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College of Natural Resources and Environment

Western Forestry and Conservation Association

Department of
Forest Resources and Environmental Conservation
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2018

IUFRO 4.01 SOMENS NEMO

Oct. 28 - 30
Virginia Tech, Blacksburg, VA

2018 Joint Southern and Northeastern Mensurationists and IUFRO4.01 Conference

Inn at Virginia Tech, Blacksburg, Virginia
October 28 - 31, 2018

Agenda

Sunday, October 28

2:00 PM IUFRO Division 4.01: *Welcome and Introductions* (Jay Sullivan, Temesgen Hailemarian)
Session 1
Moderator: Peter Marshall

- Ed Green: **Model Choice and Posterior Predictive Distributions**
- Guillermo Trincado: **Modeling the influence of cambial age, radial growth and climate on wood density in *Pinus radiata* D. Don grown in Chile**
- Matthew Russell: **Evaluating Ponderosa Pine Growth and Yield Equations for Application in Minnesota**
- Clara Antón-Fernández: **An R package for flexible cross-platform individual tree simulations: SITREE**
- Astor Torano Caicoya: **Forest management optimization for the state of Bavaria (southern Germany) using the single tree-based growth simulator SILVA 3.0**

3:30 BREAK
Session 2
Moderator: Temesgen Hailemarian

- Greg Reams: **Integrating Science and Technology in Delivery of the Forest Inventory and Analysis Program**
- Sergio Orrego: **Using Biophysical Variables and Stand Density to Estimate Growth and Yield of *Pinus patula*: a Case Study in Antioquia, Colombia**
- David Affleck: **Efficient Tree Selection Designs for Biomass Equation Development and Estimation**
- Bogdan Strimbu: **A Scalar Measure Tracing Tree Species Composition in Space or Time**
- Rong Fang: **Branch Sampling of Tree Structural Models Fitted from Lidar Point Clouds, a Case Study of an Experimental Douglas-fir Forest**
- Laura Ramirez: **Spatial Financial Analysis of Potential Forest Plantations in Antioquia, Colombia**

5:30 **Reception (Inn at Virginia Tech)**
901 Prices Fork Rd, Blacksburg, VA 24061

Monday, October 29

8:00 SOMENS/NEMO: *Welcome and Introductions* (Ralph Amateis)

8:15 Keynote Speaker – Harold Burkhart, University Distinguished Professor, Virginia Tech
Forest Mensuration and Modeling: Past Successes, Current Challenges and Future Prospects: A Personal Perspective

8:45 Session 3
Moderator: Dean Coble

- Margarida Tomé: **Science supporting cork oak stands management: a stakeholder´s driven development of forest management support tools**
- Chad Babcock: **On Spatial Autocorrelation in Design-based and Model-assisted Estimation Using Systematic Samples and Remote Sensing in Forest Inventory**
- Diane Kiernan: **Assessing Small-stem Density in Northern Hardwood Selection System Stands**
- Josh Bankston: **Effect of Sample-plot Size and Diameter Moments/Percentiles Prediction Model on Stand Diameter Distribution Recovery Accuracy**

9:45 BREAK
Session 4
Moderator: Diane Kiernan

- David MacFarlane: **Exploring Branch, Stem and Tree Wood Density Relationships for Temperate Tree Species in the Eastern USA**
- Stephanie Patton: **Postthinning Response of White Spruce Plantations Affected by Eastern Spruce Budworm in Minnesota**
- Quang Cao: **Deriving a Tree Survival Model from an Existing Stand Survival Model**
- Jim Westfall: **Double Sampling for Post-Stratification in Forest Inventory**
- Frank Roesch: **Truth or Consequences: Evaluation of the Re-measurement Period Assumption**
- John Kershaw: **Application of Mixture Distributions to Describing Biomass Distribution Using TLS Data**
- David Walker: **Regional and National Scale Aboveground Biomass Estimators for Applications Involving Multiple Tree Species**

12:00 LUNCH (provided)

1:15 Session 5

Moderator: Margarida Tomé

- Brian Clough: **Estimating Precision of Uncruised Stands: Applications for Model-based Forest**
- Mingling Wang: **Understanding Dominant Height Projection Accuracy of Anamorphic Models**
- Garrett Dettmann: **Generalized Predictors of Foliage Biomass for Tree Species of the United States**
- Corey Green: **Comparison of Two Projection Strategies in Simulated Loblolly Pine Stands Under Various Levels of Spatial Heterogeneity**
- Sheng-I Yang: **Evaluation of Total Volume and Stand Tables Estimates with Alternate Measurement-Tree-Selection Methods in Point Samples**
- Poster Presentations
    - Corey Green: **Improved Removal Estimates with Small Area Estimation Methods**
    - Thomas Harris: **Methods for Developing New Longleaf Pine Individual Tree Taper, Green Weight and Volume Equations**
    - Priscila Dias: **Interactive Growth and Yield Models: An Example with Longleaf Pine in R**
    - Anil Koirala: **Analysing the Influence of Plot Size on Site Index and Dominant Height Estimates**
    - Mark Porter: **Estimating Tree Height from Multiple Stem Diameters**
    - Steve Knowe: **Overview of the FMRC Forest Sampling Simulator**
    - Åsa Ramberg: **Production Potential of Loblolly and Slash Pine in the Southeastern USA and a Comparison to the Potential of Scots Pine in Sweden**

3:00 BREAK

Session 6

Moderator: Aaron Weiskittel

- Yingbing Chen: **Application of Big BAF Sampling for Estimating Carbon on Small Woodlots**
- Stephen Kinane: **A Model to Estimate Leaf Area Index in Loblolly Pine Plantations**
- Rebecca Wylie: **Estimating Stand Age From Airborne Laser Scanning Data to Improve Ecosite-based Models of Black Spruce Wood Quality in the Boreal Forest of Ontario**
- Karol Bronisz: **Taper Equations for Scots Pine Based on Terrestrial Laser Scanner Data for Poland**
- Mauricio Zapata: **A New Taper Equation for Loblolly Pine Using Penalized Spline Regression**
- Dehai Zhao: **More Discussion on the Compatibility and Additivity of Tree Taper, Volume and Biomass Equations**

- Micky Allen: **Relationships Between Volume Growth and Stand Density - An Examination of Past Hypotheses in Two Conifer Species**

5:30 **Conference Banquet** (Inn at VT)

Tuesday, October 30

8:00 Session 7:
Moderator: Phil Radtke

- James McCarter: **Annualizing FIA – Combining FIA Plots, Satellite Imagery, FVS to Create Single Year Estimates of Forest Inventory**
- Ting-Ru Yang: **Application of Terrestrial LiDAR for Estimating Diameter Distributions in Newfoundland**
- Cristian Montes: **A Dynamic State-space Specific Gravity Model for Loblolly Pine Using Data Assimilation to Improve Wood Property Estimates with Explicit Uncertainty**
- Spencer Peay: **A Maximum Entropy Approach to Defining Geographic Bounds on Growth and Yield Model Usage**
- Eddie Bevilacqua: **Additive Aboveground Dry Biomass Equations for Naturally Regenerated Pinus Occidentalis Sw. Trees**
- Bharat Pokharel: **Predictive Mapping of Stand Characteristics Using A Non-Parametric Approach**

9:45 BREAK
Session 8
Moderator: Clara Antón-Fernández

- John Brown: **Power Estimation for Binary Response Variables in a Randomized Block Setting**
- Krishna Poudel: **Does Calibration Using Upper Stem Diameter Measurement Improve Predictive Ability of a Segmented Polynomial Taper Equation in Presence of Measurement Error?**
- Hector Restrepo: **Prediction of Timber Product Class Proportions for Loblolly Pine in the Southeastern U.S.**
- Chris Cieszewski: **Update on InFORM and Other Developments in the Fiber Supply Assessment Program**
- Poster presentations

12:00 LUNCH (provided)

1:15 Session 9

Moderator: Guillermo Trincado

- Jim Smith: **Forest Measurements: *Outside the Lines***
- Jacob Putney: **Assessing Shifts in Vertical Distribution of Stem Cross-Sectional Increment in Response to Nitrogen Fertilization of Douglas-fir using a Nonlinear Mixed-Effects Modeling Approach**
- Salvador Gezan: **Incorporating Genetics Into a Slash Pine Growth and Yield Model**
- Yung-Han Hsu: **3P Sampling with a Ricoh 360 Camera**
- Mike Strub: **Measures of Goodness of Fit for Mortality Models**

2:30 Awards, Business, Adjourn

Wednesday, October 31

Optional Field Tour – Reynolds Homestead and Forestry Research Center, Critz, Virginia. Cost is $25.00.

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COMPILED LIST OF ORAL ABSTRACTS

(Alphabetical order by last name of first author)

EFFICIENT TREE SELECTION DESIGNS FOR BIOMASS EQUATION DEVELOPMENT AND ESTIMATION

David Affleck,
Department of Forest Management, University of Montana
david.affleck@umontana.edu

Collection of tree biomass and carbon data is labor intensive and expensive, but necessary for the development and calibration of individual-tree biomass and carbon equations. Given the cost, the selection of trees for destructive sampling should be guided by efficient designs, yet this topic has received little attention. Instead, sample trees (or stands) are commonly selected opportunistically where destructive sampling is permitted, and then efforts are undertaken to distribute selected trees across size classes. In this research, we develop and apply techniques from optimal design to i) identify efficient sample distributions of tree sizes for aboveground biomass equation calibration and estimation, and ii) compare the efficiencies of these distributions to size-balanced and frequency-weighted designs. In doing so, we consider parameter uncertainty in the underlying nonlinear allometric relationships and intrinsic variance heterogeneity. We also incorporate population tree size distributions into the optimization criteria, and use the current size distribution of Douglas-fir (*Pseudotsuga menziesii*) across the interior northwest (as estimated from Forest Inventory & Analysis plots) as a case study. Results demonstrate the importance of collecting data from the largest size classes, even for size distributions skewed heavily to smaller trees and under models where error variance increases with size. Related to this, we also show that the footprint of the optimal design for a given allometric model is sparse, but that size-balanced designs are superior to frequency-weighted designs. Practical applications and limitations of these results are discussed, as well as avenues for future research.

RELATIONSHIPS BETWEEN VOLUME GROWTH AND STAND DENSITY - AN EXAMINATION OF PAST HYPOTHESES IN TWO CONIFER SPECIES

Micky G. Allen II, Harold E. Burkhart, Andreas Brunner, and Clara Antón-Fernández

Hypothesized growth-density relationships of the past century suggest that volume growth follows either an optimal or constant pattern with stand density. Under these hypotheses, volume growth is maximized at a specific density or over a range of densities, respectively, somewhat less than the maximum density. These hypotheses differed from earlier beliefs that volume growth increased with increasing density up to the maximum levels sustainable on a given site. The alternative hypotheses (optimal, constant, and increasing) were tested using data from thinning studies in loblolly pine plantations in the southeastern US and in Norway spruce plantations in Norway. Relationships between gross volume growth and four measures of stand density including basal area, standing volume, stand density index, and relative spacing were examined. Analyses indicated that when accounting for stand age, site quality, and average tree size, volume growth increases with increasing stand density, for both species and for all four density measures.

AN R PACKAGE FOR FLEXIBLE CROSS-PLATFORM INDIVIDUAL TREE SIMULATIONS: SITREE

Clara Antón-Fernández, and Rasmus Astrup

Sitree is a flexible, open-source individual tree simulator that facilitates flexible analyses of forest growth and yield simulations. We provide the broad forestry community of R-users with an easily adaptable individual-tree simulator. sitree provides the fundamental simulation framework while the users either select existing models or add new individual-tree models for describing the different processes applied in their simulation. sitree allows, for example, to "plug and play" a new mortality function without having to change other models in the simulator, and using only R. We present the package, its structure, potential applications and several examples.

ON SPATIAL AUTOCORRELATION IN DESIGN-BASED AND MODEL-ASSISTED ESTIMATION USING SYSTEMATIC SAMPLES AND REMOTE SENSING IN FOREST INVENTORY

Dr. Chad Babcock and Dr. Andrew O. Finley
Michigan State University, Department of Forestry, East Lansing, MI 48824, USA

Systematic sampling is commonly employed to select plot locations for forest inventory estimation. However, it is not possible to derive an unbiased variance estimator for a systematic sample employing one random start. As a result, many forest inventory analysts resort to applying variance estimators commonly used following simple random sampling and Horwitz-Thompson estimation of the population mean, even though it is well known that this substitution typically leads to conservative estimates of error. We explore the role of spatial autocorrelation in systematic sampling variance estimation using Monte Carlo sampling from a series of synthetic populations and a tree census plot in Harvard Forest, Massachusetts. Results indicate that applying variance estimators for the mean that are design-unbiased under simple random sampling to systematic samples from populations exhibiting stronger spatial autocorrelation tend to be more conservative. We also find that incorporating ancillary wall-to-wall covariates, e.g., remote sensing data, via model-assisted estimation can reduce variance over-estimation by explaining some or all of the spatial structure in the population units. These findings illustrate tangible benefits to incorporating remote sensing data via model-assisted estimation in forest inventory. Remote sensing data can account for spatial autocorrelation leading to not only improved estimation of forest inventory parameters, but also better approximations of the variance when systematic sampling is used.

EFFECT OF SAMPLE-PLOT SIZE AND DIAMETER MOMENTS/PERCENTILES PREDICTION MODEL ON STAND DIAMETER DISTRIBUTION RECOVERY ACCURACY

[1]Joshua B. Bankston, [2]Charles O. Sabatia, and [3]Thomas G. Matney
[1]Graduate Student and [3]Professor (Retired), Mississippi State University,
Department of Forestry, P.O. Box 9681 Mississippi State, MS 39762
[2]Forest Biometrician, The Westervelt Company, 1400 Jack Warner Pkwy, Tuscaloosa, AL 35405

Diameter distribution of a forest stand provides insights into the stand's value. In whole stand forest growth and yield prediction systems, the future diameter distribution of a stand gets predicted by use of models that predict the stand's diameter statistical moments and/or percentiles in conjunction with a mathematical system to recover the diameter distribution from the predicted moments and/or percentiles. Weibull probability distribution is widely used to model the predicted diameter distribution. Studies that have compared Weibull diameter distribution recovery systems based on moments only to those based on moment-percentile hybrid approaches arrived at varied conclusions regarding the best approach of recovering a stand's future diameter distribution from predicted stand level statistics. In the current study, quantity of data used in model development as well as the form of diameter moments/percentiles prediction models were assessed in terms of how they affect the accuracy of three Weibull distribution recovery approaches – method of moments, percentile, and moments-percentile hybrid. Data from five plot sizes were used to fit each moments/percentile prediction model used to recover Weibull diameter distributions. Prediction error was calculated by comparing each plot's predicted timber yield (green tons/acre) to its respective observed yield. Across the model forms and diameter distribution recovery approaches investigated, prediction error was smaller the larger the size of plot used to develop the diameter recovery system. There was some evidence of interaction between plot-size and the diameter distribution recovery approaches but no evidence of interaction between diameter-statistics prediction model form and the recovery approaches.

ADDITIVE ABOVEGROUND DRY BIOMASS EQUATIONS FOR NATURALLY REGENERATED PINUS OCCIDENTALIS SW. TREES

Eddie Bevilacqua
ebevilacqua@esf.edu

Precise species-specific aboveground tree component biomass equations are needed in the Dominican Republic to quantify potential carbon storage in the context of climate change and sustainable forest management. To date, there has been a lack of available information concerning component (stem plus bark, branches, and foliage) and total aboveground biomass and/or carbon content for naturally occurring *Pinus occidentalis* trees. The objectives of the study were to develop allometric component and total aboveground biomass equations for *P. occidentalis* while ensuring the property of additivity. Predictor variables included diameter at breast height (DBH) and total tree height (H), alone and in combination. Two additivity modeling approaches using nonlinear equations were evaluated; aggregative and disaggregative. Fit statistics indicate the aggregative approach produced better predictions of each component and total biomass. Average distribution of stem plus bark, branches, and foliage represent 82%, 8% and 10% of the total biomass, respectively, with relative proportion of foliage and branch components increasing with larger DBH trees.

TAPER EQUATIONS FOR SCOTS PINE BASED ON TERRESTRIAL LASER SCANNER DATA FOR POLAND

Karol Bronisz, Michał Zasada
Karol.bronisz@wl.sggw.pl
Laboratory of Dendrometry and Forest Productivity, Faculty of Forestry, Warsaw University of Life Sciences - SGGW

One of the ways to define the longitudinal shape of trees is to develop special regression models – taper functions. These models allow us to determine the diameter of the tree at any height, its volume, biomass and the share of products that can be obtained from a tree after cutting.

One of the groups of taper models are linear ones that describe the shape of a tree using a number of diameters from different relative tree heights. Notwithstanding the largest group of solutions are provided by nonlinear models, where the shape of the tree is mapped using a single mathematical function (e.g. polynomial). However, nonlinear variable-form taper models of trunk shape composed of several mathematical functions are also available.

The objectives of this study were to: 1) fit taper equations based on terrestrial laser scanner data for standing trees for Scots pine - the most important tree species in Poland; 2) examine the accuracy of these equations in prediction of inside bark tree diameter based on felled reference trees.

The empirical material consisted of more than 4000 trees from six different objects located in various parts of the country. In this study 8 different taper models, using total tree height, height of diameter measurement along trunk and diameter at breast height as predictors were taken into account. Models were fitted using non-linear least squares approach. The accuracy and precision of diameter estimates of each model as well as goodness-of-fit measures of each model were analyzed. Additionally all analyzed models were subject to validation based on sectional measurements measured directly on felled reference trees.

Obtained results indicate that standing trees data allows do define the shape of a tree based on taper functions. Moreover single and variable-form taper functions are characterized by similar accuracy.

POWER ESTIMATION FOR BINARY RESPONSE VARIABLES IN A RANDOMIZED BLOCK SETTING

John Brown

Binary response variables are frequently included as measures of interest in many forest inventories. Seedling and tree survival, disease presence, logging damage, and fire scarring are a few examples. Yet for the same binary response, researchers oftentimes utilize different statistical techniques. Seedling survival is one such response variable. Researchers often convert survival data to a proportion for analysis in a general linear model, and may or may not use an arcsine square root transformation of the proprotion to adjust for the bounds on survival [0, 1]. Binary data however can be analyzed directly with generalized linear models using a logit link. Which method is better is a matter of conjecture. A seedling survival study was simulated within the framework of a randomized complete block design. Three levels each of replications per block, total number of blocks, and treatment proportion differences were crossed, with each combination considered an experiment. Using known treatment proportions, data for each experiment was randomly generated and perturbed by random error and random block effects. The experimental data was then simulated 1000 times and statistical power was estimated for the three methods: percent survival in a general linear model, a transformation of percent survival in a general linear model, and survival as a binary variable in a generalized linear model. While the untransformed and transformed proportion data eventually achieved acceptable power levels, the generalized linear model with a logit link had consistently greater power given the same experimental conditions. Based on these results, it is recommended therefore that researchers maintain response variables as binary and not convert data to percentages for analysis.

FOREST MENSURATION AND MODELING: PAST SUCCESSES, CURRENT CHALLENGES, AND FUTURE PROSPECTS – A PERSONAL PERSPECTIVE

Harold E. Burkhart

Forest mensuration and modeling has been focused on a number of common themes and important problems – such as estimating contents of standing trees, quantifying site quality and stand density, and modeling growth of individual trees and stands – but the methods used for collecting field data, managing databases, analyzing data, and delivering results have changed dramatically over recent decades. Steady progress has resulted from applying increasingly sophisticated quantitative analysis techniques and cutting-edge technologies to measure and model trees and stands. The computer revolution has made the capture, storage, management, and use of large amounts of data feasible, data- and computational-intensive analytical methods possible, and running complex models with personal computers routine. Technical challenges remain, of course, and there are concerns about maintaining adequate levels of support for advancing forest biometrics teaching and research programs to address future needs. However, given the critical role that forests have in addressing global issues of sequestering carbon while providing renewable materials and energy, future prospects augur well for forest biometricians.

Forest management optimization for the state of Bavaria (southern Germany) using the single tree-based growth simulator SILVA 3.0

Astor Toraño Caicoya*, Laura Zeller*, Hans Pretzsch*
*Chair for Forest Growth and Yield Science. Faculty of Forest Science and Resource Management. Technische Universität München. Hans-Carl-von-Carlowitz-Platz 2. D-85354 Freising. Germany.
astor.torano-caicoya@tum.de

The single tree-based forest growth simulator SILVA 3.0 is capable of simulating forest structures into the future in 5-year periods. This model incorporates competition effects between trees and estimates the potential height growth depending on climate and site parameters. Currently optimized for the German federate state of Bavaria, it is used by the Bavarian State Forest Company as standard tool in the forest management of the almost 800,000 ha of state-owned forests.

Within the frame of the European Project GreenFutureForest and thanks to the availability of inventory data from the Federal Forest Inventory, forest simulations can be also performed on all types of forest ownership. Moreover, nowadays the need of adapting forest management to the needs of a society that demands multifunctional forestry arises as one the current challenges of forest modelling. Thus, tests and optimization techniques for different alternatives and over the territory are particularly relevant, especially in order to support decision making in large administrative regions, under high population pressure, like Bavaria.

With this work, we will present different management scenarios, which will be simulated over 100 years using SILVA 3.0. Depending on land ownerships, different alternatives will be evaluated and the best alternative for each forest structure type and region will be optimized depending on harvesting volume targets and the maximization of biodiversity. The different volume targets will be based on predictions by the GLOBIOM model from IIASA (Nordström et al., 2016). Biodiversity will be based on the Shannon index and the species profile index (Pretzsch, 2009). Optimized results can be performed just attending to one criteria, e.g. harvesting volume, or to the combination of multiple factors.

The forest management alternatives will comprise different levels of intensity and multifunctionality. For the state-owned forest, we will use the three alternatives based on the "business as usual planning" of the Bavarian public forest enterprise, for the private forests and other types of land we will use combinations of productive (enhancement of conifers and fast growing species) and multifunctional (enhancement of broadleaves and mixtures) scenarios. Set-asides where only natural mortality is considered will also be part of the optimization set.

We will show the special resulting causality based on the diverse growing regions of Bavaria, combined with the distribution of ownership and therefore, the implications that management objectives based on ownership can have on forest productivity and ecosystem services.

Nordström, E.-M., Forsell, N., Lundström, A., Korosuo, A., Bergh, J., Havlík, P., Kraxner, F., Frank, S., Fricko, O., Lundmark, T., Nordin, A., 2016. Impacts of global climate change mitigation scenarios on forests and harvesting in Sweden. Can. J. For. Res. 46, pp 1427–1438. https://doi.org/10.1139/cjfr-2016-0122

Pretzsch, H., 2009. Chapter 7: Species Richness, Species Diversity, and Structural Diversity in: Forest Dynamics, Growth and Yield. Springer Berlin Heidelberg, pp 223 - 289.

UPDATE ON InFORM AND OTHER DEVELOPMENTS IN THE FIBER SUPPLY ASSESSMENT PROGRAM

Chris Cieszewski
University of Georgia, Athens, GA

The Interactive Fast Online Reports & Maps (InFORM) development has been dormant for some time, and it is currently under reconstruction in preparation for further development. Following a fatal server crash, we have managed with the help of the USDA Forest Service to revive the software; although, changing environments are continuously creating new challenges. The InFORM installation has proven to be exceptionally resilient to the volatile and rapidly changing software development world; many other developments are getting rapidly outdated. I discuss this and other associated developments in the Fiber Supply Assessment program in the context of changing technology and new software challenges and opportunities.

DERIVING A TREE SURVIVAL MODEL FROM AN EXISTING STAND SURVIVAL MODEL

Quang V. Cao
Louisiana State University, qcao@lsu.edu, (225) 229-3853

Daniels and Burkhart (1988) introduced the concept of an integrated system in which models of different levels of resolutions have the same mathematical structure. In this talk, different methods will be presented to derive a tree survival model from each of three existing stand survival models. A set of stand survival model and related tree survival model should form an integrated system. Statistics computed at both stand and tree levels will be used to evaluate the methods.

ESTIMATING PRECISION OF UNCRUISED STANDS: APPLICATIONS FOR MODEL-BASED FOREST INVENTORY

Brian Clough, Nan Pond, Henry Rodman, & Zack Parisa; SilviaTerra

Model-based inventory provides substantial opportunity for estimating forest attributes in inaccessible areas, reducing cost within two-stage sampling frameworks, and for developing small area estimates from national forest inventory data. However, standard methods for developing model-based precision estimates and incorporating them into operational forest inventory have not been established.

In this talk, we outline an approach for developing and reporting model-based precision estimates of forest attributes that utilizes two components: (1) Bayesian simulation techniques that naturally integrate multiple sources of error (i.e., data, measurement, and model error) into pixel posterior predictive distributions; and (2) algorithms for aggregating these pixel distributions into stand-level precision estimates. We demonstrate this method for estimating precision of total basal area, predicted using remote sensing covariates, in two contexts: (1) for uncruised stands within a two-stage sample; and (2) for small area estimates based on the Forest Inventory and Analysis (FIA) data.

Results show this approach may inform multiple operations including acquisition and divestiture, setting management priorities, and planning future inventory efforts. However, the depth of the information that arises from model-based inference presents challenges for integration into forest operations, where summary statistics and single target thresholds are often used to support decision making. We will conclude by highlighting some lessons learned through the process of developing these methods for applied inventory projects.

A NEW TAPER EQUATION FOR LOBLOLLY PINE USING PENALIZED SPLINE REGRESSION

Mauricio Zapata Cuartas[1] and Bronson P. Bullock[2]
[1] Ph.D. Student, Warnell School of Forestry and Natural Resources, University of Georgia
[2] Professor of Forest Biometrics and Co-Director, Plantation Management Research Cooperative (PMRC)
Warnell School of Forestry and Natural Resources University of Georgia

Loblolly pine (*Pinus taeda* L.) plantations are extensive in the southeastern United States and represent a major component of the forest products market in this region. For this reason, taper modelling for loblolly pine has been extensively studied. Taper equations have been obtaining using different functional forms ranging from simple linear models to highly non-linear systems of equations. The published taper functions can be classified into the following groups: single equations, segmented taper models, and variable-form taper models. Although a wide range of taper model forms exist, most of the empirical taper equations assume the relationship between the diameter at a given height and the independent variables to be parametric. This implies an *a priori* fixed functional form and a finite set of parameters can fully describe the taper form. However, such parametric representation could be restrictive and rarely is a unique functional form useful, instead it can lead to seriously biased estimates and misleading inferences. Our presumptions are that the stem shape varies continuously along the length of a tree and across the size class.

Contrary to parametric approaches, in non-parametric estimation, there aren't statements about the functional form and a very flexible relationship is allowed, imposing only data-driven smoothness criteria. Thereby semiparametric methods, like penalized regression spline estimation, extend the classic parametric estimation with the flexible incorporation of non-linear relationships into the taper regression analysis.

We hypothesize that the relative taper form in loblolly pine changes with the position along the DBH class distribution. If this is true, then no unique fixed functional form produces accurate estimations of volume or upper stem diameters for all trees size. A flexible and nonlinear relationship is required to explain the changing taper across diameter classes sizes. We used a semi-parametric approach called penalized spline regression to prove our hypothesis and propose a new taper equation for loblolly pine.

Taper data from 120 loblolly pine trees were obtained from unthinned stands located in Whitehall Forest at the University of Georgia during the fall season of 2014-17. Trees without severe anomalies in their profile were subjectively chosen in the stands to ensure coverage over the entire DBH range. The sample trees were felled and bucked.

To evaluate the performance of our semiparametric approach we performed a leave-one-out cross-validation methodology to compare our approach against other taper equations from the published literature. Two representative equations of each group: single equations, segmented equations and variable exponent equations were selected. Totally we evaluate six models and fitted them with our available data. Measurements of bias and precision showed that our semiparametric model was consistently the best out of the six competitors tested for estimating diameter outside bark. Then, we presented a procedure to obtain simultaneous confidence intervals for the mean response, and then confidence intervals for total and merchantable volume.

GENERALIZED PREDICTORS OF FOLIAGE BIOMASS FOR TREE SPECIES OF THE UNITED STATES

Garret T. Dettmann[1]*, David W. MacFarlane[1], Phillip J. Radtke[2], Aaron R. Weiskittel[3], David Affleck[4], Krishna Poudel[5], James Westfall[6]
*Corresponding and presenting author
[1]Michigan State University, Department of Forestry, 480 Wilson Rd, East Lansing, MI 48824, USA
[2]Virginia Tech, Forest Resources and Environmental Conservation, 319 Cheatham Hall, Blacksburg, VA 24060 [3]University of Maine, School of Forest Resources, 5755 Nutting Hall, Orono, ME 04469-5755
[4]College of Forestry and Conservation, The University of Montana, 32 Campus Drive, Missoula, MT 59812
[5]Department of Forest Engineering, Resources and Management, Oregon State University, Corvallis, OR 97333
[6]USDA Forest Service, Northern Research Station, 11 Campus Blvd., Suite 200, Newtown Square, PA 19073

Tree foliage biomass is an important, but highly variable component of forest ecosystems. Estimating the foliage mass of standing trees is challenging, because it varies with species, age, disturbance, climate, geography, and stand dynamics. A common method is to predict leaf mass from stem diameter at breast height (DBH) using species-specific models. Such models generally assume a low degree of intra-specific variation and ignore the many other factors (beyond DBH) that cause foliage biomass to vary; they also provide no way to predict foliage mass for species with little or no data. The latter is a very large problem for national scale forest inventories that cover a diverse array of tree species, such the Forest Inventory and Analysis (FIA) program of the United States (US). To address this issue, Dettman and MacFarlane (in review) developed a single 'trans-species' model for foliage biomass estimation that could be applied to a wide range of species in Michigan, USA. They identified key variables relating to tree size, life-history traits, and competitive environment that accurately predicted foliage mass for the diverse tree population sampled, which could possibly be applied to species for which no leaf mass data exists. Leveraging this latter modeling approach, we explored the potential for a generalized 'trans-species' tree foliage mass model that could be applied by FIA at the US national scale, employing additional datasets from a nationwide destructive sampling effort by FIA to cover major tree species in the US.

INCORPORATING GENETICS INTO A SLASH PINE GROWTH AND YIELD MODEL

Priscila Aiko Someda Dias[1]; Salvador A. Gezan[1]
[1] University of Florida, School of Forest Resource and Conservation, College of Agricultural and Life Science. Gaineville, FL, USA. priscilasomeda@ufl.edu, sgezan@ufl.edu

Slash pine (*Pinus elliottii* Engelm.) has an important economical, social and ecological role in the southeast United States. Its increased use of genetic improved material, together with more intensive silvicultural practices in slash pine stands, expands the demand for suitable growth and yield (G&Y) models to help predict conditions about forests and to plan future silvicultural managements. With the aim of bridging the gap between slash pine growth and yield model, and their need to consider silviculture and genetic specific modules, this study tests and recalibrates an existing slash pine model that considers silviculture information and updates the G&Y model to incorporate genetic specific modules of mortality and site index. The recalibrated model was modified to consider as input the genetic entry, by developing flexible genetic specific modules, such as dominant-height or mortality. The different genetic entries and correlate these simulations against breeding values, generating a system including silvicultural and genetics. This system of equations is converted into an application to predict and project G&Y of stands, with or without silviculture information, accepting tree measurements or stand-level data input. Our tool also includes an option to perform simulations by projections starting at the desired age from known initial stand conditions. The open source code is based on R programming with a flexible modular structure and an interactive web application build using shiny, which appeals to many potential users. This tool constitutes a framework that can be extensively modified to easily construct G&Y models for other tree species with an array of dynamic web interfaces.

Keywords: R library, shiny, system of equations, simulation.

BRANCH SAMPLING OF TREE STRUCTURAL MODELS FITTED FROM LIDAR POINT CLOUDS, A CASE STUDY OF AN EXPERIMENTAL DOUGLAS-FIR FOREST

Rong Fang and Bogdan Strimbu
Department of Forest Engineering, Resources & Management
Oregon State University, Corvallis, Oregon, 97330, USA

Unbiased branch sampling is required for developing comprehensive tree allometric models. Field branch sampling is cumbersome as it is limit for the branches located at the middle to upper sections of the stem. Since branch system is massive even for an individual tree, the census of branches is almost impossible. Few studies harvested trees to test the sampling efficiency of estimating branch parameters. However, tree harvesting is limited to small to medium sized trees located at easily accessible areas. Lidar point clouds enable the measurements of canopy metrics without harvesting trees. Furthermore, most lidar-based canopy applications describe the canopy profiles. In the last decade, the focus has been shifted from aggregated metrics to individual tree. However, few studies have been carried out aiming at modeling individual tree branching system of natural forests. Randomized branch sampling (RBS) is an unbiased way of sampling path systems. When it is used for tree branch sampling, branch enumeration is not required for calculating sampling probability. Previous studies have adapted several RBS strategies of excurrent crown forms. However, its efficiency has not been tested on conifer trees with large dbh. Therefore, the objective of this study is to measure Douglas fir branch attributes with lidar point clouds in a computer-aid system and compare the efficiency of different RBS strategies in big Douglas firs in natural stands. We measured the attributes describing the branches of 10 Douglas firs by using branch skeletons and pipe models fitted with lidar point clouds. For the best accuracy, only the woody parts of the stems and first- order branches are identified and modeled with pipe forms. The dbh of the sample trees is averaged on 63 cm, ranging from 51 to 120 cm. Tree height of the sample trees is averaged on 42.5 m, ranging from 38 to 45 m. We used a randomized imputation to fill the missing branch variables, due to the insufficient terrestrial lidar point clouds at the upper section of the trees. We used five branch aggregation methods proposed by a previous study to group the branches as the selection nodes of RBS. We generated 1000 realizations of branch samples for each branch aggregation strategy. Our results indicate that lidar point cloud is applicable in developing branching models and the efficiency of RBS strategies applied to Douglas firs are related to the branch aggregations.

MODEL CHOICE AND POSTERIOR PREDICTIVE DISTRIBUTIONS

Edwin J. Green[1] and Chad Babcock[2]
[1] Rutgers University, New Brunswick, NJ
[2] Michigan State University, East Lansing, MI

We explore various Bayesian methods for model selection, especially the use of posterior predictive distributions. The latter are under-utilized but are easily obtained and provide a convenient frame of reference for observed data. If the observed data distribution does not look like a sample from a model's posterior predictive distribution, then the model is inadequate. Furthermore, posterior predictive distributions provide a quick means of checking modeling assumptions, such as: should the dependent variable be $log Y$ or Y? Is conditional normality a reasonable assumption? Is homogeneous variance a reasonable assumption? As far as possible we use the **R** data set trees in our example, since anyone with **R** has access to it.

COMPARISON OF TWO PROJECTION STRATEGIES IN SIMULATED LOBLOLLY PINE STANDS UNDER VARIOUS LEVELS OF SPATIAL HETEROGENEITY

P. Corey Green

The estimation of current stand conditions and monetary value is often required for making informed management decisions; however, costs and logistical constraints often make annual inventory impractical. Projection of plots aggregated within stands, denoted as stand-level projection, and aggregation of individual projected plots within stands, denoted as plot-level projection, are two strategies to predict future stand parameters. Using simulated mapped stands and samples, along with three common whole stand growth models, this study investigated the differences in two inventory projection strategies under various levels of spatial heterogeneity and points in stand development.

The results indicated that, apart from total volume, the two projection methods produced similar results for dominant height, stand basal area, and number of trees per hectare under low to moderate levels of spatial heterogeneity. At higher levels of spatial heterogeneity, the differences of predicted total volume in the two projection methods increased regardless of the sample unit size. The growth and yield model used made a significant impact on the differences, while simulated thinning did not alter the patterns of observed differences compared with unthinned stands. When implementing projections at the whole-stand level, a careful evaluation of spatial heterogeneity and the choice of growth and yield model is recommended.

METHODS FOR DEVELOPING NEW LONGLEAF PINE INDIVIDUAL TREE TAPER, GREEN WEIGHT, AND VOLUME EQUATIONS

Thomas B. Harris[1], Bronson P. Bullock[1], Cristian R. Montes[1]
[1]Warnell School of Forestry and Natural Resources, Univ. of GA, Athens, GA

Longleaf pine is an alternative where low site productivity precludes the establishment of loblolly or slash pine or when the landowner objectives favor wildlife habitat on forestland in the SE US. However, it is hypothesized that existing models for longleaf pine do not adequately differentiate between the different stand characteristics where longleaf pine is currently planted in Georgia and elsewhere. Models are needed for longleaf pine plantations that have been established on old-field and cut-over sites. The objective of this research is to estimate new equations to predict individual tree taper, green weight, and volume for longleaf pine in Georgia and the SE US.

This research will emphasize individual tree data collected using destructive sampling. Selection of sample sites will be restricted to areas of longleaf pine planted on old-field and cut-over land that have not been thinned. Individual tree data will be collected from felled longleaf pine trees; destructive sampling will provide measurements of inside and outside bark diameter and weight along the length of each stem. The data compiled from all the felled stems will be used to generate individual tree models specific to these sites. The new models will be tested against other available models. These new equations will be useful for many recently established longleaf pine stands in GA and the SE US.

APPLICATION OF MIXTURE DISTRIBUTIONS TO DESCRIBING BIOMASS DISTRIBUTION USING TLS DATA

John Kershaw and Ting-Ru Yang
Faculty of Forestry and Environmental Management

Terrestrial LiDAR scanning provides a rich point cloud of data. Various approaches have been utilized to estimate and/or extract area-based and individual tree attributes. The potential for using TLS data to describe components of stand structure that have been difficult or impossible to describe from field data is largely unexplored. In this study, we use Weibull mixture distributions to estimate vertical biomass distributions and compare the total estimates to estimates obtained from allometric equations.

A MODEL TO ESTIMATE LEAF AREA INDEX IN LOBLOLLY PINE PLANTATIONS

Stephen M. Kinane[1] and Cristian R. Montes[2,3]
[1]Ph.D. student, Warnell School of Forestry and Natural Resources, University of Georgia
[2]Warnell School of Forestry and Natural Resources, University of Georgia
[3]Co-Director, Plantation Management Research Cooperative (PMRC), University of Georgia

Modern forest biometrics applications rely on information derived from remote sensing to cost-effectively measure forest and stand features. Peak leaf area index (LAI) is an important indicator of a stand's productivity as it measures the stand's ability to exchange material and energy with its environment and has been shown to maintain a positive correlation with biomass production. When looking at managed loblolly pine stands, LAI is commonly estimated from passive satellite sensors using a simple ratio between the red and far red bands or a more sophisticated normalized difference vegetation index. The common problem associated with using these indices results from issues in saturation, which lead to an underestimation of the peak LAI at higher values.

To overcome these limitations, additional vegetation indices were evaluated with atmospherically corrected satellite images to improve model behavior. The Kalman Filter, an algorithm that uses previous states of a system to predict the future state, was used to estimate the process and measurement errors associated with the satellite imagery. The objective of this study is to develop an unbiased model that estimates LAI for loblolly pine plantations in the southeastern United States from Landsat 5 and 7 derived vegetation indices coupled with below canopy Li-Cor 2000 measurements.

A new model to predict LAI was calibrated using normalized difference moisture index (NDMI) and the error in-variable method SIMEX (simulation extrapolation) to account for measurement errors. The new model was able to provide unbiased estimates of LAI using freely available Landsat 5 and 7 imagery to drive management decisions regarding loblolly pine plantations.

EXPLORING BRANCH, STEM AND TREE WOOD DENSITY RELATIONSHIPS FOR TEMPERATE TREE SPECIES IN THE EASTERN USA

David W. MacFarlane[1], Phil Radtke[2] and David Walker[2]
[1]Michigan State University, Department of Forestry, 480 Wilson Rd, East Lansing, MI 48824, USA
[2]Virginia Tech, Forest Resources and Environmental Conservation, 319 Cheatham Hall, Blacksburg, VA 24060, USA

Wood density is strongly related to key aspects of a trees physiological performance (e.g., hydraulic conductance) and mechanical structure (e.g., resistance to stress) and can be used as a proxy for tree form and function. Most studies focus on the density of the wood in the stem or trunk, usually measured from a single location at breast height (1.3 m above the ground). The overwhelming focus on the stem has likely arisen from the need to understand wood properties for commercial purposes, because the most valuable wood is found in the lower trunk of the tree. Much less attention has been paid to the density of branches, though they perform vital functions as part of the tree's vascular network and play a complex, but less clearly understood role in mechanical stability. Since tree density is a composite of the density of all parts of a tree, stem density may be a biased predictor of aboveground tree mass, unless branch density is proportional to it. Nonetheless, few studies of branch-stem density relationships have been conducted; mostly in tropical forests, where the prospect of estimating stem density from branch clippings, for use in general allometric equations, has been an important motivator. Here, we compiled data from thousands of trees from temperate forests in eastern North America, covering a wide range of tree sizes and species, over a large geographic area, to try to better understand covariation in branch and stem wood density and relate it back to tree form, function and phylogeny.

ANNUALIZING FIA – COMBINING FIA PLOTS, SATELLITE IMAGERY, FVS TO CREATE SINGLE YEAR ESTIMATES OF FOREST INVENTORY

James McCarter

This project combines satellite imagery used for disturbance and management detection to update FIA inventory plots using the Forest Vegetation Simulator (FVS). A disturbance (fire, insect, and management) map was developed using true FIA plot locations and Landfire. This disturbance map was used to preform FVS simulations for those disturbances for the plots affected. All other FIA plots a grown under a no management scenario. Each plot is grown from inventory year into the future. This allows for the individual plots measured in different years to be assembled into a single year tree list for analysis. The annualized results are compared to the weighted average method currently used by FIA.

A DYNAMIC STATE-SPACE SPECIFIC GRAVITY MODEL FOR LOBLOLLY PINE USING DATA ASSIMILATION TO IMPROVE WOOD PROPERTY ESTIMATES WITH EXPLICIT UNCERTAINTY

C. Montes[1], J. Dahlen[1], D. Auty[2], and T.L. Eberhardt[3]
[1] Warnell School of Forestry and Natural Resources, University of Georgia, Athens GA 30602; crmontes@uga.edu, jdahlen@uga.edu
[2] School of Forestry, Northern Arizona University, Flagstaff AZ 86011; David.Auty@nau.
[3] Forest Products Laboratory, US Forest Service, Madison WI 53726; teberhardt@fs.fed.us

Intensively managed loblolly pine (*Pinus taeda*) yields merchantable volumes at younger rotation ages, which allows companies managing the species to reduce the harvesting age to increase stand profit and reduce risk. As a consequence, this reduction in rotation age results in a progressive increase in the proportion of corewood and thus a reduction in wood specific gravity (SG), mainly due to a lower proportion of latewood. To quantify this effect, we executed a study to model ring-level properties (width and SG). Ninety-three trees from 5 stands between 24 and 33 years of age were harvested and disks cut between log ends, which in turn were cut into 490 pith-to-bark radial strips. Within-tree values of SG and ring width were measured by X-ray densitometry. Overall, the measured properties were highly variable, particularly in rings close to the pith. Rather than using traditional mixed-effects models, a new modelling framework was developed to predict SG. Data assimilation using an extended Kalman filter was used to separate measurement from process noise, which allowed us to explicitly quantify the uncertainty related to the process.

The Kalman filter approach resulted in a much higher log likelihood values (-2,302) compared to a mixed-effects model (-3,124) (Dahlen et al., 2018). Additionally, the model is dynamic, which allows for silvicultural treatments effects, such as thinning and fertilization, to be easily incorporated into the model. The resulting model was used to predict within-stem variation of annual ring width and specific gravity over time and represents a step forward in integrating wood quality models into growth and yield systems for loblolly pine.

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ASSESSING SMALL-STEM DENSITY IN NORTHERN HARDWOOD SELECTION SYSTEM STANDS

Lindsay Nystrom, Ralph Nyland, Diane Kiernan, Eddie Bevilacqua

Data from three uneven-aged northern hardwood stands in New York were analyzed to assess changes of small stems within the 2.54- to 5.08-cm diameter class during the first cutting cycle under single-tree selection system. Findings show that the amount of understory American beech (*Fagus grandifolia* Ehrh.) on a regeneration plot, quantified using a Species Index Value (SIV), affects the abundance of other species. Results reveal the future stocking of these small trees for: 1. all species (including American beech) as related to time since cutting and residual basal area; or 2. only non-beech species based on a Species Importance Value (SIV), time since cutting, and residual basal area. Findings indicate that small-stem stem density will increase from post-cut levels to a peak at 8-12 yrs after selection system cutting, and then decrease. The higher the residual basal area, the sooner numbers of small trees reach a peak level, and the fewer present of that threshold size. Findings confirm that no or only minimal numbers of small non-beech trees develop on plots with high levels of understory American beech (SIV $\geq$ 0.5).

POSTTHINNING RESPONSE OF WHITE SPRUCE PLANTATIONS AFFECTED BY EASTERN SPRUCE BUDWORM IN MINNESOTA

Stephanie Patton, Matthew Russell, Marcella Windmuller-Campione and Christopher Edgar
University of Minnesota Department of Forest Resources

White spruce (*Picea glauca* [Moench] Voss) plantations have historically been an important source of high quality forest products in the Great Lakes Region. Thinning in spruce plantations is a common, cost-effective silvicultural practice for reducing intraspecific competition and promoting resiliency to forest health threats such as eastern spruce budworm (*Choristoneura fumiferana* Clemens). Spruce budworm is a native forest pest of the eastern United States which typically targets balsam fir (*Abies balsamea*) and spruce (*Picea spp*.) trees. Larvae feed on the foliage of trees, which reduces growth and potentially leads to mortality during a budworm outbreak. This research addressed the response of white spruce 18 years after initial thinning with spruce budworm activity relatively high at the onset of the study. Stands were established between 44 and 64 years ago and thinned two decades ago. Some stands received a second thinning in recent years and spruce budworm activity fluctuated throughout the study. We used nonlinear mixed effects models to estimate annual diameter growth using common tree and stand metrics such as diameter, basal area, and uncompacted crown ratio. We also investigated growth model improvement by including multiple thinnings and spruce budworm defoliation. Results of this study highlight how thinning in combination with insect disturbance affects stand productivity and mortality in white spruce plantations of northern Minnesota.

A MAXIMUM ENTROPY APPROACH TO DEFINING GEOGRAPHIC BOUNDS ON GROWTH AND YIELD MODEL USAGE

W. Spencer Peay[a], Bronson P. Bullock[bc], Cristian R. Montes[bc]
[a] M.S. Student, Warnell School of Forestry and Natural Resources, University of Georgia
[b] Warnell School of Forestry and Natural Resources, University of Georgia
[c] Co-Director, Plantation Management Research Cooperative (PMRC), University of Georgia

Growth and yield models are immensely important in forest management today. These models allow managers to predict and project future characteristics of forest stands and subsequently make informed management decisions based on each stand's growth trajectory. Growth and yield models are typically developed for use in broad physiographic regions, however these regions may be too broad given the general locality where the data was collected to fit the model.

Maximum entropy modeling can be used to determine the geographic areas where it is appropriate to use a growth and yield model. Maximum entropy is a machine learning technique that has commonly been applied in species distribution modeling. This technique makes use of presence-only data (geographic coordinates) and the environmental envelope (including climatic variables such as average annual precipitation, temperature, etc.) at these locations to determine the probability of occurrence of a species across a user-defined landscape. This is done by comparing the environmental envelope and soil characteristics recorded at each presence location with the environmental envelope and soil characteristics across the entire user-defined landscape.

This presentation uses a maximum entropy approach in an attempt to determine suitable areas for the use of a PMRC growth and yield model across the lower coastal plain of Florida, Georgia, and South Carolina based on the geographic locations where data was collected to fit the model and the environmental envelope and soil characteristics at each of the data collection locations.
This research should allow for more targeted growth and yield model usage based on locational and environmental characteristics.

PREDICTIVE MAPPING OF STAND CHARACTERISTICS USING NON-PARAMETRIC APPROACH

Bharat Pokharel[1]; Dennis M. Jacobs[2]; Man Kumari Giri[1]; James T. Vogt[3]; and Todd A. Schroeder[2]
[1]Department of Agricultural and Environmental Sciences, Tennessee State University, 3500 John A. Merritt Blvd. Nashville TN 37209
[2]USDA Forest Service, Southern Research Station, Forest Inventory and Analysis, 4700 Old Kingston Pike, Knoxville TN 37919
[3]USDA Forest Service, Southern Research Station, Insects, Diseases and Invasive Plants of Southern Forests, 320 Green Street Athens, GA 30602

Stand level forest attributes such as number of trees, biomass, volume and basal area per acre have become increasingly important especially for a large scale strategic forest management planning. For example, mapping spatial distribution of woody biomass from forest or extent of trees per acre loss from fire or damage from insects and diseases are important estimates that are critical for strategic forest management planning. Traditional field based timber cruising and forest inventory are costly and time consuming; therefore, we explored an opportunity to utilize remote sensing data for mapping forest attributes both temporal and spatial scales that are relevant for large scale forest management planning. We hypothesized that variables derived from remote sensing data could be important predictors while estimating stand level attributes from pixel to landscape level. Landsat 5 TM satellite imagery and their derivatives, national land cover dataset, and digital elevation model were paired with Forest Inventory and Analysis (FIA) data from 2007 to 2011. First we evaluated the use of non-parametric approach – random forests to build predictive model for aboveground total biomass and trees per acre (TPA) for five USGS zones that cover the entire state of Tennessee, USA. The models explained over 44 percent of variability with RMSE of 17.6 tons per acre for biomass and over 52 percent of variability with RMSE of less than 90 trees per acre for TPA estimates. Among many other variables canopy cover was the most important predictor variable for both aboveground biomass and TPA prediction. We further replicated this approach of map modeling in R Statistical computing environment to generate continuous gridded TPA raster map across the United States.

DOES CALIBRATION USING UPPER STEM DIAMETER MEASUREMENT IMPROVE PREDICTIVE ABILITY OF A SEGMENTED POLYNOMIAL TAPER EQUATION IN PRESENCE OF MEASUREMENT ERROR?

Krishna P. Poudel[1] and Temesgen Hailemariam[2]
[1]Mississippi State University, Department of Forestry, PO Box 9681, Mississippi State, MS 39762
[2]Oregon State University, Department of Forest Engineering, Resources, and Management, Corvallis, OR 97330

Volume and taper equations are essential to estimate total and merchantable stem volume. Taper functions are advantageous to merchantable volume equations because they provide estimates of diameter at specified heights along the stem, enabling the estimation of total and merchantable stem volume, volume of individual logs, and a height at a given diameter. With the increasing availability of laser devices, standing tree upper stem diameter measurements have been used to calibrate the taper equations. However, the error in upper stem diameter measurement and its effect on taper prediction and subsequently volume prediction is rarely tested. Using the destructively sampled dataset, we tested the statistical significance of measurement error and its effects on calibration of a segmented taper equation. Paired two one-sided test (TOST) and t-test were used to determine the equivalence of true diameter and diameter obtained using a laser device. Other objectives of this study were to test whether upper-stem diameter, when affected by measurement error, actually improve taper and taper-based volume estimates and to determine the acceptable level of measurement error without hampering the equivalence of calibrated volume estimates. Equivalence of volume estimates obtained from calibrated taper equation to the actual volume were tested. Preliminary results indicate that calibration at DBH and 16’ performed poorly and calibration at breast height and rh=0.5 performed best. Hence, testing the effect of measurement error at that point is more useful.

ASSESSING SHIFTS IN VERTICAL DISTRIBUTION OF STEM CROSS-SECTIONAL INCREMENT IN RESPONSE TO NITROGEN FERTILIZATION OF DOUGLAS-FIR USING A NONLINEAR MIXED-EFFECTS MODELING APPROACH

Jacob D. Putney[1] and Douglas A. Maguire[1]
[1]Department of Forest Engineering, Resources and Management,
College of Forestry, Oregon State University

Nitrogen fertilizer is commonly applied as a silvicultural tool in intensively managed Douglas-fir [*Pseudotsuga menziesii (*Mirb.) Franco] plantations. To maximize average growth response and associated return on investment, prioritization of stands for fertilization must be based on attributes indicating likely magnitude of each stand's response. Field trials were established to better understand Douglas-fir growth response to nitrogen fertilization, in part by empirically quantifying the direct and indirect effects on stem growth. Twenty-three units were established in the northern Coast Range of western Oregon in a randomized complete block design (RCBD), with units identified as blocks. Each unit was divided into two parts, with random assignment of the fertilizer treatment and the unfertilized control. Fertilizer was applied aerially at a rate of 224 kg N/ha as urea during the 2009-2010 dormant season. Seven-years following fertilization, forty trees (twenty per treatment) were destructively sampled and annual cross-sectional area increment was measured for each year following fertilization and at numerous heights on each tree. The objective was to model vertical shifts in stem cross-sectional increment induced by fertilization. A variable-exponent, mixed-effects nonlinear model was fitted to the data to account for the hierarchical sampling, but the variance-covariance structure was also modeled directly to further eliminate autocorrelation, and to thereby provide minimum-variance unbiased estimators (MVUE) and accurate p-values for making statistical inferences. Results from this study will be incorporated into growth models for intensively managed Douglas-fir plantations to provide more accurate estimates of scaling diameters, board-foot growth responses, and value enhancement. Stem responses to nitrogen fertilization at an annual resolution, along with accompanying foliage analysis, will also help build the foundation of more mechanistic growth models to improve prioritization of candidate sites for fertilization.

SPATIAL FINANCIAL ANALYSIS OF POTENTIAL FOREST PLANTATIONS IN ANTIOQUIA, COLOMBIA

Laura I. Ramirez[1]; Sergio A. Orrego[2]; Héctor I. Restrepo[3]; Cristian R. Montes[4]; Bronson P. Bullock[5]

[1]M.S. Student in Forest Resources, National University of Colombia, Medellín
[2]Associate Professor, Department of Forest Science, National University of Colombia, Medellin
[3]Ph.D. candidate, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA
[4]Associate Professor, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA
[5]Professor, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA

Timberland investment opportunities in Colombia are expected to increase as a result of the peace agreement recently signed between Colombian government and the Revolutionary Armed Forces of Colombia. Rigorous financial analyses are required to evaluate the profitability of timber production and timberland investment in Colombia.The bare land value (BLV) of potential forest plantations was calculated for areas previously identified as having high suitability for the establishment of commercial forest plantations in Antioquia, Colombia. The study focused on *Pinus patula* which is the most planted forest species in the region. A Chapman-Richards type model that considers environmental and stand density covariates was used to estimate a forest yield map. A financial analysis was conducted by considering the estimated yield and a cash flow that includes revenues for stumpage sales, and establishment and management costs. The stumpage price was estimated, and further represented in a spatial way, using the residual price approach, which allows for calculating the stumpage price backwards from the mill by subtracting hauling and harvest costs from at-mill-gate timber prices. The results show that the areas with high potential for forest plantations are those with both yield greater than 200 m^3/ha and located less than 20 km from the mills. However, meeting either one of these two criteria is not enough to guarantee profitability for the potential forest plantations. It was also found that under current stumpage prices and production costs some subsidies will be required to guarantee an investment return higher than 6%. The analysis provides valuable information for the evaluation of potential timber production and timberland investments under a scenario of post-conflict scenario, showing promising results for areas that were previously inaccessible. A similar framework can be applied to high-valued forest species to assess for the financial profitability and risk of timberland investments in Colombia and promote rural development.

INTEGRATING SCIENCE AND TECHNOLOGY IN DELIVERY OF THE FOREST INVENTORY AND ANALYSIS PROGRAM

Gregory A. Reams
USDA Forest Service, FIA National Program Leader
1400 Independence Ave., SW, Washington, DC 20250

The Forest Inventory and Analysis (FIA) program of the U.S. Forest Service has been inventorying U.S. forest lands since 1930. The first 70 years of FIA relied on periodic forest inventory methods to estimate status and trends of forest area and associated estimates of number of trees, volume and biomass. Over the past 20 years FIA has completed implementation of an annualized inventory with many enhancements to the overall delivery of science, data, and estimates. These enhancements are presented and how they have led to continuing improvement in the integration of science into delivery of the program to partners, clients and the public.

PREDICTION OF TIMBER PRODUCT CLASS PROPORTIONS FOR LOBLOLLY PINE IN THE SOUTHEASTERN U.S.

Hector I. Restrepo[1], Bronson P. Bullock[2], Nicole Lazar[3], Cristian R. Montes[4]
[1]Ph.D. Student, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA
[2]Professor of Forest Biometrics, Co-Director PMRC, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA
[3]Professor in the Department of Statistics, University of Georgia, Athens, GA
[4]Associate Professor, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA

The ultimate goal of forest modeling, from the timber management perspective, is to obtain an accurate estimation of the merchantable volume as an input for financial return calculations. Finding the proportions of timber in each of the commercial pine product classes (i.e. sawtimber, chip-n-saw, and pulpwood) is an important part in estimating merchantable volume. Since timber products have different market prices, merchantable volume must be adjusted based on product classes. Stem quality may differ as a function of forest growth factors, i.e. age, environmental conditions, genetics, planting density and management regimes. The objective of this research is to predict the timber product class proportions over time as a function of forest growth factors and early field measurements of stem quality at age six. Data from a designed research trial evaluating the impacts of density and management over ages 6-21 (years) will be used. Proportions of timber product classes can be used to adjust the timber prices. Those proportions can be used to obtain a blended price of timber, resulting in a simplification of the financial calculations. Furthermore, timber product class proportions can be used to optimize financial returns by performing marginal analysis of applying certain management regimes.

USING BIOPHYSICAL VARIABLES AND STAND DENSITY TO ESTIMATE GROWTH AND YIELD OF *PINUS PATULA*: A CASE STUDY IN ANTIOQUIA, COLOMBIA

Héctor I. Restrepo[1]; Sergio A. Orrego[2]; Juan C. Salazar[3]; Bronson P. Bullock[4]; Cristian R. Montes[5]

[1] Ph.D. candidate, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA
[2] Associate Professor, Department of Forest Science, National University of Colombia, Medellin
[3] Associate Professor, Statistics Department, National University of Colombia, Medellin
[4] Professor, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA
[5] Associate Professor, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA

Timberland investment opportunities in Colombia are expected to increase as a result of the peace agreement recently signed between Colombian government and the Revolutionary Armed Forces of Colombia. This new scenario facilitates the establishment of commercial forest plantations in rural areas, challenging existing biometric tools to include site factors to allow further extrapolation of current sample plots into these unplanted areas. To meet this goal, the yield from 1119 temporary plots of unthinned *Pinus patula* established in the Antioquia region was combined with their biophysical attributes to define a spatial model. The importance of each co-variable was tested for their statistical contribution using a likelihood ratio test. The model was validated using an independent set of 133 observations. Our results suggest soil *pH*, terrain slope, and the ratio of mean annual temperature to mean annual precipitation as the main variables determining yield at any given age and stand density. The asymptote of the estimated yield model can be expressed as a function of soil *pH*, terrain slope and stand density. On sites where *pH* was in the range 5-6, the model asymptote was reduced to a half compared to sites where *pH* was in the range 4-5. Moreover, each additional degree in terrain slope resulted in an increase of 2.2 m^3 ha^{-1} on the expected asympthotic value. The marginal increase of stand density resulted in an increase of 0.18 m^3 ha^{-1} in the model's asymptote. The parameter representing the growth rate in the estimated model can be expressed as a function of an intercept, equal to -0.12, and the ratio of mean annual temperature to mean annual precipitation. The model was further presented as a map identifying suitable geographical areas to establish *Pinus patula* plantations in Antioquia, Colombia. The estimated yield model provides a reliable baseline for timber production and valuable information to evaluate timberland investments in Colombia.

TRUTH OR CONSEQUENCES: EVALUATION OF THE RE-MEASUREMENT PERIOD ASSUMPTION

Francis A. Roesch
Southern Research Station, USDA Forest Service, 200 WT Weaver Blvd., Asheville, NC 28804, USA;
froesch@fs.fed.us, Tel.: +01-828-424-8169

The Re-measurement Period (or REMPER) Assumption is usually made without acknowledgement (or recognition) in continuous forest inventories. This often tacit assumption is being made whenever growth or change estimates are made from observations based on the aggregation of interval observations of multiple lengths. For instance, this is the case for most of the USDA's Forest Inventory and Analysis (FIA) Program's published growth or change estimates. In these estimates, a 1-year equivalent is calculated (say per plot), regardless of the temporal interval length actually observed, by dividing the growth or change by the interval length. Growth estimates are then calculated based on an aggregation of these 1-year equivalents. In this paper I give a brief explanation of the theoretical difficulties associated with this practice and describe an ongoing investigation into the practical implications of those difficulties with respect to a standard set of estimands. This standard set of estimands was defined in Roesch [2018] to address a varying set of potential user expectations for estimates based on "average annual growth." Various estimators are evaluated in a simulation for their effectiveness in the presence of several simple distributions of measurement intervals, such as those that might arise from a regularly re-measured plot list under various levels of control on the order of plot observations.

Keywords: NFI; simulation; average annual growth.

Citation:

Roesch, Francis. 2018. Composite estimators for growth derived from repeated plot measurements of positively-asymmetric interval lengths. *Forests* 2018, *9*(7), 427;

EVALUATING PONDEROSA PINE GROWTH AND YIELD EQUATIONS FOR APPLICATION IN MINNESOTA

Matthew B. Russell[1], Brian D. Anderson[1], Marcella A. Windmuller-Campione[1], Andrew J. David[1]
[1] University of Minnesota, Department of Forest Resources

As early as 1932, forest managers in Minnesota have been interested in establishing ponderosa pine (*Pinus ponderosa* var. ponderosa), a western conifer species. Although Minnesota is outside the native range of ponderosa pine and early trials of the survival and growth of the species in the state have been mixed, a renewed interest exists in the species because it is thought to do well in Minnesota's future climate. This work will highlight the challenges and opportunities in adapting growth and yield equations for a western species and applying them in Minnesota's growing conditions. Survival and growth data were examined for ponderosa pine planted at five provenance tests established across Minnesota from 1968-1970. Three of those sites were revisited in 2018 with the collection of additional height, diameter, and increment data for four provenances that showed the best performance in early trials. Results indicate that equations from the Eastern Montana and Central Rockies variants of the Forest Vegetation Simulator show overpredictions of Minnesota ponderosa pine tree height (mean bias of 9 m for trees approximately 50 years old). Preliminary analysis of increment data from tree cores also indicates challenges with applying western models to represent ponderosa pine diameter increment in Minnesota. Although limited data exists for the species in Minnesota, this work highlights the process of adapting growth and yield equations for use in novel geographic areas.cl

FOREST MEASUREMENTS: *OUTSIDE THE LINES*

James L. Smith[1] and Stephen P. Prisley[2]
[1]LANDFIRE Program Lead, The Nature Conservancy, 1822 Swiss Oaks Street, St. Johns, FL 32259
Jim_smith@tnc.org
[2]Principal Research Scientist, NCASI, 541 Washington Ave SW, Roanoke, VA 24016
sprisley@nscasi.org

When we think of forest measurements, the first applications that likely come to mind are forest products and forest planning. What is the maximum MAI under this management scenario? How many board-feet of sawtimber will be available in this stand at age 30? How many sample points do I need to reach my desired level of precision in this inventory? The future may be different, however, because the successes of decades of productive research in forest measurements (sampling, statistical and simulation modeling, operations research, etc.) have *bled* into other fields, such as wildland fire, climate change, threatened species/habitat analysis, mapping, ecological assessment, etc. Undoubtedly, at minimum these types of applications need a more “quantitative perspective”. This presentation will briefly describe some of these key “outside the lines” applications of forest measurements and aims to encourage those not doing so to apply some of their skills, energy and experience to help those focusing on potentially new areas of application.

A SCALAR MEASURE TRACING TREE SPECIES COMPOSITION IN SPACE OR TIME

Strimbu BM[1], Paun M[2], Montes C[3], Popescu SC[4]
[1]College of Forestry, Oregon State University, Corvallis OR, USA
[2]Faculty of Business and Administration, University of Bucharest, Bucharest, Romania
[3]Warnell School of Forestry and Natural Resources, University of Georgia, Athens GA, USA
[4]Department of Ecosystem Science and Management, Texas A&M University, College Station, TX, USA

The tree species composition of a forest ecosystem is commonly represented with weights that measure the importance of one species with respect to the other species. Inclusion of weight in practical applications is difficult because of the inherent multidimensional perspective on composition. Scalar indices overcome the multidimensional challenges, and, consequently, are commonly present in complex ecosystem modeling. However, scalar indices face two major issues, namely non-uniqueness and non-measurability, which limit their ability to generalize. The objective of this study is to identify the conditions for developing a univariate true measure of composition from weights. We argue that six conditions define a scalar measure of species mixture: (1) usefulness, (2) all species have equal importance, (3) all individuals have the same importance, (4) the measurements expressing importance of an individual are consistent and appropriate, (5) the function measuring composition is invertible, and (6) the function is a true-measure. We support our argument by formally proving all the conditions. To illustrate the applicability of the scalar measure we develop a rectilinear-based measure, and apply it in yield modeling and assessment of ecosystem dynamics.

MEASURES OF GOODNESS OF FIT FOR MORTALITY MODELS

Mike Strub
inspiration by Quang Cao

Measures of goodness of fit for discrete data appropriate to mortality modeling are demonstrated with data and models from Cao (2017). Both likelihood based measures and the newer Coefficient of Discrimination by Tjur (2009) are examined. Tree and plot level measures are compared. Differences between discrete and continuous measures of goodness of fit are also illustrated.

References:

Quang V. Cao; Evaluation of Methods for Modeling Individual Tree Survival, Forest Science, Volume 63: 356–361.

Tjur, T. (2009) “Coefficients of determination in logistic regression models—A new proposal: The coefficient of discrimination.” The American Statistician 63: 366-372.

SCIENCE SUPPORTING CORK OAK STANDS MANAGEMENT: A STAKEHOLDER'S DRIVEN DEVELOPMENT OF FOREST MANAGEMENT SUPPORT TOOLS

Margarida Tomé[1], Joana A Paulo[1], João H N Palma[1], Sonia P Faias[1]
[1] Centro de Estudos Florestais, Universidade de Lisboa, Tapada da Ajuda 1349-017 Lisboa, Portugal

Most of cork oak stands have historically been managed as agroforestry systems, combining trees with annual cultures such as wheat, that have been gradually transformed into silvopastoral systems that combine the trees with pastures and grazing under the trees. However, several management systems can be found, from stands managed with the objective to optimize cork productions to stands for which the multifunctionality is the management objective. Landowners are quite dynamic, always trying to adapt management to new market opportunities and changing edaphoclimatic conditions. Cork oak management encompasses three main decisions: tree density (evaluated by crown cover), how often cork must be extracted (cork debarking rotation) and stand regeneration method (silvicultural system). The first decision implies the selection of the type of system, from a sparse stand compatible with agriculture, pasture or game, to a denser forest that aims at producing cork as a main product. The decisions are not straightforward, and, in a changing world, management must be adaptive, it is difficult to provide "fixed" silvicultural guidelines. Instead, adaptive management based on the monitoring and revision of the objectives, combined with the use of decision support tools to help landowners to analyse the best way to change management to face new frontiers (climate change, new markets, etc) and/or owner decision must be used. Such tools can be used for long term optimization of the system (strategic planning) to short term adaptation to optimise decisions at stand level through on-going conditions.
The objective of this presentation is to analyse the importance of short term refining of cork oak stands management versus using an a priori decision about the management approach based on long term optimisation of initial landowners' objectives. The research used several stands, representing different edaphoclimatic conditions and stand structures, as case studies. Initial landowners' objectives and present cork price structure are used to propose an optimized management approach using net present value as the main criteria but providing also information on other indicators (e.g. carbon stock). Alternative scenarios for cork price structure are used to refine management with a periodicity around 9 years (depending on the case) and the impact of this short term refining evaluated. Cork oak stand simulations are based on the SUBER model. The results show that the landowner has a clear advantage in using and adaptive management concept based on short term decision support tools. Cork oak landowners must use silvicultural guidelines selected with a long term analysis combined with the use of flexible tools that help them to adapt management to on-going conditions leading to an optimisation of benefits.

MODELING THE INFLUENCE OF CAMBIAL AGE, RADIAL GROWTH AND CLIMATE ON WOOD DENSITY IN *PINUS RADIATA* D. DON GROWN IN CHILE

Guillermo Trincado[1] (gtrincad@uach.cl), Alonso Barrios[2] (abarriost@ut.edu.co), Horacio Bown[3] (hbown@uchile.cl)

[1]Facultad de Ciencias Forestales y Recursos Naturales, Universidad Austral de Chile
[2]Facultad de Ingeniería Forestal, Universidad del Tolima, Colombia
[3]Facultad de Ciencias Forestales y de la Conservación de la Naturaleza, Universidad de Chile.

This research focuses on identifying climate variables that explain inter-annual variability of ring wood density (RWD) in radiata pine plantations using a linear mixed-effects modeling approach. The genetic effect was accounted using the same 17 years-old half-sib family growing in six different site conditions. Firstly, we modeled the effect of cambial age (CA) trend on RWD using a restricted cubic spline function. Then, ring width (RW) and climatic variables (monthly rainfall and temperature values) were included as fixed-effects. Between-tree and inter-annual variability was also accounted for by including tree and year random-effects, respectively. Significant site differences were found for RW and RWD, where within-tree variation across sites accounted for 99% and 80.9% of total variation, respectively. On the contrary, between-site variation accounted only for 1.0% and 6.1% of total variation in RW and RWD, respectively. RW showed a significant negative effect on RWD variation across sites. The climatic variables explained significantly between 0.5 to 17% of the between-sites annual variability in RWD and their effects showed to be site specific.

Keywords: radial variation, wood properties, radiata pine, SilviScan.

REGIONAL AND NATIONAL SCALE ABOVEGROUND BIOMASS ESTIMATORS FOR APPLICATIONS INVOLVING MULTIPLE TREE SPECIES

David Walker[1], Phil Radtke[1], Aaron Weiskittel[2], Jereme Frank[2], Dave MacFarlane[3], Dehai Zhao[4], John Coulston[5], Jim Westfall[6]

[1] Virginia Tech, Blacksburg, VA
[2] University of Maine, Orono, ME
[3] Michigan State University, East Lansing, MI
[4] University of Georgia, Athens, GA
[5] USDA Forest Service Southern Research Station, Blacksburg, VA
[6] USDA Forest Service Northern Research Station, Newtown Square, PA

Functional forms for allometric-type models of individual-tree aboveground biomass have been investigated for many species and applications. An emerging need involves the development of broad-scale models based on large regional data sets with wide ranges of tree sizes, many species of interest, and sample sizes that vary considerably among different species. Modified Schumacher-Hall equation forms were evaluated here for their suitability to accommodate relatively complex nonlinear biomass patterns that vary between species and for predictors spanning wide domains. A mixed-effects modeling approach was adopted as a way to borrow information from species with large numbers of observations available for model fitting to inform predictions for species with few observations. Best performing model forms included the Schumacher-Hall model segmented at one-to-three diameter thresholds to account for differing allometric relationships for trees in different size classes. Another promising formulation involved the specification of allometric coefficients in the Schumacher-Hall equation to vary continuously with tree diameter at breast height. While sample sizes as large as 50-200 trees gave best results when fitting models to single species, mixed-effects models showed promise for their ability to accommodate species having as few as 10 trees in a model fitting data set.

UNDERSTANDING DOMINANT HEIGHT PROJECTION ACCURACY OF ANAMORPHIC MODELS

Mingliang Wang, Cristian Montes, Bronson Bullock, Dehai Zhao
Warnell School of Forestry and Natural Resources, the University of Georgia, Athens, GA 30602

We used simple yet fundamental correlation-regression theory to show that anamorphic height models are a special case of linear (with respect to heights) prediction. As such, projection performances of anamorphic models are influenced by correlations between paired heights. We gave an example using repeated measurements taken on 117 plots of PMRC (Plantation Management Research Cooperative at the University of Georgia) loblolly pine site preparation study to examine dominant height projection accuracy achieved by an anamorphic model. Caution is needed with long-term projection!

DOUBLE SAMPLING FOR POST-STRATIFICATION IN FOREST INVENTORY

J.A. Westfall, A.J. Lister, C.T. Scott, T.A. Weber

Many national forest inventories (NFI) use auxiliary data to increase the precision of estimates. Typically, this is accomplished via stratified estimation techniques that rely on assignment of similar sample plot observations into each stratum. While early applications were often based on photo-interpretation of aerial photography, current technology makes using wall-to-wall digital map information more appealing due to automated processing capabilities; however, there is generally a reduction in classification accuracy in comparison to photo-interpretation and a concomitant decrease in the precision of estimates. For most established NFI, post-stratification is usually employed as the plot locations have already been established. In this study, differences in cost and precision were evaluated for post-stratification (PS) using a digital map and double sampling for post-stratification (DSPS) based on photo-interpretation of aerial imagery. It was found that DSPS consistently provided better precision than PS for estimates of total biomass and forestland area with approximately 13 PI points per sample plot; which incurred a cost increase equivalent to 0.5% per ground plot. Increasing the number of PI points per plot resulted in further gains in precision, with cost increases proportional to the PI intensity. To attain specific precision goals, DSPS was generally less costly than increasing the sample size under PS; although the PS design was more cost effective if the PI intensity was too small.

ESTIMATING STAND AGE FROM AIRBORNE LASER SCANNING DATA TO IMPROVE ECOSITE-BASED MODELS OF BLACK SPRUCE WOOD QUALITY IN THE BOREAL FOREST OF ONTARIO

Rebecca Wylie, Jeff Dech, and Murray Woods
Nipissing University, Ontario, Canada

Models that provide reliable estimates of wood quality could enable value chain optimization approaches that consider the market potential of trees prior to harvest. Ecological land classification units (e.g. ecosite) and forest structural metrics derived from Airborne Laser Scanning (ALS) data have been shown to be useful predictors of wood quality. However, much of the variation in wood quality among trees is driven by differences in age, and this variation has been unaccounted for in models because age is poorly represented in most inventory systems. The objectives of this study were (i) to develop a model to predict mean stem age of black spruce-dominated stands across a representative boreal forest landscape, and (ii) refine models of black spruce wood quality by including age as a predictor variable. The study was conducted in the Hearst Forest in northern Ontario, and included age data from 116, 400m^2 plots and wood quality data from 80, 400m2 plots representing a broad range of forest conditions. Plots were linked to a raster (20 x 20m) of ALS derived structural variables covering the entire forest. A stand age model was produced using a non-parametric approach that combined k Nearest Neighbour (k-NN) with random forests as the distance metric. This model performed well, with a root mean squared distance of 15 years and explained 62% of the variation. The wood density model used random forest to produce a model that preformed fairly well predicting 13% of the variation within the sample population and a RMSE of 59.1 kg·m^{-3}. Although the introduction of age into wood quality models did not improve performance, it did bring this type of large-scale wood quality prediction closer to becoming operational by accounting for changes across the entire stem associated with age.

Keywords
Black spruce, forest stand age, Airborne Laser Scanning (ALS), wood quality modelling, boreal forest, predictive modeling, k-nearest neighbor, forest resource inventory, LiDAR, remote sensing, value chain optimization, ecosite, random forests, regression tree

EVALUATION OF TOTAL VOLUME AND STAND TABLES ESTIMATES WITH ALTERNATE MEASUREMENT-TREE-SELECTION METHODS IN POINT SAMPLES

Sheng-I Yang, Harold E. Burkhart

Point sampling (i.e. various-radius plot sampling) has been widely applied in forest inventory. Although measuring plot area is not required in point sampling, it is necessary to take tree measurements for calculating stand variables, which is the most time-consuming and labor-intensive part of the field work. In this study, measurement trees selected by three methods: Big BAF, measuring every tree on every fourth point, and randomly selecting two trees on every point, were used to estimate total volume and stand tables. Point samples were implemented in nine 37.63-ha (93 ac) simulated loblolly pine plantations with varying levels of spatial heterogeneity, and the three measurement-tree selection methods were evaluated.

Results indicated that all three tree-selection methods evaluated in point sampling were adequate for estimating total volume. Total volume estimates were not noticeably improved by including number of trees selected at each sample point as a weight when measurement trees were randomly selected. For all three tree-selection methods, stand tables were overestimated by binned samples, especially for small diameter classes. Recording exact dbh of selected measurement trees in the field for calculation of a precise expansion factor is recommended to improve the reliability of the estimates for stand tables.

MORE DISCUSSION ON THE COMPATIBILITY AND ADDITIVITY OF TREE TAPER, VOLUME AND BIOMASS EQUATIONS

Dehai Zhao[1]*(zhaod@uga.edu), James Westfall[2], John W. Coulston[3], Thomas B. Lynch[4], Bronson P. Bullock[1], Cristian R. Montes[1]

[1] Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA 30602
[2] U.S. Forest Service, Northern Research Station, 11 Campus Blvd., Suite 200, Newtown Square, PA 190733
[3] U.S. Forest Service, Southern Research Station, 1710 Research Center Drive, Blacksburg, VA 24060
[4] Dept. NREM, Oklahoma State University, Stillwater, OK 74078

USDA-FIA is striving to develop/update estimators for compatible volume, biomass, and carbon contents of trees and tree components for top 25 tree species. It is desirable and possible to develop completely compatible taper and volume equation systems that have algebraic compatibility and numeric consistency among all the component equations. First, we will show that four conditions need to be satisfied for developing algebraically compatible of taper and volume equations, and the development methods could be mathematically unified. Three fitting methods used to obtain numerically consistent estimates of parameters were empirically evaluated, and the results suggested that optimization of parameters of the system for both taper and cumulative volume simultaneously is preferable to separate optimization for taper or volume only. Finally we will discuss aggregative and disaggregative strategies for modeling additive biomass equations. In the aggregative approach, total tree biomass equation was specified by aggregating the expectations of component biomass models, and their parameters were estimated by jointly fitting all component and total biomass equations using weighted nonlinear seemingly unrelated regression (NSUR) (SUR1) or by jointly fitting component biomass equations using weighted NSUR (SUR2). In an alternative disaggregative approach (DRM), the biomass component proportions were modeled using Dirichlet regression, and the estimated total tree biomass was disaggregated into biomass components based on their estimated proportions. We empirically demonstrated and analytically confirmed that SUR2 should be recommended.

Field Trip Attendees – 2018 IUFRO4.01-SOMENS-NEMO Joint Conference

Blacksburg, VA. October 31, 2018

First Name	Last Name	Affiliation
Ralph	Amateis	Virginia Tech
Madeleen	Algera	Komatiland Forests
Laura Denise	Bonnette	Hancock Forest Management
Fernando	Bustamonte	
Yingbing	Chen	University of New Brunswick
Sandro	Diaz	Forestal Mininco S.A.
Chris	Cieszewski	University of Georgia
James	Goudie	
Brad	Graham	GreenWood Resources
Nabin	Gyawali	Weyerhaeuser
Dale	Hogg	Green Diamond Resource Co.
Yung-Han	Hsu	University of New Brunswick
John	Kershaw	University of New Brunswick
Menzi Sibusiso	Lukhele	South African Forestry Companies
Xu	Ma	University of New Brunswick
Douglas	Maguire	Oregon State University
Nathaniel	Naumann	PotlatchDeltic
Bharat	Pokharel	Tennessee State University
Jose	Rivera	
Timothy	Robards	TYLD Corp
Jame	Sanchez	MASISA
Sanusi	Shamaki	Usmanu Danfodiyo University
Margarida	Tomé	Universidade de Lisboa
Astor	Torano Caicoya	Technical University of Munich
Guillermo	Trincado	Universidad Austral de Chile
David	Walters	Olympic Resource Management
Rebecca	Wylie	Nipissing University
Ting-Ru	Yang	University of New Brunswick

Name	Company	City	State	Email
David Affleck	University of Montana Forestry	Missoula	MT	david.affleck@umontana.edu
Madeleen Algera	Komatiland Forests	Graskop		madeleen@safcol.co.za
Micky Allen II	Norwegian Institute of Bioeconomy	Oslo		micky.allen@nibio.no
Ralph Amateis	Virginia Tech	Blacksburg	VA	ralph@vt.edu
Clara Anton Fernandez	Norwegian Institute of Bioeconomy Research	Ås		caf@nibio.no
Chad Babcock	Michigan State University	East Lansing	MI	babcoc76@msu.edu
Josh Bankston	Mississippi State University	Starkville	MS	jbb450@msstate.edu
Alonso Barrios Trilleras	Universidad del Tolima	Ibague		abarriost@ut.edu.co
Martin Beavers	Resource Management Service	Trussville	AL	mbeavers@resourcemgt.com
Eddie Bevilacqua	SUNY-ESF	Syracuse	NY	ebevilacqua@esf.edu
Andréa Bittencourt Moreira		Campo Limpo Paulista		bmoreira.dea@gmail.com
Laura Denise Bonnette	Hancock Forest Management	Charlotte	NC	dbonnette@hnrg.com
Bruce Borders	Resource Management Service	Watkinsvill e	GA	bborders@resourcemgt.com
Ernest Bowling	James W. Sewall Company	Old Town	ME	ernest.bowling@sewall.com
Karol Bronisz	Warsaw University of Life Sciences	Warsaw		karol.bronisz@wl.sggw.pl
Bronson Bullock	Warnell School of Forestry, University of Georgia-Athens	Athens	GA	bronsonbullock@uga.edu
Harold Burkhart	Virginia Tech	Blacksburg	VA	burkhart@vt.edu
Ian Cameron	Azura Formetrics Ltd	Kamloops		ian.cameron@azura.ca
Quang Cao	Louisiana State University	Baton Rouge	LA	qcao@lsu.edu
Yingbing Chen	University of New Brunswick	Fredericton		
Chris Cieszewski	University of Georgia - Warnell School of Forestry	Athens	GA	biomat@uga.edu
Clara Clark	American Forest Management	Charlotte	NC	clara.clark@afmforest.com
Brian Clough	SilviaTerra	San Francisco	CA	brian@silviaterra.com
Patrick Clune	Campbell Global	Vancouver	WA	pclune@campbellglobal.com
Dean Coble	Washington University in St. Louis	University City	MO	dcoble@wustl.edu
John Coulston	USDA Forest Service	Knoxville	NC	jcoulston@fs.fed.us
Garret Dettmann	Michigan State University	East Lansing	MI	dettman4@msu.edu

Sandro Diaz	Forestal Mininco S.A.	Los Angeles		sandro.diaz@cmpc.cl
Adam Dick	Canadian Forest Service	Fredericton		adam.dick@gmail.com
Rong Fang	Oregon State University	Corvallis	OR	rong.fang@oregonstate.edu
Robert Froese	Michigan Technological University	Houghton	MI	froese@mtu.edu
Donald Gagliasso	Mason, Bruce & Girard	Berwyn	IL	dgaglias@masonbruce.com
Salvador Gezan	University of Florida	Gainesville	FL	sgezan@ufl.edu
Glenn Glover	Auburn University	Auburn	AL	glover@auburn.edu
James Goudie		Victoria		jimgoudie@shaw.ca
Brad Graham	GreenWood Resources	Portland	OR	brad.graham@gwrglobal.com
Edwin Green	Rutgers University	Monroe Township	NJ	edwin.j.green.7@gmail.com
Corey Green	Virginia Tech	Blacksburg	VA	pcgreen7@vt.edu
Nabin Gyawali	Weyerhaeuser	Seattle	WA	nabin.gyawali@weyerhaeuser.com
Temesgen Hailemariam	Oregon State University	Corvallis	OR	hailemariam.temesgen@oregonstate.edu
David Hamlin	Campbell Global	Portland	OR	dhamlin@campbellglobal.com
Thomas Harris	University of Georgia	Athens	GA	thomas.harris@uga.edu
Nathan Herring	American Forest Management	Charlotte	NC	nate.herring@afmforest.com
Dale Hogg	Green Diamond Resource Co.	Bogart	GA	dale.hogg@greendiamond.com
Yung-Han Hsu	University of New Brunswick	Fredericton	NB	yhsu@unb.ca
David Hyink	Deerfield Consulting LLC	Rapid City	SD	dave_hyink@msn.com
John Kershaw	University of New Brunswick	Fredericton	NB	kershaw@unb.ca
Diane Kiernan	SUNY-ESF	Auburn	NY	dhkiernan@esf.edu
Stephen Kinane	Warnell School of Forestry, University of Georgia-Athens	Athens	GA	smkinane@uga.edu
Steve Knowe	Steve Knowe Biostatistics Consulting, LLC	Tega Cay	SC	userid@steveknowe.com
Anil Koirala	Warnell Schoo, University of Georgia - Athens	Athens	GA	anilk@uga.edu
Valerie LeMay	University of British Columbia	Vancouver		valerie.lemay@ubc.ca
Menzi Sibusiso Lukhele	South African Forestry Companies	Sabie		menzi@safcol.co.za
Thomas Lynch	Oklahoma State University	Stillwater	OK	tom.lynch@okstate.edu
Xu Ma	University of New Brunswick	Fredericton		
David MacFarlane	Michigan State University	East Lansing	MI	macfar24@msu.edu
Douglas Maguire	Oregon State University	Philomath	OR	doug.maguire@oregonstate.edu
Jerry Mahon	Stafford Capital Partners	Austin	TX	jerrymahon@staffordcp.com

Peter Marshall	University of British Columbia	Vancouver		peter.marshall@ubc.ca
James McCarter	NC State University	Knightdale	NC	jbmccart@ncsu.edu
Cristian Montes	Warnell School of Forestry, University of Georgia-Athens	Athens	GA	crmontes@uga.edu
Christian Mora	Fibraconsult	Concepcion		crmora@fibraconsult.cl
Nathaniel Naumann	PotlatchDeltic	Spokane	WA	nathaniel.naumann@potlatchdeltic.com
Travis Norman	GreenWood Resources, Inc.	Spartanburg	SC	travis.norman@gwrglobal.com
Sergio Orrego	Universidad Nacional de Colombia	Athens	GA	saorrego@unal.edu.co
Nate Osborne	Rayonier	Yulee	FL	nathaniel.osborne@rayonier.com
Zack Parisa	SilviaTerra	San Francisco	CA	zack@silviaterra.com
Stephanie Patton	University of Minnesota	St. Paul	MN	patt0373@umn.edu
Spencer Peay	Warnell School of Forestry, University of Georgia-Athens	Athens	GA	wpeay26@uga.edu
Bharat Pokharel	Tennessee State University	Nashville	TN	bpokhare@tnstate.edu
Nan Pond	SilviaTerra	Albuquerque	NM	nan@silviaterra.com
Mark Porter	Warnell School of Forestry, University of Georgia-Athens	Athens	GA	smp68529@uga.edu
Krishna Poudel	Mississippi State University	Mississippi State	MS	kpp70@msstate.edu
Steve Prisley	Nat. Council for Air and Stream Improvement	Roanoke	VA	sprisley@ncasi.org
Jacob Putney	Oregon State University	Adair Village	OR	jacob.putney@oregonstate.edu
Philip Radtke	Virginia Tech	Blacksburg	VA	pradtke@vt.edu
Åsa Ramberg	SLU, Swedish University of Agricultural Sciences	Athens	GA	asrg0003@stud.slu.se
Laura Ramirez	Universidad Nacional de Colombia	Athens	GA	laurar1891@gmail.com
Gregory Reams	USDA Forest Service	Owings	MD	greams@fs.fed.us
Hector Restrepo	Warnell School of Forestry, University of Georgia-Athens	Athens	GA	hrestrepo@uga.edu
Ben Rice	LandVest	West Stewartstown	NH	brice@landvest.com
Timothy Robards	TYLD Corp	Dixon	CA	tim.robards@tyldcorp.com
Henry Rodman	SilviaTerra	Duluth	MN	henry@silviaterra.com
Francis Roesch	USDA Forest Service	Asheville	NC	froesch@fs.fed.us
Matthew Russell	University of Minnesota	St. Paul	MN	russellm@umn.edu
Charles Sabatia	The Westervelt Company	Tuscaloosa	AL	csabatia@westervelt.com

Sanusi Shamaki	Usmanu Danfodiyo University, Sokoto	Sokoto		sanusi.shamaki@udusok.edu
Mahadev Sharma	Ontario Forest Research Institute	Sault Ste Marie	ON	mahadev.sharma@ontario.ca
Vitor/Passos Silva Júnior	University of Florida	Gainesville	FL	vitorpsjunior@hotmail.com
Jim Smith	The Nature Conservancy	Jacksonville	FL	jim_smith@tnc.org
Priscila Aiko Someda Dias	University of Florida	Gainesville	FL	priscilasomeda@ufl.edu
Christina Staudhammer	University of Alabama - Dept. Biol. Sciences	Tuscaloosa	AL	cstaudhammer@ua.edu
Bogdan Strimbu	Oregon State University	Corvallis	OR	bogdan.strimbu@oregonstate.edu
Mike Strub	Retired	Little River	SC	mike.r.strub@gmail.com
Randy Taylor	Molpus Woodlands Group	Hattiesburg	MS	rtaylor@molpus.com
Guillaume Therien		Montreal		giom.therien@gmail.com
Jim Thrower	Sophostats Data Services Ltd.	Kamloops	BC	jimt@sophostats.com
Margarida Tomé	Centro de Estudos Florestais, Instituto Superior de Agronomia, Universidade de Lisboa	Lisboa		magatome@isa.ulisboa.pt
Astor Torano Caicoya	Technical University of Munich (TUM)	Freising	Bayern	astortc@gmail.com
Guillermo Trincado	Universidad Austral de Chile	Valdivia	Los Rios	gtrincad@uach.cl
William VanDoren	Mass. Dept. of Conservation & Recreation	Amherst	MA	william.vandoren@state.ma.us
David Walker	Virginia Tech	Blacksburg	VA	walkedm@vt.edu
David Walters	Olympic Resource Management	Poulsbo	WA	dwalters@orminc.com
Mingliang Wang	University of GA - Athens, Plantation Mgmt. Research Coop	Athens	GA	mwang@warnell.uga.edu
Aaron Weiskittel	University of Maine	Orono	ME	aaron.weiskittel@maine.edu
James Westfall	US Forest Service	Newtown Square	PA	jameswestfall@fs.fed.us
Rebecca Wylie	Nipissing University	North Bay		rrmwylie@gmail.com
Sheng-I Yang	Virginia Tech	Blacksburg	VA	siyang23@vt.edu
Ting-Ru Yang	University of New Brunswick	Fredericton	NB	tyang1@unb.ca
Mauricio Zapata	Warnell School of Forestry, University of Georgia-Athens	Athens	GA	mauricio.zapatacuartas@uga.edu
Michal Zasada	Warsaw University of Life Sciences	Warsaw		michal.zasada@wl.sggw.pl
Yang Zhan	University of New Brunswick	Fredericton		
Lianjun Zhang	SUNY-ESF	Syracuse	NY	lizhang@esf.edu
Dehai Zhao	University of Georgia	Johns Creek	GA	zhaod@uga.edu