COOPERATIVE FORESTRY RESEARCH UNIT
FULL RESEARCH PROPOSAL

PROJECT TITLE:

Modeling natural regeneration and ingrowth in managed stands of the Acadian Region

ABSTRACT:

Accurate representation and projection of managed, naturally-regenerated stands requires a methodology for predicting the amount, composition, and size distribution of ingrowth. The Forest Vegetation Simulator (FVS) has been to shown be significantly biased in prediction of ingrowth. This project uses the comprehensive regional growth and yield database recently constructed for another CFRU project (Refinement of FVS) and would provide the data necessary to begin developing a tool to predict ingrowth. The key equations would be ones to predict the amount, composition, and size distribution of ingrowth. The predictions would be driven by a combination of stand- and site-factors. A key deliverable of this project of this project is a tool that will provide a method for better integrating ingrowth into future FVS simulations. These equations would also assist in understanding the factors that drive stand dynamics in this region.

PRINCIPAL INVESTIGATORS:

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PLANNED START DATE: *October 2010*

PLANNED TERMINATION DATE: *September 2012*

BACKGROUND:

Ingrowth is defined as number of trees that periodically grow into the smallest measured size class of a forest stand. Accurate representation and projection of managed, naturally-regenerated stands requires a methodology for predicting the amount and composition of ingrowth. Despite its importance, relatively little work on predicting ingrowth has occurred in the Acadian Region. The widely used Forest Vegetation Simulator (FVS) does not support a full establishment model. The FVS Ingrowth Tool of Arseneault *et al.* (2008) provides a means for including ingrowth tree lists into FVS projections, but doesn't help to create realistic ingrowth tree lists. Recent work by Ray *et al.*(2008) indicates that the Northeast variant of FVS is particularly biased in predicting the amount and composition of ingrowth. Moreover, Ray *et al.*(2008) found that limiting the amount of ingrowth to <1,800 trees per acre largely eliminated the bias in FVS, but only modestly improve model accuracy. Thus, a method for predicting the amount and composition of ingrowth is needed in this region.

Forest ingrowth is a highly stochastic process and is influenced by a variety of factors, which can only be partially accounted for by stand- and site-level factors. Ingrowth models have been developed in several other regions, particularly the northern hardwoods. For example, Ek (1974) predicted the number of ingrowth trees in a northern hardwood stands as a function of the number of trees and basal area of trees larger than the ingrowth threshold. Hann (1980) developed a model to predict ingrowth of ponderosa pine as a function of site index and basal area of trees up to 3 inches larger than the ingrowth threshold. Alternatively, Ek *et al.* (1997) used tabular imputation methods to predict regeneration and ingrowth rather than fitting an empirical model.

Shifley *et al.* (1993) reviewed several ingrowth models for the northern hardwoods region and found that most of the equations suggested ingrowth to be related to stand density and size structure as well as the number of trees that are near the threshold. However, most of these previous models were limited to a single diameter threshold value and Shifley *et al.* (1993) developed an approach to predict the amount of ingrowth for a variety of threshold values. Their model is driven by the crown competition factor of Krajicek *et al.* (1961), which is adaptable to stands with mixed species, size, and age distributions.

Given that ingrowth is the cumulative result of events and conditions over several years including seed source, regeneration success, climate, and disturbance, the number and species of ingrowth is driven by a variety of complex factors. Consequently, the proportion of variation explained by previous ingrowth models has varied widely from 0.08 to 0.81 (Shifley *et al.*, 1993). Thus, a large and comprehensive database is often necessary to develop an effective tool for predicting regional ingrowth behavior. As part of the Refinement of FVS CFRU project, a comprehensive regional growth and yield database has been constructed and would provide the necessary data to complete this analysis. This analysis would be unique in that it covers a variety of regions, species, and stand types. This would help to serve as a true test of the generalized approach of Shifley *et al.* (1993) and understand the various factors that influence ingrowth dynamics in the Acadian Region.

Relatively few analyses have looked at ingrowth patterns and their interaction with forest management in the Acadian Region. For example, Kenefic et al. (in review) recently indicated that there was high within treatment variability in recruitment patterns at the Penobscot Experimental Forest, but variation between treatments was limited. This suggests that local site factors like density and composition may be more important than the influence of forest management *per se*. However, an extensive database that includes both unmanaged and managed stands would be needed to test this important question.

PROJECT OBJECTIVES:

The overall goal of this project is to provide a robust methodology and software tool for incorporating ingrowth in future growth and yield projections, particularly those involving FVS. Specific objectives are to:

1. Compile and identify existing ingrowth and regeneration data
2. Assess the relationship between ingrowth and various stand and site factors
3. Develop regional equations to predict the amount and composition of ingrowth
4. Provide a software tool that predicts ingrowth and incorporates it into FVS

ANALYTICAL APPROACH:

The recently compiled growth and yield database from the Refinement of FVS CFRU project contains over 200,000 ingrowth trees that will be used in the analysis Table 1. These ingrowth trees would be identified and compiled for each measurement period and used as the primary data source for the analysis. An exploratory analysis would be conducted to identify the key stand- and site-level factors that influence the amount and composition of ingrowth. Based on previous analyses, key stand-level factors would likely include the total basal area, percent basal area in a certain species, skewness of diameter at breast height, quadratic mean diameter, and crown competition factor. Important site-level factors to be considered are elevation, soil site index, depth to soil water table, growing degree days, soil water balance, aspect, and percent slope. These factors would be quantitatively related to the amount and composition of ingrowth at each measurement period.

Final equations would be identified and annualized using the approach outlined in Weiskittel *et al.*(2007). The final parameter estimates would be obtained using nonlinear mixed effects modeling and restricted maximum likelihood. For comparison, the approach of Shifley *et al.* (1993) would be evaluated. This approach consists of using the crown competition factor to set a biologically realistic upper limit on the number of ingrowth trees. The difference between the maximum crown competition factor and the stand's current crown competition factor determines the amount of ingrowth. The form of the equation is:

Table 1. Counts of the number of ingrowth trees present within the current growth and yield database for 15 species common to the forests of Maine.

Common Name	**Scientific Name**	**Count of Ingrowth Trees**
Balsam fir	*Abies balsamea*	97,452
red maple	*Acer rubrum*	18,980
red spruce	*Picea rubens*	18,449
black spruce	*Picea mariana*	15,597
paper birch	*Betula papyrifera*	12,662
sugar maple	*Acer saccharum*	7,061
white spruce	*Picea glauca*	6,973
eastern hemlock	*Tsuga canadensis*	5,728
yellow birch	*Betula alleghaniensis*	4,906
American beech	*Fagus grandifolia*	4,546
northern white-cedar	*Thuja occidentalis*	3,770
eastern white pine	*Pinus strobus*	2,996
quaking aspen	*Populus tremuloides*	2,979
tamarack (native)	*Larix laricina*	2,205
spruce spp.	*Picea*	2,204

[1] $$\text{Ingrowth} = R \cdot \frac{CCF_{nax} - CCF_{current}}{CW_T^2 \cdot 100 \frac{\pi}{4} * 43{,}560^{-1}}$$

Where Ingrowth is the amount of annual ingrowth (stems per acre per year), CCF_{max} is the estimated maximum crown competition factor that is dependent upon threshold diameter, $CCF_{current}$ is the current crown competition factor of the stand, CW_T is the crown width of an open grown tree with a DBH equal to the ingrowth threshold diameter, and R is a ratio bounded

between 0 and 1 that determines the maximum ingrowth trees to the actual. R could be a constant or dependent on stand factors and forest type. Shifley *et al.* (1993) found it to be dependent on forest type. One attractive alternative to using crown competition factor in Eqn [1] is to simply use basal area (Vanclay, 1994). Both options would be explored in this analysis. Finally, a two-stage approach will be evaluated for predicting the amount of ingrowth. At the first stage, the probability of ingrowth occurring would be predicted from stand and site factors. Given the probability of ingrowth occurring, an equation would then be used to predict the amount of ingrowth. The size of the ingrowth would be estimated using a Weibull 3-parameter diameter distribution. The shape and size parameters would be a function of several stand-level factors like density and depth to water table.

To predict composition of the ingrowth, a set of equations would be developed that would relate the proportion of ingrowth to the proportion of basal area of the different species in a given stand. This is an approach similar to the one used by Vanclay (1989), who found that it worked well despite its simplicity.

These equations would be incorporated into a simple software tool that would produce treelists that can be incorporated into FVS.

ANTICIPATED BENEFITS TO THE CFRU:

This project addresses the need for better regional growth and yield models, which was recently identified by the CFRU as a high priority item. The project complements the ongoing work also funded by the CFRU to develop refined growth equations for the primary species in the region. Specifically, the project addresses an important deficiency of FVS and the Ingrowth Tool of Arseneault *et al.* (2008), while trying to identify the factors that influence the amount and composition of ingrowth in the region.

SCHEDULE OF DELIVERABLES:

The primary deliverables of this analysis would be a regional database on ingrowth, equations to predict ingrowth, and a software tool for using this information. This would be provided to CFRU members in the form of technical reports, presentations, and a software package.

Date	*Deliverables*
Dec 2010	Database: Compiled ingrowth data for the Northeast
Jun 2011	Report: Equations for predicting the occurrence of ingrowth in the Northeast
Jun 2011	Computer program: Alpha version of refined FVS ingrowth tool
Oct 2011	Report: Equations for predicting the composition of ingrowth in the Northeast
Oct 2011	Computer program: Beta version of refined FVS ingrowth tool
Dec 2011	Report: Predicting the composition and ingrowth in the Northeast
Jun 2012	Computer program: Final version of refined FVS ingrowth tool

COMMUNICATIONS PLAN:

The research results of this projected will be communicated to the CFRU with annual reports, oral progress presentations, and a final project report. The data produced by the project will be deposited in the CFRU databank according to the required specifications. Two peer-reviewed journal articles will also be written based on the results of the project. Documentation and workshops for using the developed computer simulation tool will also be given.

LITERATURE CITED:

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Curriculum Vitae – Aaron R. Weiskittel

EDUCATION

Ph.D. in Forest Science, 2007, Oregon State University
M.S. in Forest Resources, 2003, Oregon State University
B.S. in Natural Resources, 2001, The Ohio State University,

EXPERIENCE

Cooperating Scientist, University of Maine Cooperative Forestry Unit, Orono, ME

Assistant Professor of Forest Modeling and Biometrics, University of Maine, Orono, ME

Production Forestry Research Fellow, 2007, The Weyerhaeuser Company, Albany, OR

Research Fellow, 2006, Forest Research Institute of Baden-Württemberg, Freiburg, Germany

SELECTED PUBLICATIONS

Weiskittel, A.R., Kenefic, L.S., Seymour, R.S., and Phillips, L.M. 2009. Long-term effects of precommercial thinning on stem dimensions, form, and branch characteristics of red spruce and balsam fir crop trees. Silva Fennica: in press.

Kershaw, J.A., Benjamin, J., and *Weiskittel, A.R.* 2009. Approaches for modeling vertical distribution of maximum knot size in black spruce: A comparison of fixed and mixed effects nonlinear models. Forest Science: in press.

Hein, S. and *Weiskittel, A.R.* 2009 Cutpoint analysis for models with binary outcomes: A case study on branch mortality. European Journal of Forest Research: in press.

Weiskittel, A.R., Gould, P.J., and Temesgen, H. 2009. Sources of variation in the self-thinning boundary line for three species with varying levels of shade tolerance. Forest Science 55: 84-93.

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Curriculum Vita – Jeremy Wilson

EDUCATION

Ph.D. in Silviculture, 1998, University of Washington
M.F., 1993, Yale University School of Forestry and Environmental Studies
A. B. Economics, 1987, Bowdoin College

EXPERIENCE

Associate Professor of Forest Resources and Irving Chair for Forest Ecosystem Management, 2001-present, University of Maine, Orono, ME

Research Forester, 1998-2000, USFS PNW Research Station, Seattle, WA

Environmental Policy Analyst, 1988-1991, Abt Associates, Cambridge, MA

SELECTED PUBLICATIONS

Perry, T.E. and J.S. Wilson. 2008. Evaluating the Vulnerability of Maine Forests to Wind Damage. In: Pye, J.M.; Rauscher, H.M.; Sands, Y.; Lee, D.C.; Beatty, J.S., eds. Advances in Threat Assessment and their Application to Forest and Rangeland Management. Gen. Tech. Rep. PNW xxx. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Station & Southern Research Station: xxx-xxx.

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Baker, P.J. and J.S. Wilson. 2003. Coexistence of tropical trees. Nature 422:581-582.

Curriculum Vita –John Kershaw

Education:

BS in Forest Management, Purdue University, West Lafayette, IN
MS in Forestry, Purdue University, West Lafayette, IN
PhD in Forest Management, University of Washington, Seattle, WA

Professional Experience:

Professor of Forest Mensuration, Faculty of Forestry and Environmental Management, University of New Brunswick, 7/1991 – present

Selected Publications -- Journal Articles, Research Bulletins, and Book Chapters

Kershaw, J.A., Jr., Morrissey, R.C., Jacobs, D.F., Seifert, J.R., and McCarter, J.B. 2008. Dominant Height Based Height-Diameter Equations for Trees in Southern Indiana. In: Jacobs, D.F. and Michler, C.H., eds. Proceedings, 16th Central Hardwood Forest Conference; 2008 April 8-9; West Lafayette, IN. Gen. Tech. Rep. NRS-P-24. Newtown Square, PA: USDA, Forest Service, Northern Research Station: 341-355.

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