From the Director

This issue welcomes another SMC member, notes that the updated database is available, summarizes planned activities of the summer field crew, provides information regarding the fall meeting, notes success with the AGENDA 2020 proposal for the paired-tree fertilization installations, and summarizes the spring meeting. Abstracts of two new articles in the Canadian Journal of Forest Research, (abstracts are provided). The feature article summarizes “Sources of variation in the self-thinning boundary line for Douglas-fir, red alder, and western hemlock” by Aaron Weiskittel, Peter Gould, and Hailemariam Temesgen.

New Membership

SMC continues to grow; we would like to welcome a new Analytic Organization member, Cortex Consultants, Victoria, BC., represented by Andrew Howard.

Database update

Field work for 07/08 has been completed and the database update will be finished by the time this issue reaches you. Please contact Randy Collier (rcollier@u.washington.edu) to request a copy. You may also wish to review the rules associated with use and distribution of the database which are covered in the SMC By-laws. Randy has also been working on a contract to develop a database for The Long-Term Site Productivity (LTSP) studies; he expects that it will be available in late early July.
SMC Fall Policy Committee Meeting

The fall meeting will be held on September 16-17 at the Little Creek Casino in Kamilche, WA which is near Shelton. The 16th will include a business meeting, updates on strategic planning, and research presentations. The 17th will be a field trip to visit one of the genetic-gain/type IV (GGTIV) installations, the Matlock long-term site productivity experiment, and either a Type III installation or possibly a new “Type V” paired-tree fertilization installation. For information contact Megan O’Shea (moshea@u.washington.edu).

Summer Field Crew

The summer 08 field crew, consisting of graduate students Paul Footen, Kim Littke, and Gonzalo Thienel began work on June 23. The main focus will be site characterization of the three genetic-gain/type IV (GGTIV) installations that were planted in 2006. After this is completed, other installations will be visited for understory vegetation/habitat characterization data, soil sampling, and tree acoustic velocity measurements.

CONIFERS Young Stand Simulator Version 4.00

Version 4.00 is now released and up on the web site. http://www.fs.fed.us/psw/programs/ecology_of_western_forests/projects/conifers/. This version is a major revision of the code with the addition of a new variant.

A number of issues that came up during the April 23rd workshop have been addressed in version 4, including the application of genetic gains multipliers.

There are some minor revisions needed on this page but the program download is up to date. If you have any problems installing or running the simulator, please let me know.

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Success with the FY08-10 AF&PA-USFS Agenda 2020 proposal

The SMC and CIPS submitted the following pre-proposal “Management of PNW forest plantations: Additional site characterization and instrumentation for SMC/CIPS Paired-Tree Fertilization Projects.” By Rob Harrison¹, Doug Maguire², Eini Lowell³, Dave Briggs¹, Doug Mainwaring³, Eric Turnblom¹ and Kim Littke¹. ¹SMC-Univ. of Washington, ²CIPS-Oregon State University, ³USFS-Portland. This pre-proposal was selected as one of several funded at $50,000 per year for 3 years. A brief update by Ph.D. student Kim Littke on the design of the paired-tree fertilization studies and information that will be collected using the grant funds is presented in the remainder of this section.

The Paired Tree Project
Kim Littke CFR Graduate student

The objective of the Paired Tree Project is to find site and soil factors that might predict the responsiveness of Douglas-fir to nitrogen fertilization. Specifically, water availability, soil nitrogen content, and leaf area index are going to be examined as predictors of N fertilization response. Sites with varying levels of these factors will be chosen throughout British Columbia, Washington, and Oregon.

Figure 1. Example of tree pairing by DBH and crown height.
Study trees are the center of a 10 meter diameter circle with 15 meters between study trees. The study trees are dominant and co-dominants that are best matched by DBH and live crown height (Figure 1). One of each tree pair is chosen randomly to be fertilized with 224 kg N/ha.

Water availability will be measured using soil moisture probes and rain gauges (Figure 2). The soil moisture sensors and rain gauges log continuously up to one year. Total soil N content will be measured through a one meter pit in the center of the plot (Figure 3). “A” horizon samples will also be sampled around 6 trees of each treatment after two years. Leaf area index will be measured through under canopy LIDAR or estimation through sapwood area.

Currently, 10 sites have been installed in Washington and Oregon (Figure 4). Six of these sites were fertilized last winter. These six sites have also had soil moisture and temperature sensors, air temperature and humidity sensors, and rain gauges installed since May 2008. One center soil pit has been dug and sampled for nutrients and bulk density on each of the six sites. The SMC field crew is in the process of finding and installing new sites. I recently visited British Columbia and helped locate three sites on Vancouver Island and the Sunshine Coast. We hope to find up to six sites in British Columbia.
SMC Spring Meeting

The spring meeting was held on April 22-23 at the Gifford Pinchot NF Headquarters, in Vancouver, WA. This year’s program was different from past years in that the second day was devoted to a special workshop on the Young Stand Model that was developed by Martin Richie, David Marshall, Nick Vaughn and Eric Turnblom. On the 22nd we had 52 participants from 29 organizations while the workshop on the following day had 24 participants from 19 organizations.

Policy Committee Chair Louise de Montigny opened the meeting, welcomed the attendees, commented on the changes affecting forestry in BC and the US, and stressed the importance of, and opportunities for international collaboration as part of our continued strategic planning process.

Accomplishments: Dave Briggs reviewed accomplishments of 2007 and 2008 to date. A few highlights:

- Cumulative SMC funding since founding in 1985 has reached $18.1 million.
- Completion of the 07/08 field program on time in spite of access issues due to wind damage and heavy snow.

Terrestrial LIDAR Grant Received by the Precision Forestry Cooperative

Dr. Monika Moskal, UW Assistant Professor for remote sensing and spatial statistics and CFR graduate student Joshua Hegarty recently received a grant to purchase a terrestrial LIDAR system. These units, which are mounted on a ground station, can obtain high resolution horizontal to vertical LIDAR data sets that can be used to measure stem and branch sizes, and crown characteristics such as leaf-area index. These data allow one to examine distributions and changes within crown layers, etc. Collaboration to obtain data from SMC installations, such as the new paired-tree fertilization sites, (see article in this issue) is underway.

Figure 1. Our selected tree shown in an airborne LiDAR point distribution (top), ground LiDAR point distribution (center), and the combined distribution on the bottom (red points come from airborne LiDAR data and blue points come from ground based LiDAR data).
• Complete set up of six new Type V paired tree fertilization installations, and submission of an AGENDA 2020 proposal for environmental instrumentation, measurement of quality (acoustics), and leaf area index.

• Completion of the young stand model project.

• Hiring of a field crew for summer 2008, priority is site characterization of the GGTIV installations planted in 2006.

• 14 publications plus a similar number of symposium and workshop presentations per year.

• 7 graduate students in residence per year with a completion rate of about 2 per year.

**Budget:** Operational funding in 2007 was $570,699 versus $568,248 in 2006. This is the net amount after deductions for in-kind credits associated with the GGTIV installations and special contract income. Institutional Funding from the BC Ministry of Forests Research Branch was $70,652 from a competitive grant to support field measurement work in BC. Other institutional members provided $136,795 in the form of salaries of scientists, facilities, administrative support. External grants and research assistant funding from the University of Washington totaled $200,064. The balance at the end of 2007 was $11,555, compared to a deficit of $16,809 at the end of 2006.

For 2008, operational funding increased to $618,235, a combination of the addition of two new members and a net gain of special contract income versus expected in-kind credits for maintenance of the GGTIV installations. The BC Ministry of Forests Research Branch will have grant funds ($70,500) to support measurement and treatment costs in BC. Other institutional members are anticipated to provide support similar to 2007. External grant scholarship and other funds of approximately $120,000 have been received to date and may increase depending on the outcome of submitted proposals. Projections suggest that 2008 will end with a small surplus that will carry into 2009. Two factors that will weigh heavily on this are rising transportation costs and potential opportunities to charge some SMC staff time to external grants.

**Strategic Planning:** The Strategic Planning Committee did not meet since the last Policy Committee meeting. Over the summer we hope to have meetings of the TAC’s to discuss progress on the strategic plan and possible new activities and to have a Strategic Planning Committee meeting to summarize results for discussion at the fall meeting. SMC strategic planning also needs to consider integration with other efforts in the region including the Center for Intensive Planted-forest Silviculture (CIPS) at Oregon State University, the Center for Advanced Forest Systems...
Doug Maguire summarized ongoing activities of CIPS and also gave Glen Howe’s presentation on CAFS, which was formed under the Industry/University Cooperative Research Centers Program within the Industrial Innovation Partnership (IIP) Division of the National Science Foundation. The goal of IIP is to provide catalyst funding to foster industry/university cooperatives to enhance the intellectual capacity of the engineering and science workforce through integration of research and education. Four forestry universities, North Carolina State, Oregon State, Purdue, and Virginia Tech were successful in creating CAFS, which held its inaugural meeting in early 2008. The SMC is taking the lead to develop a proposal for University of Washington membership. It is likely that CAFS membership, which will bring only a modest level of new funding, will provide new opportunities for more integrative, synthesized research.

David Briggs summarized the UWFC which is being discussed as a possible approach to improve the communication and planning at the UW to utilize the talents within the various discipline oriented forest-related centers and cooperatives to respond to broader forest policy issues such as climate change, carbon accounting, timber and water supply, etc. Presently, policy makers, agencies and other organizations find the array of discipline-oriented centers and cooperatives difficult to understand and relate to in the context of these larger issues and indicated that they would prefer a single point of contact. Unlike CIPS, which tends to focus on filling scientific gaps, UWFC would focus on integrating and using the best science available to address environmental, economic and social aspects of forest issues. Several mechanisms for creating UWFC are being explored. One likely option, would be re-charter, and possibly rename, the existing Institute of Forest Resources (IFR) in the College of Forest Resources. The IFR was originally created by the State Legislature which has periodically modernized its mission, name, and funding structure. It has been dormant since the 1990’s and revising it again may be the most appropriate approach to the issues being raised in the UWFC discussions.

**Silviculture Project Report:** Eric Turnblom reviewed the work for the field season on the installations. A total of 47 installations (357 plots) were visited during the 07/08 season, including 8 installations measured in BC by the BC Ministry of Forests Research Branch. This includes 7 Type I installations (70 plots) with full measurements and 13 installations (21 plots) with partial measurements. Two Type II installations (10 plots) received full measurements. Nine Type III installations (88 plots) received full measurements and one (9 plots) received partial measurement. The three 2006 GGTIV installations (66 plots) received their first measurement and the three 2006 GGTIV’s had survival surveys. The status of
fence maintenance and vegetation control activities was reviewed and it was noted that site characterization of the 2006 planted GGTIV’s will be completed by the summer 2008 field crew. The first six paired-tree (24 pairs, 48 trees) fertilization installations, designated as Type V installations, have been established and fertilized. Finally, six contract installations (43 plots) were measured. Eric noted that Nick Vaughn finished his Masters and is continuing on a PhD and that Andrew Hill finished his PhD. He also noted progress on the NCASI-funded study “Vegetation composition and succession in managed coastal Douglas-fir ecosystems.” Kevin Ceder, who is working on this project for his PhD, gave a progress report during the afternoon session.

**Modeling Project Report:** Dave Marshall introduced Martin Ritchie who provided background and preview of the young stand model, which was the topic of the workshop on the next day. We will have a feature article on this model in the next issue of the newsletter.

**Nutrition Project Report:** Rob Harrison reviewed the status of past students, projects of current students that were presented later in the meeting, and the funding status of current and incoming graduate students. Rob then reviewed the status of current research proposals. These are (1) “Management of PNW forest plantations: additional site characterization and instrumentation for SMC/CIPS paired tree fertilization project”, in review with AGENDA 2020, (2) “Strategic linking of forest plantation productivity studies in the Pacific Northwest”, in review with AGENDA 2020, and (3) “Leveraging forest industry participation into fertilization research: a unique opportunity to investigate the controls on the short-term fate of applied nitrogen”, in review with the USDA National Research Initiative Managed Ecosystems.

**Wood Quality Project Report:** Eini Lowell summarized the TAC meeting held on November 28, 2007. The TAC reviewed the strategic plan to identify potential areas where the wood quality project could contribute. These are briefly summarized as follows:

**Goal:** “Define and design research to understand the short and long term effects of silvicultural treatments on timber (growth and yield, wood quality, etc.) and environmental (habitat, carbon, water, etc.) values of forests”. The TAC discussed wood quality opportunities in the existing installations. While the new paired-tree fertilization installations could have a wood quality component designed into them, this would only be short term response. The longer term SMC installations, particularly Type III’s, and potentially the GGTIV’s, could provide more information. Next steps will involve discussions to design appropriate field sampling and property measurement procedures for wood quality, including new technologies such as obtaining acoustic measurements and use of ground-based LIDAR.
Goal 3: “Analyze the high quality data to produce information that furthers global competitiveness of the forest products sector and improves environmental benefits to society.” Discussion focused on improvements to the current wood quality module in ORGANON. Improvements suggested were (1) to develop alternative output file formats, (2) to build more realistic tree descriptions, and (3) to develop a new WQ DLL.

Goal 4: “Conduct technology transfer to assist in the application of information gained from the research.” The SMC sponsored wood quality workshops in the early 1990’s and there is now both new information and a new audience. As a result, a 2-day wood quality workshop will be held in May 2008. A second topic was the idea of working with extension specialists to develop a web site on Douglas-fir wood quality. The website should have a technical focus but be written so that a broader audience would find it useful.

Goal 6: “Seek opportunities for collaboration with other organizations and individuals to leverage SMC research programs.” The TAC reviewed a number of upcoming research grant opportunities and possible collaborations with the Canadian Wood Fibre Centre. The WQ TAC is involved in the development of three pre-proposals for the next AGENDA 2020 funding cycle.

Eini also reviewed the status of the nondestructive testing study and a project with Scion, New Zealand, in which photographs of a subsample of the veneer sheets were photographed to use in developing an automated image processing system as part of a glass-log model.
Sources of Variation in the Self-Thinning Boundary Line for Douglas-Fir, Red Alder, and Western Hemlock

Aaron Weiskittel¹, Peter Gould², and Hailemariam Temesgen³
¹University of Maine, ²US Forest Service PNW Research Station, ³Oregon State University

Introduction

Coastal Douglas-fir and western hemlock individual stand maximum stand density indexes (SDI$_{\text{max}}$) have been reported to vary significantly in the Pacific Northwest, but the values of the individual stands plotted over site index, latitude, purity, and stand origin have showed no distinct trends (Hann et al. 2003). In addition, Hann et al. (2003) indicated that fertilization had no influence on the SDI$_{\text{max}}$ trajectory and the overall size-density slope did not differ from the value set forth by Reineke (1933). This is also consistent for red alder in the region as Puettmann et al. (1993b) found that initial density and stand origin had no effect on the size-density relationship. However, most studies on the species self-thinning line have utilized subjective or significantly limited statistical techniques for fitting the boundary line, which has made testing the influence of other site and stand factors difficult. There is growing evidence that stochastic frontier analysis (SFA), a technique used in econometrics to fit a boundary line to a cloud of points, is an effective technique for estimating the self-thinning line in forestry (Bi 2001; Zhang et al. 2005). The goal of this study was to utilize SFA to examine maximum size-density relations in coastal Douglas-fir, red alder, and western hemlock. The primary objective was to test the influence of potential stand and site factors that may drive regional variation in this relationship.

Methods

Three regional datasets were combined to achieve our goal. The datasets included: Douglas-fir and western hemlock data from the Stand Management Cooperative (SMC; University of Washington) and red alder data from a variety of sources compiled by the University of Washington. Each dataset is described separately below.

Douglas-fir

Three hundred nineteen SMC installations in western Oregon, Washington, and Vancouver Island, British Columbia were used in this analysis. The data consisted of 93 plantations and 226 even-aged natural stands. In the natural stands, various plot sizes (ranging from 0.1 to 0.5-acre), plot shapes, and remeasurement lengths were used. In the plantations, several square 0.5-acre permanent plots were established by the SMC at each installation between 1986 and 1998. Since establishment, the
plots have received a variety of silvicultural treatments with three primary regimes. Type 1 installations were established in young plantations (i.e. 10-15 years) and have received differing silvicultural treatments since plot establishment. The treatments in the Type 1 installation used in this analysis included control plots (n = 29) and plots receiving fertilization with 200 lbs ac\(^{-1}\) of urea every four years (n = 17). Finally, the SMC has established 30 initial spacing trials (Type 3) that have at least five square 0.5-acre plots with planting densities of 100, 200, 350, 700, and 1200 trees acre\(^{-1}\). All these plots are remeasured every 4 years for growth. A total of 3,804 observations were available for this analysis.

**Red alder**

One hundred twenty-one installations in western Oregon, Washington, and Vancouver Island, British Columbia were used in this analysis. The data consisted of 62 plantations and 59 even-aged natural stands. The data were obtained from a variety of sources including the British Columbia Ministry of Forests, the Hardwood Silviculture Cooperative (HSC; Oregon State University; http://www.cof.orst.edu/coops/hsc/), and the Weyerhaeuser Company. The installations were located between Coos Bay, Oregon (43°12' N, 124°12' W) and Sayward on Vancouver Island, British Columbia (50° 22'N, 125° 58'). The stands were established between 1981 and 1996.

The HSC dataset included the Type 2 plots (0.3 acre in size), which were established between 1989 and 1997. Each Type 2 installation included at least five different initial densities ranging from 100 to 1250 trees per acre. Since canopy closure, the plots have received a variety of thinning regimes. Mean site index was 90.8 ± 19.0 ft (base-age of 25 years; Nigh and Courtin 1998) with range of 37.5 to 152.4 ft. A total of 2,026 observations were available for this analysis.

**Western hemlock**

Seventy-two SMC installations in western Oregon, Washington, and Vancouver Island, British Columbia were used for this analysis. The data consisted of 12 plantations and 60 even-aged natural stands. The plantations were established between 1977 and 1991 with varying densities and levels of vegetation control. The natural stands were regenerated between 1968 and 1988. The initial planting densities of the plantations averaged 583 stems acre\(^{-1}\) with a range of 313 to 922 stems acre\(^{-1}\).

Various plot sizes (ranging from 0.1 to 0.5-acre), plot shapes, and remeasurement lengths were also used in the western hemlock natural stands. In the plantations, several square 0.5-acre permanent plots were established by the SMC at each installation between 1986 and 2001. Similar to the Douglas-fir plantations, Type 1 (various silvicultural regimes) and 2 (varying levels of initial planting densities) plots were available for this analysis. A total of 2,009 observations were available for this analysis.
Data analysis

The influence of other covariates on the self-thinning boundary line intercept and slope was examined in two stages. First, several stand factors were examined for significance including: stand origin (natural vs. planted), site index, fertilization, stand purity (proportion of basal area in the primary species), slope, aspect, and elevation. Site index for Douglas-fir, red alder, and western hemlock were obtained using the equations of Bruce (1981), Nigh and Courtin (1998), and Bonner et al. (1995), respectively. In addition, the skewness of the diameter distribution was also used as a potential covariate. The general model form used in this analysis was:

\[
\ln(\text{TPA}) = \beta_0 + \beta_1 \ln(\text{QMD}) + \beta_2 \ln(\text{SI}) + \beta_3 \text{Planted} + \beta_4 \ln(\text{PBA}) + \beta_5 \text{SK}_{1.5}
\]

Where TPA is trees per acre, QMD is quadratic mean diameter in inches, SI is species site index (ft), PBA is the proportion of basal area in the primary species, Planted is an indicator variable for stand origin (1 if planted, 0 otherwise), and SK_{1.5} is the skewness of the DBH_{1.5} distribution. In addition, all interactions were tested. Preliminary analysis indicated that this selected model form was more parsimonious than an alternative model form that included the proportion of basal area in other conifers as well as other hardwood species.

In the second stage of the analysis, mean climate information from DAYMET (http://www.daymet.org) and USDA National Resource Conservation Service (NRCS) soil attributes were obtained for each research installation located in the United States along with GPS coordinates. Variables such as mean annual precipitation, growing degree days, and soil water holding capacity were combined with the stand-level information to assess the influence of climate and soils information on a subset of the data for each species. Significance of the covariates was tested using likelihood ratio tests because autocorrelation may influence estimated parameter standard errors in these types of models (e.g. Bi 2001). Parameters were estimated using SFA with a maximum likelihood estimator, which was achieved with FRONTIER v4.1 (Coelli 1996).

Results

The intercept and slope of the self-thinning boundary line for each of the species are given in Table 1. Both the intercept and slope estimated using ordinary least squares regression were significantly lower than those given by SFA for each of the species. Western hemlock had the largest intercept and the steepest slope of the three species examined (Figure 1), while red alder had the smallest intercept and slope. The Douglas-fir self-thinning boundary line showed the highest goodness of fit and western hemlock had the lowest. The implied SDI_{max} (predicted TPH when QMD = 10 in) for Douglas-fir, red alder, and western hemlock were 592, 406 and 634 respectively.
Table 1. Summary of parameter and variance estimates with standard errors (in parentheses) of self-thinning boundary line equation \( \ln(\text{TPA}) = \beta_0 + \beta_1 \ln(\text{QMD}) \) by species and fitting technique.

<table>
<thead>
<tr>
<th>Species</th>
<th>Quantile Regression</th>
<th>Stochastic Frontier</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intercept</td>
<td>Slope</td>
</tr>
<tr>
<td></td>
<td>(0.0331)</td>
<td>(0.0147)</td>
</tr>
<tr>
<td>Red alder</td>
<td>8.7382</td>
<td>-1.1562</td>
</tr>
<tr>
<td></td>
<td>(0.2428)</td>
<td>(0.1601)</td>
</tr>
<tr>
<td>Western hemlock</td>
<td>10.7098</td>
<td>-1.8327</td>
</tr>
<tr>
<td></td>
<td>(0.0781)</td>
<td>(0.0335)</td>
</tr>
</tbody>
</table>

Figure 1. Plots of natural logarithm of trees per acre over the natural logarithm of quadratic mean diameter (in) with stochastic frontier analysis estimated self-thinning boundary line by species.
Likelihood ratio tests and considerable reductions in AIC indicated that other stand-level covariates significantly influenced the intercept of the self-thinning boundary line for all species (p<0.0001). In all species, the intercept of the self-thinning boundary line was significantly influenced by site index, stand origin (planted vs. natural), and stand purity. The intercept of the self-thinning boundary line increased with site index and stand purity, while it was significantly lower in plantations in all species. The slope of the self-thinning boundary line was significantly influenced by stand origin in Douglas-fir and western hemlock. In Douglas-fir, the slope of the self-thinning boundary line was also significantly influenced by site index. Fertilization did not have a significant influence on the species self-thinning boundary intercept or slope in Douglas-fir and western hemlock. In addition, the skewness of the diameter distribution did not significantly influence the self-thinning boundary line for any of the species examined.

Based on a subsample of the data, climate and soils information significantly influenced the self-thinning boundary line only in red alder. The self-thinning boundary line in red alder was influenced by stand-level covariates as well as the cosine transformation of aspect (COSA) and mean 25-year annual dryness index (DI; ratio of growing degree days above 5°C to annual precipitation (in)). The intercept of the self-thinning boundary line was significantly lower on north-facing slopes than south-facing ones and increased with the dryness index in this species. The slope of the self-thinning boundary line was not significantly influenced by any of the soil or climatic covariates.

Discussion

Previous analyses on the species self-thinning boundary line generally considered it to be one-dimensional or at most, a two-dimensional surface (e.g. Bi 2001). This analysis utilized SFA to indicate it is a multi-dimensional surface as site index, stand origin, and stand purity all significantly influenced both the self-thinning boundary line intercept in three ecologically distinct species. The slope of the self-thinning boundary line was also sensitive to stand origin in Douglas-fir and western hemlock. This study supports the idea that the species self-thinning line can vary significantly within a region, which studies on the dynamic self-thinning line have also suggested (e.g. Pittman and Turnblom 2003; Turnblom and Burk 2000). The conclusions from this study differ from others who have concluded the species self-thinning boundary to be insensitive to site index (e.g. Tang et al. 1995) or stand origin (e.g. Puettmann et al. 1993b). The study also supports previous studies that have suggested mixed species stands have different SDI<sub>max</sub> than pure ones (e.g. Puetteeman et al. 1992; e.g. Woodall et al. 2005). Our conclusions likely differ from these other studies for at least two reasons, namely (1) the power of our tests owing to our large datasets and (2) the fitting approach used. Relatively large datasets across a range of site qualities were available for the present study, particularly for Douglas-fir. This makes it more likely to be
able to detect differences in boundary line compared to studies that used
smaller datasets or ones with a limited range of site qualities. In addition,
this study used an objective statistical approach for fitting the line, while
most other studies have used highly subjective techniques.

Similar to previous studies, the steepness of the slope did follow
shade tolerance rankings as western hemlock had the steepest slope and
red alder had the smallest slope. However, the slope of the self-thinning
boundary line and the implied species SDI$_{\text{max}}$ were different from previous
studies on the same species. Previous estimates of SDI$_{\text{max}}$ for Douglas-fir,
red alder, and western hemlock have been estimated to be 598 (Long
1985), 450 (Puettmann et al. 1993a), and 850 (Scott et al. 1998), respec-
tively. Except for Douglas-fir, the estimates given in this analysis are con-
siderably lower than these previous values. The differences may be attrib-
uted to increased long-term data, the greater availability of plantation
data, and differing statistical techniques. Most of these previous studies
were based on data from natural stands, which this study indicated have a
higher SDI$_{\text{max}}$.

In all the species examined in this study, stand origin had the most
significant impact on the self-thinning boundary line and the intercept of
the line was statistically lower in plantations. Stand origin also influenced
the slope of the self-thinning boundary line in Douglas-fir and western
hemlock. This supports the idea proposed by Reynolds and Ford (2005)
that differences in initial stand conditions affect self-thinning behavior. The
influence of initial stand conditions has also been reported in other
studies on the dynamic self-thinning line as Turnblom and Burk (2000)
concluded that plantation stands of red pine established at high and low
densities self-thin in different ways. On the other hand, previous studies
have also found no significant influence of initial planting density (e.g. Tang
et al. 1995). Naturally-established stands tend to have higher aggregation
of individuals and significantly different developmental patterns than
plantations. The finding that plantations self-thin at a lower density sup-
ports the observation that highly clumped plants may experience less
overall competitive effect than regularly spaced plants at the same initial
density (Reynolds and Ford 2005). By evenly spacing individuals and
removing competing vegetation, plantations effectively alter the allometric
relationship by tree size and the area occupied by the tree, which intensi-
fies competition and ultimately, the self-thinning trajectory of these stands.
In this analysis, the decrease in SDI$_{\text{max}}$ ranged from 15% for red alder to
45% for Douglas-fir at a given level of site index and stand purity. These
results illustrate the strong influence that initial stand conditions can have
on the maximum size-density relationship. However, the reductions
observed for western hemlock and red alder should be taken with cau-
tion as the number of plantations relative to the number of natural stands
was small and most of these plantations were still relatively young.
Several other studies have not found a significant influence of site productivity on the species self-thinning boundary line (de Montigny and Nigh 2007; Smith and Hann 1984; Tang et al. 1995). The results of this study support the findings of Bi (2001) as site index significantly increased the intercept of the self-thinning boundary line in all the species that were examined. This present study also found the slope of the self-thinning boundary line was significantly influenced by site index in Douglas-fir. This suggests that similar to stand origin, site index presumably alters the allometric relationship between tree size and biomass. Higher sites are able to support greater levels of biomass and tend to progress through stand development at faster rates than sites of lower quality. Although statistically significant, the influence of site index on SDI\textsubscript{max} was relatively small when compared to stand origin and purity. For example, red alder was the most responsive to changes in site index as SDI\textsubscript{max} increased by over 9% for a 10% increase in site index, while Douglas-fir and western hemlock SDI\textsubscript{max} only increased by 1-3%. Consistent with Hann et al. (2003), fertilization had no significant effect on the Douglas-fir or western hemlock self-thinning boundary line intercept or slope.

The productivity and stand dynamics of mixed-species stands have been shown to be significantly different than pure ones (e.g. Amoroso and Turnblom 2006; e.g. Garber and Maguire 2004). This analysis indicates that stand composition can also influence maximum size-density relationships in three species with varying levels of shade tolerance. Likewise in a recent analysis of eight common species in the United States that included Douglas-fir, the SDI\textsubscript{max} that any particular species attained was significantly influenced by the species composition of the subject stands (Woodall et al. 2005). The level of the response to stand composition was also found not to be easily explained by species shade tolerance (Woodall et al. 2005), which is similar to the findings of this present study. For example, red alder SDI\textsubscript{max} increased by 97% when stand purity was changed from 0.6 to 0.9, while Douglas-fir and western hemlock SDI\textsubscript{max} increased by 30% and 50% for a similar change in stand composition, respectively. Woodall et al. (2005) reported a 69% increase in Douglas-fir SDI\textsubscript{max} when stand purity was changed from 0.5 to 0.9 and a 46% increase was found in this study. Woodall et al. (2005), however, did not account for additional factors such as stand origin or site index that can significantly influence estimated SDI\textsubscript{max} as suggested by this study. Mixed species stand behavior is different than pure stands because of alterations in the level of inter- and intraspecific competition (e.g. Amoroso and Turnblom 2006; e.g. Garber and Maguire 2004). This effectively modifies key allometric relationships and limits the ability of a given species to reach its maximum potential size.

Given the significance of site index in this study, high significance of climatic and soil variables was expected in this analysis. In contrast, climate and soil variables were not significant for Douglas-fir or western hemlock and only marginally improved the red alder model. This finding is
consistent with Hann et al. (2003) as well as Poage et al. (2007) who were unable to relate variation in the self-thinning boundary line to other environmental factors. This study found that the red alder boundary line was sensitive to both site aspect and an index of dryness. A previous analysis on red alder site index also highlighted the species sensitivity to aspect and moisture availability (Harrington 1986). However, the limited predictive power of soil and climatic variables may be the result of using interpolated climate and modal pit soils information.

**Literature Cited**


Abstracts and Publications


Abstract

Estimating the growth response of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands after nitrogen (N) fertilization is difficult because of the high site variability present in the Pacific Northwest. Our objective was to determine how site and soil variables relate to stand response to repeat applications of 224 kg N ha⁻¹ as urea once every 4 years. The unstandardized residuals of two dependent variables (total cumulative volume and 4-year periodic annual increment, or PAI) were regressed against site and soil variables using stepwise regression. Data were stratified by three different stand density treatments: unaltered stand density (SD), one-half SD (SD/2), and one-quarter SD (SD/4). Both total cumulative volume and 4-year PAI after the second application of urea was significantly higher in the fertilized plots (*p* = 0.008; 0.009), whereas only total cumulative volume was significant after the third fertilizer application (*p* = 0.021). Thinning effects were highly significant (*p* < 0.001) for all three fertilizer applications. The strongest related stand, site, or soil variable to fertilization response existed between percent N at the 30–50 cm depth and total cumulative volume (*R²* = 0.833) for the SD/2 stand density management regime. Regression analysis showed that C, N, NH₄⁺, and NO₃⁻ concentration data explained the most variation, while stand and site variables contributing the least. The results demonstrate that multiple applications of urea provide significant increases in total volume, but effects of successive applications diminish over time.


Abstract

The effect of precommercial thinning in 6- to 13-year-old Douglas-fir (*Pseudostuga menziesii* (Mirb.) Franco var. menziesii) plantations with and without fertilization with 224 kg ha⁻¹ nitrogen (N) as urea on the mean diameter of the largest limb at breast height (DLLBH) was modeled. DLLBH is a simple, nondestructive field measurement related to log knot indices used to measure log quality in product recovery studies. Model [1] succeeded in predicting mean DLLBH (RMSE = 2.80 and *r*_adj² = 0.84) using only site, initial stocking, and treatment variables. Model [2], which used only mean tree variables, improved on model [1] and was simpler. However, model [3], which used a combination of both groups of variables, produced the best model. Model [4] successfully predicted mean DLLBH using variables that can be measured with light detection and ranging (LIDAR), a high-resolution remote sensing technology. Since the age when the live crown receded above breast height is an important variable in some of the models, model [5] was developed to predict when crown recession above breast height occurs. This study found that mean DLLBH of Douglas-fir plantations can be estimated using variables obtained from stand-level growth models or remote sensing, providing a quality indicator that can be easily measured and verified in the field.
Upcoming Meetings and Events


**July 14-17, 2008, Advanced Insect and Disease Field Session Identification, Life Cycles, Control Measures and Silvicultural Regimes**, Klamath Falls, OR. Registration info: [www.westernforestry.org](http://www.westernforestry.org)


**Sept 16-17, 2008. SMC's Annual Fall Meeting.** Little Creek Casino Kamilche, WA. Registration info: [www.standmgt.org](http://www.standmgt.org)
SMC Fall Policy Committee Meeting

The fall meeting will be held on September 16-17 at the Little Creek Casino in Kamilche, WA which is near Shelton. The 16th will include a business meeting, updates on strategic planning, and research presentations. The 17th will be a field trip to visit one of the genetic-gain/type IV (GGTIV) installations, the Matlock long-term site productivity experiment, and either a Type III installation or possibly a new “Type V” paired-tree fertilization installation. For information contact Megan O’Shea (moshea@u.washington.edu).

Summer Field Crew

The summer 08 field crew, consisting of graduate students Paul Footen, Kim Littke, and Gonzalo Thienel began work on June 23. The main focus will be site characterization of the three genetic-gain/type IV (GGTIV) installations that were planted in 2006. After this is completed, other installations will be visited for understory vegetation/habitat characterization data, soil sampling, and tree acoustic velocity measurements.

CONIFERS Young Stand Simulator Version 4.00

Version 4.00 is now released and up on the web site.  http://www.fs.fed.us/psw/programs/ecology_of_western_forests/projects/conifers/. This version is a major revision of the code with the addition of a new variant.

A number of issues that came up during the April 23rd workshop have been addressed in version 4, including the application of genetic gains multipliers.

There are some minor revisions needed on this page but the program download is up to date. If you have any problems installing or running the simulator, please let me know.

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The Paired Tree Project
Kim Littke CFR Graduate student

The objective of the Paired Tree Project is to find site and soil factors that might predict the responsiveness of Douglas-fir to nitrogen fertilization. Specifically, water availability, soil nitrogen content, and leaf area index are going to be examined as predictors of N fertilization response. Sites with varying levels of these factors will be chosen throughout British Columbia, Washington, and Oregon.

Figure 1. Example of tree pairing by DBH and crown height.
Study trees are the center of a 10 meter diameter circle with 15 meters between study trees. The study trees are dominant and co-dominants that are best matched by DBH and live crown height (Figure 1). One of each tree pair is chosen randomly to be fertilized with 224 kg N/ha.

Water availability will be measured using soil moisture probes and rain gauges (Figure 2). The soil moisture sensors and rain gauges log continuously up to one year. Total soil N content will be measured through a one meter pit in the center of the plot (Figure 3). “A” horizon samples will also be sampled around 6 trees of each treatment after two years. Leaf area index will be measured through under canopy LIDAR or estimation through sapwood area.

Currently, 10 sites have been installed in Washington and Oregon (Figure 4). Six of these sites were fertilized last winter. These six sites have also had soil moisture and temperature sensors, air temperature and humidity sensors, and rain gauges installed since May 2008. One center soil pit has been dug and sampled for nutrients and bulk density on each of the six sites. The SMC field crew is in the process of finding and installing new sites. I recently visited British Columbia and helped locate three sites on Vancouver Island and the Sunshine Coast. We hope to find up to six sites in British Columbia.

Figure 2. Installation of soil moisture probes and soil temperature sensors

Figure 3. Soil pit to 1 meter at Adna 1 site.

Figure 4. Current CIPS and SMC fertilization sites in Washington and Oregon
SMC Spring Meeting

The spring meeting was held on April 22-23 at the Gifford Pinchot NF Headquarters, in Vancouver, WA. This year's program was different from past years in that the second day was devoted to a special workshop on the Young Stand Model that was developed by Martin Richie, David Marshall, Nick Vaughn and Eric Turnblom. On the 22nd we had 52 participants from 29 organizations while the workshop on the following day had 24 participants from 19 organizations.

Policy Committee Chair Louise de Montigny opened the meeting, welcomed the attendees, commented on the changes affecting forestry in BC and the US, and stressed the importance of, and opportunities for international collaboration as part of our continued strategic planning process.

Accomplishments: Dave Briggs reviewed accomplishments of 2007 and 2008 to date. A few highlights:

- Cumulative SMC funding since founding in 1985 has reached $18.1 million.
- Completion of the 07/08 field program on time in spite of access issues due to wind damage and heavy snow.

Figure 1. Our selected tree shown in an airborne LiDAR point distribution (top), ground LiDAR point distribution (center), and the combined distribution on the bottom (red points come from airborne LiDAR data and blue points come from ground based LiDAR data).

Terrestrial LIDAR Grant Received by the Precision Forestry Cooperative

Dr. Monika Moskal, UW Assistant Professor for remote sensing and spatial statistics and CFR graduate student Joshua Hegarty recently received a grant to purchase a terrestrial LIDAR system. These units, which are mounted on a ground station, can obtain high resolution horizontal to vertical LIDAR data sets that can be used to measure stem and branch sizes, and crown characteristics such as leaf-area index. These data allow one to examine distributions and changes within crown layers, etc. Collaboration to obtain data from SMC installations, such as the new paired-tree fertilization sites, (see article in this issue) is underway.

Terrestrial LIDAR system
• Complete set up of six new Type V paired tree fertilization installations, and submission of an AGENDA 2020 proposal for environmental instrumentation, measurement of quality (acoustics), and leaf area index.
• Completion of the young stand model project.
• Hiring of a field crew for summer 2008, priority is site characterization of the GGTIV installations planted in 2006.
• 14 publications plus a similar number of symposium and workshop presentations per year.
• 7 graduate students in residence per year with a completion rate of about 2 per year.

Budget: Operational funding in 2007 was $570,699 versus $568,248 in 2006. This is the net amount after deductions for in-kind credits associated with the GGTIV installations and special contract income. Institutional Funding from the BC Ministry of Forests Research Branch was $70,652 from a competitive grant to support field measurement work in BC. Other institutional members provided $136,795 in the form of salaries of scientists, facilities, administrative support. External grants and research assistant funding from the University of Washington totaled $200,064. The balance at the end of 2007 was $11,555, compared to a deficit of $16,809 at the end of 2006.

For 2008, operational funding increased to $618,235, a combination of the addition of two new members and a net gain of special contract income versus expected in-kind credits for maintenance of the GGTIV installations. The BC Ministry of Forests Research Branch will have grant funds ($70,500) to support measurement and treatment costs in BC. Other institutional members are anticipated to provide support similar to 2007. External grant scholarship and other funds of approximately $120,000 have been received to date and may increase depending on the outcome of submitted proposals. Projections suggest that 2008 will end with a small surplus that will carry into 2009. Two factors that will weigh heavily on this are rising transportation costs and potential opportunities to charge some SMC staff time to external grants.

Strategic Planning: The Strategic Planning Committee did not meet since the last Policy Committee meeting. Over the summer we hope to have meetings of the TAC’s to discuss progress on the strategic plan and possible new activities and to have a Strategic Planning Committee meeting to summarize results for discussion at the fall meeting. SMC strategic planning also needs to consider integration with other efforts in the region including the Center for Intensive Planted-forest Silviculture (CIPS) at Oregon State University, the Center for Advanced Forest Systems.
Doug Maguire summarized ongoing activities of CIPS and also gave Glen Howe’s presentation on CAFS, which was formed under the Industry/University Cooperative Research Centers Program within the Industrial Innovation Partnership (IIP) Division of the National Science Foundation. The goal of IIP is to provide catalyst funding to foster industry/university cooperatives to enhance the intellectual capacity of the engineering and science workforce through integration of research and education. Four forestry Universities, North Carolina State, Oregon State, Purdue, and Virginal Tech were successful in creating CAFS, which held its inaugural meeting in early 2008. The SMC is taking the lead to develop a proposal for University of Washington membership. It is likely that CAFS membership, which will bring only a modest level of new funding, will provide new opportunities for more integrative, synthesized research.

David Briggs summarized the UWFC which is being discussed as a possible approach to improve the communication and planning at the UW to utilize the talents within the various discipline oriented forest-related centers and cooperatives to respond to broader forest policy issues such as climate change, carbon accounting, timber and water supply, etc. Presently, policy makers, agencies and other organizations find the array of discipline-oriented centers and cooperatives difficult to understand and relate to in the context of these larger issues and indicated that they would prefer a single point of contact. Unlike CIPS, which tends to focus on filling scientific gaps, UWFC would focus on integrating and using the best science available to address environmental, economic and social aspects of forest issues. Several mechanisms for creating UWFC are being explored. One likely option, would be re-charter, and possibly rename, the existing Institute of Forest Resources (IFR) in the College of Forest Resources. The IFR was originally created by the State Legislature which has periodically modernized its mission, name, and funding structure. It has been dormant since the 1990’s and revising it again may be the most appropriate approach to the issues being raised in the UWFC discussions.

**Silviculture Project Report:** Eric Turnblom reviewed the work for the field season on the installations. A total of 47 installations (357 plots) were visited during the 07/08 season, including 8 installations measured in BC by the BC Ministry of Forests Research Branch. This includes 7 Type I installations (70 plots) with full measurements and 13 installations (21 plots) with partial measurements. Two Type II installations (10 plots) received full measurements. Nine Type III installations (88 plots) received full measurements and one (9 plots) received partial measurement. The three 2006 GGTIV installations (66 plots) received their first measurement and the three 2006 GGTIV’s had survival surveys. The status of
fence maintenance and vegetation control activities was reviewed and it was noted that site characterization of the 2006 planted GGTIV’s will be completed by the summer 2008 field crew. The first six paired-tree (24 pairs, 48 trees) fertilization installations, designated as Type V installations, have been established and fertilized. Finally, six contract installations (43 plots) were measured. Eric noted that Nick Vaughn finished his Masters and is continuing on a PhD and that Andrew Hill finished his PhD. He also noted progress on the NCASI-funded study “Vegetation composition and succession in managed coastal Douglas-fir ecosystems.” Kevin Ceder, who is working on this project for his PhD, gave a progress report during the afternoon session.

**Modeling Project Report:** Dave Marshall introduced Martin Ritchie who provided background and preview of the young stand model, which was the topic of the workshop on the next day. We will have a feature article on this model in the next issue of the newsletter.

**Nutrition Project Report:** Rob Harrison reviewed the status of past students, projects of current students that were presented later in the meeting, and the funding status of current and incoming graduate students. Rob then reviewed the status of current research proposals. These are (1) “Management of PNW forest plantations: additional site characterization and instrumentation for SMC/CIPS paired tree fertilization project”, in review with AGENDA 2020, (2) “Strategic linking of forest plantation productivity studies in the Pacific Northwest”, in review with AGENDA 2020, and (3) “Leveraging forest industry participation into fertilization research: a unique opportunity to investigate the controls on the short-term fate of applied nitrogen”, in review with the USDA National Research Initiative Managed Ecosystems.

**Wood Quality Project Report:** Eini Lowell summarized the TAC meeting held on November 28, 2007. The TAC reviewed the strategic plan to identify potential areas where the wood quality project could contribute. These are briefly summarized as follows:

**Goal:** “Define and design research to understand the short and long term effects of silvicultural treatments on timber (growth and yield, wood quality, etc.) and environmental (habitat, carbon, water, etc.) values of forests”. The TAC discussed wood quality opportunities in the existing installations. While the new paired-tree fertilization installations could have a wood quality component designed into them, this would only be short term response. The longer term SMC installations, particularly Type III’s, and potentially the GGTIV’s, could provide more information. Next steps will involve discussions to design appropriate field sampling and property measurement procedures for wood quality, including new technologies such as obtaining acoustic measurements and use of ground-based LIDAR.
Goal 3: “Analyze the high quality data to produce information that furthers global competitiveness of the forest products sector and improves environmental benefits to society.” Discussion focused on improvements to the current wood quality module in ORGANON. Improvements suggested were (1) to develop alternative output file formats, (2) to build more realistic tree descriptions, and (3) to develop a new WQ DLL.

Goal 4: “Conduct technology transfer to assist in the application of information gained from the research.” The SMC sponsored wood quality workshops in the early 1990’s and there is now both new information and a new audience. As a result, a 2-day wood quality workshop will be held in May 2008. A second topic was the idea of working with extension specialists to develop a web site on Douglas-fir wood quality. The website should have a technical focus but be written so that a broader audience would find it useful.

Goal 6: “Seek opportunities for collaboration with other organizations and individuals to leverage SMC research programs.” The TAC reviewed a number of upcoming research grant opportunities and possible collaborations with the Canadian Wood Fibre Centre. The WQ TAC is involved in the development of three pre-proposals for the next AGENDA 2020 funding cycle.

Eini also reviewed the status of the nondestructive testing study and a project with Scion, New Zealand, in which photographs of a subsample of the veneer sheets were photographed to use in developing an automated image processing system as part of a glass-log model.

SMC SPRING MEETING RESEARCH REPORT SESSION

The Research Report Session presentations during the afternoon of April 22 can be downloaded from the SMC website (www.standmgt.org).
Sources of Variation in the Self-Thinning Boundary Line for Douglas-Fir, Red Alder, and Western Hemlock

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1University of Maine, 2US Forest Service PNW Research Station, 3Oregon State University

Introduction

Coastal Douglas-fir and western hemlock individual stand maximum stand density indexes (SDI\textsubscript{max}) have been reported to vary significantly in the Pacific Northwest, but the values of the individual stands plotted over site index, latitude, purity, and stand origin have showed no distinct trends (Hann et al. 2003). In addition, Hann et al. (2003) indicated that fertilization had no influence on the SDI\textsubscript{max} trajectory and the overall size-density slope did not differ from the value set forth by Reineke (1933). This is also consistent for red alder in the region as Puettmann et al. (1993b) found that initial density and stand origin had no effect on the size-density relationship. However, most studies on the species self-thinning line have utilized subjective or significantly limited statistical techniques for fitting the boundary line, which has made testing the influence of other site and stand factors difficult. There is growing evidence that stochastic frontier analysis (SFA), a technique used in econometrics to fit a boundary line to a cloud of points, is an effective technique for estimating the self-thinning line in forestry (Bi 2001; Zhang et al. 2005). The goal of this study was to utilize SFA to examine maximum size-density relations in coastal Douglas-fir, red alder, and western hemlock. The primary objective was to test the influence of potential stand and site factors that may drive regional variation in this relationship.

Methods

Three regional datasets were combined to achieve our goal. The datasets included: Douglas-fir and western hemlock data from the Stand Management Cooperative (SMC; University of Washington) and red alder data from a variety of sources complied by the University of Washington. Each dataset is described separately below.

Douglas-fir

Three hundred nineteen SMC installations in western Oregon, Washington, and Vancouver Island, British Columbia were used in this analysis. The data consisted of 93 plantations and 226 even-aged natural stands. In the natural stands, various plot sizes (ranging from 0.1 to 0.5-acre), plot shapes, and remeasurement lengths were used. In the plantations, several square 0.5-acre permanent plots were established by the SMC at each installation between 1986 and 1998. Since establishment, the
plots have received a variety of silvicultural treatments with three primary regimes. Type 1 installations were established in young plantations (i.e. 10-15 years) and have received differing silvicultural treatments since plot establishment. The treatments in the Type 1 installation used in this analysis included control plots (n = 29) and plots receiving fertilization with 200 lbs ac\(^{-1}\) of urea every four years (n = 17). Finally, the SMC has established 30 initial spacing trials (Type 3) that have at least five square 0.5-acre plots with planting densities of 100, 200, 350, 700, and 1200 trees acre\(^{-1}\). All these plots are remeasured every 4 years for growth. A total of 3,804 observations were available for this analysis.

**Red alder**

One hundred twenty-one installations in western Oregon, Washington, and Vancouver Island, British Columbia were used in this analysis. The data consisted of 62 plantations and 59 even-aged natural stands. The data were obtained from a variety sources including the British Columbia Ministry of Forests, the Hardwood Silviculture Cooperative (HSC; Oregon State University; http://www.cof.orst.edu/coops/hsc/), and the Weyerhaeuser Company. The installations were located between Coos Bay, Oregon (43°12' N, 124°12' W) and Sayward on Vancouver Island, British Columbia (50°22'N, 125°58'). The stands were established between 1981 and 1996.

The HSC dataset included the Type 2 plots (0.3 acre in size), which were established between 1989 and 1997. Each Type 2 installation included at least five different initial densities ranging from 100 to 1250 trees per acre. Since canopy closure, the plots have received a variety of thinning regimes. Mean site index was 90.8 ± 19.0 ft (base-age of 25 years; Nigh and Courtin 1998) with range of 37.5 to 152.4 ft. A total of 2,026 observations were available for this analysis.

**Western hemlock**

Seventy-two SMC installations in western Oregon, Washington, and Vancouver Island, British Columbia were used for this analysis. The data consisted of 12 plantations and 60 even-aged natural stands. The plantations were established between 1977 and 1991 with varying densities and levels of vegetation control. The natural stands were regenerated between 1968 and 1988. The initial planting densities of the plantations averaged 583 stems acre\(^{-1}\) with a range of 313 to 922 stems acre\(^{-1}\).

Various plot sizes (ranging from 0.1 to 0.5-acre), plot shapes, and remeasurement lengths were also used in the western hemlock natural stands. In the plantations, several square 0.5-acre permanent plots were established by the SMC at each installation between 1986 and 2001. Similar to the Douglas-fir plantations, Type 1 (various silvicultural regimes) and 2 (varying levels of initial planting densities) plots were available for this analysis. A total of 2,009 observations were available for this analysis.
Data analysis

The influence of other covariates on the self-thinning boundary line intercept and slope was examined in two stages. First, several stand factors were examined for significance including: stand origin (natural vs. planted), site index, fertilization, stand purity (proportion of basal area in the primary species), slope, aspect, and elevation. Site index for Douglas-fir, red alder, and western hemlock were obtained using the equations of Bruce (1981), Nigh and Courtin (1998), and Bonner et al. (1995), respectively. In addition, the skewness of the diameter distribution was also used as a potential covariate. The general model form used in this analysis was:

\[
\ln(TPA) = \beta_0 + \beta_1 \ln(QMD) + \beta_2 \ln(SI) + \beta_3 \text{Planted} + \beta_4 \ln(PBA) + \beta_5 \text{SK}_{1.5}
\]

Where $TPA$ is trees per acre, $QMD$ is quadratic mean diameter in inches, $SI$ is species site index (ft), $PBA$ is the proportion of basal area in the primary species, $\text{Planted}$ is an indicator variable for stand origin (1 if planted, 0 otherwise), and $\text{SK}_{1.5}$ is the skewness of the DBH$^{1.5}$ distribution. In addition, all interactions were tested. Preliminary analysis indicated that this selected model form was more parsimonious than an alternative model form that included the proportion of basal area in other conifers as well as other hardwood species.

In the second stage of the analysis, mean climate information from DAYMET (http://www.daymet.org) and USDA National Resource Conservation Service (NRCS) soil attributes were obtained for each research installation located in the United States along with GPS coordinates. Variables such as mean annual precipitation, growing degree days, and soil water holding capacity were combined with the stand-level information to assess the influence of climate and soils information on a subset of the data for each species. Significance of the covariates was tested using likelihood ratio tests because autocorrelation may influence estimated parameter standard errors in these types of models (e.g. Bi 2001). Parameters were estimated using SFA with a maximum likelihood estimator, which was achieved with FRONTIER v4.1 (Coelli 1996).

Results

The intercept and slope of the self-thinning boundary line for each of the species are given in Table 1. Both the intercept and slope estimated using ordinary least squares regression were significantly lower than those given by SFA for each of the species. Western hemlock had the largest intercept and the steepest slope of the three species examined (Figure 1), while red alder had the smallest intercept and slope. The Douglas-fir self-thinning boundary line showed the highest goodness of fit and western hemlock had the lowest. The implied $SD_{\max}$ (predicted TPH when $QMD = 10$ in) for Douglas-fir, red alder, and western hemlock were 592, 406 and 634 respectively.
Table 1. Summary of parameter and variance estimates with standard errors (in parentheses) of self-thinning boundary line equation \([\ln(TPA) = \beta_0 + \beta_1 \ln(QMD)]\) by species and fitting technique.

<table>
<thead>
<tr>
<th>Species</th>
<th>Intercept Quantile Regression</th>
<th>Slope Quantile Regression</th>
<th>Intercept Stochastic Frontier Analysis</th>
<th>Slope Stochastic Frontier Analysis</th>
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<td>(0.0147)</td>
<td>(0.037)</td>
<td>(0.0174)</td>
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<td>(0.1038)</td>
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<tr>
<td></td>
<td>(0.0781)</td>
<td>(0.0335)</td>
<td>(0.0603)</td>
<td>(0.0267)</td>
</tr>
</tbody>
</table>

Figure 1. Plots of natural logarithm of trees per acre over the natural logarithm of quadratic mean diameter (in) with stochastic frontier analysis estimated self-thinning boundary line by species.
Likelihood ratio tests and considerable reductions in AIC indicated that other stand-level covariates significantly influenced the intercept of the self-thinning boundary line for all species (p<0.0001). In all species, the intercept of the self-thinning boundary line was significantly influenced by site index, stand origin (planted vs. natural), and stand purity. The intercept of the self-thinning boundary line increased with site index and stand purity, while it was significantly lower in plantations in all species. The slope of the self-thinning boundary line was significantly influenced by stand origin in Douglas-fir and western hemlock. In Douglas-fir, the slope of the self-thinning boundary line was also significantly influenced by site index. Fertilization did not have a significant influence on the species self-thinning boundary intercept or slope in Douglas-fir and western hemlock. In addition, the skewness of the diameter distribution did not significantly influence the self-thinning boundary line for any of the species examined.

Based on a subsample of the data, climate and soils information significantly influenced the self-thinning boundary line only in red alder. The self-thinning boundary line in red alder was influenced by stand-level covariates as well as the cosine transformation of aspect (COSA) and mean 25-year annual dryness index (DI; ratio of growing degree days above 5°C to annual precipitation (in)). The intercept of the self-thinning boundary line was significantly lower on north-facing slopes than south-facing ones and increased with the dryness index in this species. The slope of the self-thinning boundary line was not significantly influenced by any of the soil or climatic covariates.

Discussion

Previous analyses on the species self-thinning boundary line generally considered it to be one-dimensional or at most, a two-dimensional surface (e.g. Bi 2001). This analysis utilized SFA to indicate it is a multi-dimensional surface as site index, stand origin, and stand purity all significantly influenced both the self-thinning boundary line intercept in three ecologically distinct species. The slope of the self-thinning boundary line was also sensitive to stand origin in Douglas-fir and western hemlock. This study supports the idea that the species self-thinning line can vary significantly within a region, which studies on the dynamic self-thinning line have also suggested (e.g. Pittman and Turnblom 2003; Turnblom and Burk 2000). The conclusions from this study differ from others who have concluded the species self-thinning boundary to be insensitive to site index (e.g. Tang et al. 1995) or stand origin (e.g. Puettmann et al. 1993b). The study also supports previous studies that have suggested mixed species stands have different SDI_max than pure ones (e.g. Puetteeman et al. 1992; e.g. Woodall et al. 2005). Our conclusions likely differ from these other studies for at least two reasons, namely (1) the power of our tests owing to our large datasets and (2) the fitting approach used. Relatively large datasets across a range of site qualities were available for the present study, particularly for Douglas-fir. This makes it more likely to be
able to detect differences in boundary line compared to studies that used smaller datasets or ones with a limited range of site qualities. In addition, this study used an objective statistical approach for fitting the line, while most other studies have used highly subjective techniques.

Similar to previous studies, the steepness of the slope did follow shade tolerance rankings as western hemlock had the steepest slope and red alder had the smallest slope. However, the slope of the self-thinning boundary line and the implied species SDI_{max} were different from previous studies on the same species. Previous estimates of SDI_{max} for Douglas-fir, red alder, and western hemlock have been estimated to be 598 (Long 1985), 450 (Puettmann et al. 1993a), and 850 (Scott et al. 1998), respectively. Except for Douglas-fir, the estimates given in this analysis are considerably lower than these previous values. The differences may be attributed to increased long-term data, the greater availability of plantation data, and differing statistical techniques. Most of these previous studies were based on data from natural stands, which this study indicated have a higher SDI_{max}.

In all the species examined in this study, stand origin had the most significant impact on the self-thinning boundary line and the intercept of the line was statistically lower in plantations. Stand origin also influenced the slope of the self-thinning boundary line in Douglas-fir and western hemlock. This supports the idea proposed by Reynolds and Ford (2005) that differences in initial stand conditions affect self-thinning behavior. The influence of initial stand conditions has also been reported in other studies on the dynamic self-thinning line as Turnblom and Burk (2000) concluded that plantation stands of red pine established at high and low densities self-thin in different ways. On the other hand, previous studies have also found no significant influence of initial planting density (e.g. Tang et al. 1995). Naturally-established stands tend to have higher aggregation of individuals and significantly different developmental patterns than plantations. The finding that plantations self-thin at a lower density supports the observation that highly clumped plants may experience less overall competitive effect than regularly spaced plants at the same initial density (Reynolds and Ford 2005). By evenly spacing individuals and removing competing vegetation, plantations effectively alter the allometric relationship by tree size and the area occupied by the tree, which intensifies competition and ultimately, the self-thinning trajectory of these stands. In this analysis, the decrease in SDI_{max} ranged from 15% for red alder to 45% for Douglas-fir at a given level of site index and stand purity. These results illustrate the strong influence that initial stand conditions can have on the maximum size-density relationship. However, the reductions observed for western hemlock and red alder should be taken with caution as the number of plantations relative to the number of natural stands was small and most of these plantations were still relatively young.
Several other studies have not found a significant influence of site productivity on the species self-thinning boundary line (de Montigny and Nigh 2007; Smith and Hann 1984; Tang et al. 1995). The results of this study support the findings of Bi (2001) as site index significantly increased the intercept of the self-thinning boundary line in all the species that were examined. This present study also found the slope of the self-thinning boundary line was significantly influenced by site index in Douglas-fir. This suggests that similar to stand origin, site index presumably alters the allometric relationship between tree size and biomass. Higher sites are able to support greater levels of biomass and tend to progress through stand development at faster rates than sites of lower quality. Although statistically significant, the influence of site index on SDI$_{\text{max}}$ was relatively small when compared to stand origin and purity. For example, red alder was the most responsive to changes in site index as SDI$_{\text{max}}$ increased by over 9% for a 10% increase in site index, while Douglas-fir and western hemlock SDI$_{\text{max}}$ only increased by 1-3%. Consistent with Hann et al. (2003), fertilization had no significant effect on the Douglas-fir or western hemlock self-thinning boundary line intercept or slope.

The productivity and stand dynamics of mixed-species stands have been shown to be significantly different than pure ones (e.g. Amoroso and Turnblom 2006; e.g. Garber and Maguire 2004). This analysis indicates that stand composition can also influence maximum size-density relationships in three species with varying levels of shade tolerance. Likewise in a recent analysis of eight common species in the United States that included Douglas-fir, the SDI$_{\text{max}}$ that any particular species attained was significantly influenced by the species composition of the subject stands (Woodall et al. 2005). The level of the response to stand composition was also found not to be easily explained by species shade tolerance (Woodall et al. 2005), which is similar to the findings of this present study. For example, red alder SDI$_{\text{max}}$ increased by 97% when stand purity was changed from 0.6 to 0.9, while Douglas-fir and western hemlock SDI$_{\text{max}}$ increased by 30% and 50% for a similar change in stand composition, respectively. Woodall et al. (2005) reported a 69% increase in Douglas-fir SDI$_{\text{max}}$ when stand purity was changed from 0.5 to 0.9 and a 46% increase was found in this study. Woodall et al. (2005), however, did not account for additional factors such as stand origin or site index that can significantly influence estimated SDI$_{\text{max}}$ as suggested by this study. Mixed species stand behavior is different than pure stands because of alterations in the level of inter- and intraspecific competition (e.g. Amoroso and Turnblom 2006; e.g. Garber and Maguire 2004). This effectively modifies key allometric relationships and limits the ability of a given species to reach its maximum potential size.

Given the significance of site index in this study, high significance of climatic and soil variables was expected in this analysis. In contrast, climate and soil variables were not significant for Douglas-fir or western hemlock and only marginally improved the red alder model. This finding is
consistent with Hann et al. (2003) as well as Poage et al. (2007) who were unable to relate variation in the self-thinning boundary line to other environmental factors. This study found that the red alder boundary line was sensitive to both site aspect and an index of dryness. A previous analysis on red alder site index also highlighted the species sensitivity to aspect and moisture availability (Harrington 1986). However, the limited predictive power of soil and climatic variables may be the result of using interpolated climate and modal pit soils information.

Literature Cited


Abstracts and Publications


Abstract
Estimating the growth response of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands after nitrogen (N) fertilization is difficult because of the high site variability present in the Pacific Northwest. Our objective was to determine how site and soil variables relate to stand response to repeat applications of 224 kg N ha⁻¹ as urea once every 4 years. The unstandardized residuals of two dependent variables (total cumulative volume and 4-year periodic annual increment, or PAI) were regressed against site and soil variables using stepwise regression. Data were stratified by three different stand density treatments: unaltered stand density (SD), one-half SD (SD/2), and one-quarter SD (SD/4). Both total cumulative volume and 4-year PAI after the second application of urea was significantly higher in the fertilized plots (*p* = 0.008; 0.009), whereas only total cumulative volume was significant after the third fertilizer application (*p* = 0.021). Thinning effects were highly significant (*p* < 0.001) for all three fertilizer applications. The strongest related stand, site, or soil variable to fertilization response existed between percent N at the 30–50 cm depth and total cumulative volume (*R²* = 0.833) for the SD/2 stand density management regime. Regression analysis showed that C, N, NH₄⁺, and NO₃⁻ concentration data explained the most variation, while stand and site variables contributing the least. The results demonstrate that multiple applications of urea provide significant increases in total volume, but effects of successive applications diminish over time.


Abstract
The effect of precommercial thinning in 6- to 13-year-old Douglas-fir (*Pseudostuga menziesii* (Mirb.) Franco var. menziesii) plantations with and without fertilization with 224 kg ha⁻¹ nitrogen (N) as urea on the mean diameter of the largest limb at breast height (DLLBH) was modeled. DLLBH is a simple, nondestructive field measurement related to log knot indices used to measure log quality in product recovery studies. Model [1] succeeded in predicting mean DLLBH (RMSE = 2.80 and *r*₂adj = 0.84) using only site, initial stocking, and treatment variables. Model [2], which used only mean tree variables, improved on model [1] and was simpler. However, model [3], which used a combination of both groups of variables, produced the best model. Model [4] successfully predicted mean DLLBH using variables that can be measured with light detection and ranging (LIDAR), a high-resolution remote sensing technology. Since the age when the live crown receded above breast height is an important variable in some of the models, model [5] was developed to predict when crown recession above breast height occurs. This study found that mean DLLBH of Douglas-fir plantations can be estimated using variables obtained from stand-level growth models or remote sensing, providing a quality indicator that can be easily measured and verified in the field.
Upcoming Meetings and Events


July 14-17, 2008, Advanced Insect and Disease Field Session Identification, Life Cycles, Control Measures and Silvicultural Regimes, Klamath Falls, OR. Registration info: www.westernforestry.org


Sept 16-17, 2008. SMC’s Annual Fall Meeting. Little Creek Casino Kamilche, WA. Registration info: www.standmgt.org