COOPERATIVE FORESTRY RESEARCH UNIT
FULL RESEARCH PROPOSAL

PROJECT TITLE:

Development of regional taper and volume equations for the primary commercial species in the Acadian Region

ABSTRACT:

Prediction of individual stem total and merchantable stem volume is necessary to evaluate financial return of forestry investments. Equations developed by Honer (1967) are widely used in the Acadian Region of Maine and Maritime Canada. Recent evidence suggests that the Honer (1967) equations can be significantly biased by 5 - 15% for red spruce and balsam fir, particularly in precommercially thinned stands (Pitt and Lanteigne, 2008; Weiskittel *et al.*, 2009). The use of taper equations has become the standard in several regions for a variety of reasons such as the ability to reconstruct stem shape, estimate merchantable volume to a specified size, and provide unbiased volume estimates (e.g. Wiant. *et al.*, 2002). The goal of this project is to develop a taper system to estimate total and merchantable stem volume for the primary commercial species in the Acadian Region.

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PLANNED START DATE: *October 2009*

PLANNED TERMINATION DATE: *September 2011*

BACKGROUND

Prediction of individual stem total and merchantable stem volume is necessary to evaluate financial return of forestry investments. Equations developed by Honer (1967) are widely used in the Acadian Region of Maine and Maritime Canada. Recent evidence suggests that the Honer (1967) equations can be significantly biased by 5 - 15% for red spruce and balsam fir, particularly in precommercially thinned stands (Pitt and Lanteigne, 2008; Weiskittel *et al.*, 2009). This bias can partly be attributed to the Honer (1967) equations being parameterized with data only from unmanaged natural stands and are a function of just tree diameter and height. In addition, Weiskittel *et al.* (2009) also indicated that several other regional volume equations including those of Lemin and Briggs (1993) and Reams and Brann (1981) show signs of bias.

Taper equations provide diameter inside (dib) or outside bark (dob) estimates at any given height along a tree bole. The use of taper equations has become the standard in several regions for a variety of reasons such as the ability to reconstruct stem shape, estimate merchantable volume to a specified size, and provide unbiased volume estimates (e.g. Wiant. *et al.*, 2002). Numerous taper model forms have been presented in the forestry literature over the past several decades. A very common approach in modeling the shape of a tree bole is to divide a tree into several sections, with each section corresponding to a regression function depicting stem diameter changes with increasing tree height. For example, Max and Burkhart (1976) proposed a segmented polynomial model that used two joining points to link three stem sections along the bole: the lower section corresponding to a neiloid shape, the upper section corresponding to a conic shape and the middle section corresponding to a parabolic shape. This idea has been widely accepted and used in many forestry taper applications. Other researchers later introduced variable-exponent or variable-form taper equations (Kozak, 1988), which used a changing exponent or a changing form to continuously describe the shape of a bole from the ground to the top, exhibiting more flexibility. Other types of taper equations can also be found in the literature such as polynomial, trigonometric, and nonparametric approaches.

A well behaved taper equation should not only give unbiased estimates of dib or dob with a minimum variance, but also have flexibility to adapt to a wide variety of species and give accurate predictions of stem volume. Most published taper equations were developed for a certain species and often its performance is compared to a limited number of alternative model forms. Therefore, it is necessary and beneficial to further study the characteristics of taper profile equations and extend their use to other species besides the ones they were originally developed on. For example, Rojo *et al.* (2005) compared 31 different model forms on maritime pine in Spain and found variable-form taper functions provided the most accurate predictions of dob, particularly the equation of Kozak (2004). However, Rojo *et al.* (2005) did not compare the taper equations' performance in predicting stem volume. Thus, the best equation for predicting stem form may not be the best equation for estimating stem volume. This project will work with the primary commercial species in the Acadian Region to find the best equation that predicts both stem form and volume accurately.

There is also no unified agreement on whether crown dimensions should be incorporated into taper equations as previous studies have shown mixed results on the benefits of adding crown variables in the taper models. For example, Muhairwe *et al.* (1994) reported that the addition of crown ratio variable improved the fit and predictive abilities in the taper equation for lodgepole pine, but found no improvement for several other species including aspen, western redcedar, and Douglas-fir. Leites and Robinson (2004) found a significant relationship between crown length, crown ratio, and the estimated random effects for the parameters in a taper equation for loblolly pine. Jiang *et al.* (2007) also found that the addition of crown ratio as a predictor variable provided modest improvements for yellow-poplar, while Burkhart and Walton (1985) found no strong relationship between crown ratio and improved predictions for loblolly pine trees in unthinned stands. In this analysis, we attempt to determine if crown dimensions can improve predictions of both diameter and volume for several commercially important species across a wide range of tree sizes and stand conditions.

Recent evidence suggests that management activities and site attributes can influence stem form. For example, Weiskittel *et al.* (2006) found that thinning, vegetation control, and defoliation all had a statistically significant influence on stem form in Douglas-fir. In West Virginia, Jiang *et al.* (2007) found that stem form of yellow-poplar differed significantly from two geographic regions. Although rarely incorporated in taper equations, site features like ecoregion, elevation, and site drainage could have an important influence on stem form. Given the large geographic range of the Acadian Region, this analysis will attempt to assess the influence of various silvicultural treatments and site attributes on stem form.

PROJECT OBJECTIVES

The goal of this project is to develop a taper system to estimate total and merchantable stem volume. Specific objectives are to:

1. Compile existing regional taper datasets;

2. Collect additional taper data;

3. Compare the performance of existing stem taper equations;

4. Test the influence of various site and stand factors on stem form;

5. Validate the performance of the developed system.

ANALYTICAL APPROACH

Field Work

In the summer of 2009, the New Brunswick Growth and Yield Unit will be randomly selecting harvest units and subsampling trees from across the diameter range of the stand. After felling, each tree will be bucked into 1-m sections from the stump. For each disc, location in the stem and two perpendicular measurements of diameter inside bark, diameter outside bark, and heartwood will be recorded. The sampling will occur throughout New Brunswick and be focused primarily on balsam fir, red spruce, and black spruce. The sampled harvest units will be scattered throughout the provenience to cover the range of ecoregions present. Also, the stands will include plantations, mixedwood, and those that have precommercially thinned.

Data

Stem analysis data have been obtained from Honer (1967), several existing CFRU datasets, and variety of other studies. Datasets include those from: Hofmeyer (2008), Lemin and Briggs (1993), Maguire *et al.*(1998), Meyer (2005), Pace (2003), and Reams and Brann (1981). Although the dataset is weighted heavily towards balsam fir and red spruce, several additional commercial species are present. These include aspen, black spruce, hemlock, jack pine, lodgepole pine, red maple, sugar maple, yellow birch, white birch, white pine, and white spruce. Additional data has also been obtained from the Quebec and New Brunswick Departments of Natural Resources.

Analysis

The performance of several taper equations would be evaluated including Bi (2000), Clark III *et al.* (1991), Kozak (2004), Max and Burkhart (1976), Sharma and Zhang (2004), Valentine and Gregoire (2001), and Zakrzewski (1999). The models would be fit using multi-level mixed effects with a specified error structure and variance power weighting. The random effects would be plotted over various site and stand factors to assess their importance. Individual tree volume would also be calculated using tree-specific splines. The performance of the equations would be evaluated by estimating mean bias and absolute error on a random subsample of the data not used during model fitting. The comparison would be done for both stem taper and stem volume. Equations would be developed for aspen, balsam fir, black spruce, hemlock, jack pine, lodgepole pine, red maple, red spruce, sugar maple, yellow birch, white birch, white pine, and white spruce

ANTICIPATED BENEFITS TO THE CFRU

Estimates of both tree and stand volume drive many key forest management decisions. The current regional volume equations are outdated and show significant biases. This project would provide equations, which can be used both to predict stem taper and volume. In addition, taper data from several previous CFRU studies would be compiled and utilized. Finally, the analysis would provide insights into the various factors that may potentially influence stem form.

SCHEDULE OF DELIVERABLES:

The primary deliverables of this analysis would be a regional database on taper and equations to predict stem taper and volume. This would be provided to CFRU members in the form of technical reports and presentations.

Date	*Deliverables*
Dec 2009	Database: Compiled taper data for the Northeast
Jun 2010	Report: Performance comparison of the various taper equations for key species in the Northeast
Sep 2010	Report: Stem taper equations for the primary conifer species in the Northeast

Dec 2010 Report: Stem taper equation for the primary hardwood species in the Northeast

Dec 2010 Report: Performance of final equation for predicting stem form and volume

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

DELIVERABLES

The primary deliverable from this project is a system of equations to predict stem taper and volume for the primary commercial species in the Acadian Region. This should replace the widely used but biased Honer (1967) equations and improve regional volume predictions.

Literature Cited

Bi, H., 2000. Trigonometric variable-form taper equations for Australian eucalypts. Forest Science 46, 397-409.

Burkhart, H.E., Walton, S.B., 1985. Incorporating crown ratio into taper equations for loblolly pine trees. Forest Science 31, 478-484.

Clark III, A.C., Souter, R.A., Schlaegel, B.E., 1991. Stem profile equations for southern tree species. In, USDA Forest Service Southeastern Forest Experiment Station Research Paper SE-282, Asheville, NC.

Hofmeyer, P., 2008. Ecology and silviculture of northern white-cedar (*Thuja occidentalis* L.) in Maine. In, PhD dissertation. University of Maine, Orono, ME.

Honer, T.G., 1967. Standard volume tables and merchantable conversion factors for the commercial tree species of central and eastern Canada. In, Information Report FMR-X-5. Forest Management Research and Services Institute, Ottawa, Ontario, p. 21.

Jiang, L., Brooks, J., Gerald, R., 2007. Using crown ratio in yellow-poplar compatible taper and volume equations. Northern Journal of Applied Forestry 24, 271-275.

Kozak, A., 1988. A variable-exponent taper equation. Canadian Journal of Forest Research 18, 1363-1368.

Kozak, A., 2004. My last words on taper equations. Forestry Chronicle 80, 507-515.

Leites, L.P., Robinson, A.P., 2004. Improving taper equations of loblolly pine with crown dimensions in a mixed-effects modeling framework. Forest Science 50, 204-212.

Lemin, J., R.C., Briggs, R.D., 1993. Stem volume equations for young precommercially thinned balsam fir, *Abies balsamea* (L.) Mill., and spruce, *Picea* spp., in Maine. In, Miscellaneous Report 384. Maine Agricultural and Forest Experiment Station, University of Maine, Orono, ME, p. 5.

Maguire, D.A., Brissette, J., Gu, L., 1998. Canopy structure and growth efficiency of red spruce in uneven-aged, mixed species stand in Maine. Canadian Journal of Forest Research 28, 1233-1240.

Max, T.A., Burkhart, H.E., 1976. Segmented polynomial regression applied to taper equations. Forest Science 22, 283-289.

Meyer, S.R., 2005. Leaf area as a growth predictor of *Abies balsamea* and *Picea rubens* in managed stands in Maine. In, M.S. Thesis. The University of Maine, Orono, ME, p. 117.

Muhairwe, C.K., LeMay, V.M., Kozak, A., 1994. Effects of adding tree, stand, and site variables to Kozak's variable-exponent taper equation. Canadian Journal of Forest Research 24, 252-259.

Pace, M.D., 2003. Effect of stand density on behavior of leaf area prediction models for eastern white pine (*Pinus strobus* L.) in Maine. In, M.S. Thesis. University of Maine, Orono, ME, p. 69.

Pitt, D., Lanteigne, L., 2008. Long-term outcome of precommercial thinning in northwestern New Brunswick: Growth and yield of balsam fir and red spruce. Canadian Journal of Forest Research 38, 592-610.

Reams, G.A., Brann, T.B., 1981. Volume equation comparison for small diameter spruce and fir in Maine. In, Technical Notes 80. School of Forest Resources, University of Maine, Orono, ME, p. 10.

Rojo, A., Perales, X., Sanchez-Rodriguez, F., Alvarez-Gonzalez, J.G., von Gadow, K., 2005. Stem taper functions for maritime pine (*Pinus pinaster* Ait.) in Galicia (Northwestern Spain). European Journal of Forest Research 124, 177-186.

Sharma, M., Zhang, S., 2004. Variable-exponent taper equations for jack pine, black spruce, and balsam fir in eastern Canada. Canadian Journal of Forest Research 198, 39-53.

Valentine, H.T., Gregoire, T.G., 2001. A switching model of bole taper. Canadian Journal of Forest Research 31, 1400-1409.

Weiskittel, A.R., Kenefic, L.S., Seymour, R.S., Phillips, L., 2009. Effects of precommercial thinning on stem form, volume, and branch characteristics of red spruce and balsam fir crop trees. Silva Fennica, in press.

Weiskittel, A.R., Maguire, D.A., Monserud, R.A., Rose, R., Turnblom, E.C., 2006. Intensive management influence on Douglas-fir stem form, branch characteristics, and simulated product recovery. New Zealand Journal of Forestry Science 36, 293-312.

Wiant., H.V., Spangler, M.L., Baumgras, J.E., 2002. Comparison of estimates of hardwood bole volume using importance sampling, the centroid method, and some taper equations. Northern Journal of Applied Forestry 19, 141-142.

Zakrzewski, W.T., 1999. A mathematically tractable stem profile model for jack pine in Ontario. Northern Journal of Applied Forestry 16, 138-143.

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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.

Hein, S., *Weiskittel, A.R.* and Kohnle, U. 2008. Effect of wide spacing on tree growth, branch, and sapwood properties of young Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] in south-western Germany. European Journal of Forest Research 127: 481-493.

Hein, S., *Weiskittel, A.R.* and Kohnle, U. 2008. Branch characteristics of widely spaced Douglas-fir in south-western Germany: Comparisons of modeling approaches and geographic regions. Forest Ecology and Management 256: 1064-1079.

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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.

Morrissey, R.C., Gauthier, M.-M., **Kershaw,** J.A., Jr., Jacobs, D.F., Fischer, B.C. and Seifert, J.R. 2008. Grapevine Dynamics after Manual Tending of Juvenile Stands on the Hoosier National Forest, 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: 395-404.

Hennigar, C.R., MacLean, D.A., Quiring, D.T.,and **Kershaw,** J.A., Jr. 2008. Differences in spruce budworm defoliation among balsam fir and white, red, and black spruce. Forest Science 54:158-166.

Kershaw, J.A., Jr., Richards, E.W., and Larusic, J. 2007. A product ratio calculator for northeastern tree species. Northern Journal of Applied Forestry. 24:307-311.

Arseneault, J., **Kershaw,** J.A., Jr., McCarter, J.B., and MacLean, D.A. In Press. Forest Vegetation Simulator Ingrowth Tool: Incorporating ingrowth tree lists into FVS growth projections. Northern Journal of Applied Forestry.

Morrissey, R.C., Jacobs, D.F., Seifert, J.R., Fischer, B.C., and **Kershaw,** J.A., Jr. In Press. Competitive success of natural oak regeneration of clearcuts in the stem exclusion stage by site on the Hoosier National Forest, south-central Indiana. Canadian Journal of Forest Research.