimates among clearcut, edge, and interior of old-growth Douglas-fir forest. Agricultural and Forest Meteorology. 63: 219-237.

Coates, K.D.; Burton, P.J. 1999. Growth of planted tree seedlings in response to ambient light levels in northwestern interior cedar-hemlock forests of British Columbia. Canadian Journal of Forest Research. 29: 1374-1382.

Franklin, J.F.; Berg, D.R.; Thornburgh, D.A.; Tappeiner, J.C. 1997. Alternative silvicultural approaches to timber harvesting: variable retention harvest systems. In: Kohm, K.A.; Franklin, J.F., eds. Creating a forestry for the 21st century. Washington, DC: Island Press: 111-139.

Hansen, A.J.; Garman, S.L.; Weigand, J.F.; Urban, D.L.; McComb, W.C.; Raphael, M.G. 1995. Alternative silvicultural regimes in the Pacific Northwest simulations of ecological and economic effects. Ecological Applications. 5: 535-554.

Hoyer, G.E. 1991. Growing Douglas-fir standards: a two-aged alternative to even-aged forests. Contribution No. 346. Forest Land Management Center, Washington Department of Natural Resources. 27 p.

Hoyer, G.E. 1993. The influence of Douglas-fir overstory on understory tree height growth in coastal forests of Washington. Contribution No. 348. Forest Land Management Center. Washington Department of Natural Resources. 23 p.

J.S. Thrower and Assoc. 2002. Stand survey and growth modeling for TFL 49 results-based pilot project: final report submitted to Riverside Forest Products. 45 p. On file with: J.S. Thrower and Assoc., 209-1730 West 2nd Ave. Vancouver, BC V6J1H6, Canada.

Kobe, R.; Coates, D. 1996. Models of sapling mortality as a function of growth to characterise interspecific variation in shade tolerance of eight tree species of northwestern British Columbia. Canadian Journal of Forest Research. 27: 227-236.

Lajzerowicz, C.C.; Walters, M.B.; Krasowski, M.; Massicotte, H.B. 2004. Light and temperature differentially co-limit subalpine fir and Engelmann spruce seedling growth in partial-cut subalpine forests. Canadian Journal of Forest Research. 34: 249-260.

Long, J.N.; Roberts, S.D. 1992. Growth and yield implications of a "New Forestry" silvicultural system. Western Journal of Applied Forestry. 7: 6-9.

Martin, P.J.; Shane, B.C.; McWilliams, E. 2002. A results-based system for regulating reforestation obligations. The Forestry Chronicle. 78: 492-497.

Messier, C.; Doucet, R.; Ruel, J.; Claveau, Y.; Kelly, C.; Lechowicz, M.J. 1999. Functional ecology of advance regeneration in relation to light in boreal forests. Canadian Journal of Forest Research. 29: 812-823.

Mitchell, K.J. 1975. Dynamics and simulated yield of Douglas-fir. Forest Science Monograph. 17. 39 p.

Polsson, K. 2003. Personal communication. Stand modeling analyst. Ministry of Forestry, Research Branch. 722 Johnson Street, Victoria, BC, Canada.

Rose, C.R.; Muir, P.S. 1997. Green tree retention: consequences for timber production in forests of the Western Cascade Oregon. Ecological Applications. 7: 209-217.

Wampler, M. 1993. Growth of Douglas-fir under partial overstory retention. University of Washington, College of Forest Resources. 97 p. M.S. thesis.

Williams, H.; Messier, C.; Kneeshaw, D.D. 1999. Effects of light availability and sapling size on the growth and crown morphology of understory Douglas-fir and lodgepole pine. Canadian Journal of Forest Research. 29: 222-231.

Wright, E.F.; Coates, K.D.; Canham, C.D.; Bartemucci, P. 1998. Species variability in growth response to light across climatic regions in northwestern British Columbia. Canadian Journal of Forest Research. 28: 871-886.

Zenner, E.K. 1995. Effects of residual trees on growth of young to mature Douglas-fir and western hemlock in western central Oregon Cascades. Corvallis, OR: Oregon State University, M.S. thesis. 58 p.

Zenner, E.K.; Acker, S.A.; Emmingham, W.H. 1998. Growth reduction in harvest-age, coniferous forests with residual trees in the west central Cascade Range of Oregon. Forest Ecology and Management. 102: 75-88.

continue