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Producing more from less: towards optimising value in the bio-economy from data driven decisions

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Editors:
Pierre Ackerman
Jennifer Norihiro
Hannél Ham
Julia Brewer

Cover Design:
Jennifer Norihiro
Elizabeth (Lise) Gleasure
Hannél Ham

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Precision Forestry Symposium 2017:

Producing more from less: towards optimising value in the bio-economy from data driven decisions

Official Proceedings (Extended Abstracts) of the

4th Precision Forestry Symposium

Held in Stellenbosch, South Africa

February 28 to March 2 2017

Edited by: Pierre Ackerman, Jennifer Norihiro, Hannél Ham & Julia Brewer

Preface

It is my honour to introduce these proceedings on behalf of the scientific and organising committees of the Precision Forestry Symposium of 2017. These proceedings represent scientific contributions to the symposium titled "Precision Forestry – Towards optimising value in the bio-economy from data driven decisions." presented in Stellenbosch, South Africa, from 28 February to 2 March 2017. The symposium is jointly hosted by Stellenbosch University (Department of Forest and Wood Science), Southern Africa Institute of Forestry (SAIF), Forestry South Africa (FSA) and the International Union of Forest Research Organizations (IUFRO).

Precision Forestry 2017, an international symposium held every four years, is a forum where forest scientists and practitioners from around the world share their research, knowledge, experience, and emerging ideas with the greater forestry community. This meeting follows previous successful symposia held in 2006, 2010 and 2014 in South Africa. The high quality of material presented and the large number of delegates attending, attest to current and continued interest in promoting the all-important facet of Precision Forestry to the forest industry.

I would like to thank all of those who were involved in the organization of this symposium. In particular, I would like to thank the scientific committee for taking time to establish the title and sub-themes of the symposium. They also conveyed considerable effort to the review of the large number of proposed oral presentations originally submitted. Additionally, I would like to thank the sponsors for their generous contributions. They are Gold: Husqvarna, Mondi and Tigercat; Silver: Sappi, Stihl and Trimble; and Bronze: MTO, PG Bison, MicroForest, York Timbers, South African Forestry Magazine and Wood & Timber Times Southern Africa.

PF 2017 is indebted to the authors of the extended abstracts included in this volume, as well as attending delegates who have travelled from everywhere to share this time with us. These proceedings are reproductions of extended abstracts submitted to the symposium with editing to achieve consistent format. No attempt was made to review or verify results, although members of the scientific committee, as set out below, reviewed the abstracts for suitability.

Pierre Ackerman
February 2017

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Table of Contents

Keynote Addresses

Rasmus Astrup; Michael Battaglia

Keynote 1

Perspectives on improved forest information through emerging technologies and applications in knowledge-based management

R. Astrup

Norwegian institute for bioeconomy research, Aas, Norway

rasmus.astrup@nibio.no

The rapid developments in sensor technology and computing power allow for the generation of very large amounts of data related to forest resources and forest operations. The forestry community will likely never become the leading developer of the technologies but is still faced with the major opportunity and challenge of utilising the developed technologies and transforming the associated large quantities of data into information that can support better decisions and the development of precision forestry.

A brief overview of the emerging sensor technologies ranging from satellites to new ground-based sensors illustrates a broad range of possibilities for improving forest information. While data from satellite and airborne sensors have long been used for commercial forest inventory purposes, ground-based sensors are relatively new and the development of good applications is still in the research domain. Two examples of ground-based sensors are given; first, an application of terrestrial laser scanning for stand-volume using distance sampling is illustrated. Secondly an application of mobile laser scanning using individual tree segmentation algorithms, distance sampling and kriging is given for the prediction of stand-level variables. However, ultimately the research challenge for the coming years will be applying data assimilation techniques that combine the different sources of information to always have the best available updated information available.

The use of data collected from forest machines namely harvesters and forwarders holds a large potential that today is hardly realised in either research or commercial applications. In the newly established H2020 project Tech4Effect, work will be undertaken to utilize machine-captured data for improving the efficiency of forest operations. A brief overview of Tech4effect with focus on the development of the efficiency portal, an interactive web based benchmarking tool, is given.

Keynote 2

Modelling forest mortality risk: moving from landscape to forest management scale; moving from description to action

M. Battaglia[1]*, A. O'Grady*[2] *and J. Bruce*[2]

[1] CSIRO Agriculture and Food, Private Bag 12 Hobart, Tasmania, 7001 Australia

Michael.Battaglia@csiro.au

[2] CSIRO Land and Water, Private Bag 12 Hobart, Tasmania, 7001 Australia

There has been an increase recently in large-scale mortality events associated with climate extremes (Allen et al. 2010, Stuart-Haentjens et al. 2015). The potential risks to terrestrial carbons stores, timber, species distribution and ecosystem services arising from the changing frequency and severity of these events has not been quantified, but these forest disturbances have the potential to offset any the benefits to terrestrial ecosystems of increased productivity associated with CO_2 fertilisation (Donohue et al. 2013) and could markedly affect species distributions (Cheaib et al. 2012). A major component of this uncertainty is our limited understanding the triggers of forest mortality (McDowell et al. 2011, McMahon et al. 2011). Consequently, many assessments of forest climate change vulnerability fail to account for forest mortality (e.g. Battaglia et al. 2009, Booth et al. 1999, Coops et al. 2010, Coops and Waring 2011, Simioni et al. 2009) , considering only net primary production or productivity changes in response to temperature and water supply, and accordingly failing to provide the basis for adaptation action to reduce risks to forests.

This limitation in modelling presents two problems. First it is almost certain that such assessments will underestimate the impacts of climate change on forest production (e.g. Seely et al. 2015) unless mortality levels are below the threshold for ecosystem response (Stuart-Haentjens et al. 2015). Because assessments often fail to understand the systemic effects of elevated CO_2 and climate change on plant and ecosystem functioning they may fail to detect increase system vulnerability to stress. The second is that these assessments are, by and large, confined to being vulnerability assessments and provide little basis for adaptive action: given the uncertainty often associated with future climate impacts vulnerability and the range of outcomes dependent on future climate assumptions such analyses can be counter-productive to action (von Detten and Faber 2013). This is precisely the information that forest managers want. Alternative approaches that explored risk thresholds could resolve the ambiguity and uncertainty for decision makers.

This talk reviews the causes of tree and forest drought mortality, looking at both physiological, climate and environmental drivers across a range of spatial and temporal scales. It reviews existing paradigms and looks at the physiological evidence for these theories, but importantly which are of utility either heuristically or in a predictive way for forest managers. It looks at modelling approaches and discusses their limitations and in doing so explores why modelling approaches have not been successful or ignored. Recent reviews (Anderegg et al. 2012, Meir et al. 2015, Seidl et al. 2011, Wang et al. 2012) go so far as to suggest modelling is impeded by uncertainty about the processes leading to drought mortality, and even by definitional uncertainty of what constitutes tree death.

In review, Adams et al. (2013) echoed the earlier review of Hawkes (2000) and strongly advocated the inclusion of process-based representations in empirical models to overcome many of the problems discussed above. Parolari et al. (2014) extended this approach with the use of a statistical-dynamical modelling approach in which the soil moisture dynamics, conditioned by climate and forest water use, was used to predict tree water stress and tree carbon-balance and hence the frequency of drought induced mortality. Similarly, Seely et al. (2015) calculated a running water stress deficit (potential – actual transpiration) and use this to generate a 2 year running cumulative stress to predict an annual drought mortality rate. The approach is pragmatic and sidesteps the lack of generality in purely empirical approaches but does not presume full system understanding or definition of thresholds and representation of the stochastic matters that is implied (and failed to be achieved) in purely mechanistic representations. Where purely mechanistic approaches have been tried (Bugmann et al. 1998, Weinstein et al.,1991) they have either been highly sensitive to parameter values or have unsuccessfully predicted dynamic behaviour. Indeed moving to a more complex representation of mortality may increase model error (Makela and Hari 1986).

An important challenge, and one often missing in discussions of the complexity of mechanistically modelling drought mortality, is that it is trees and not stands that die. Secondly, not all trees die at the same time or same stress level. A drought mortality event can progress from accelerated self thinning in which trees which would have died later as a result of intra-specific competition are lost earlier than otherwise, to patches of trees being lost where, for example, roots are restricted, through to whole stand death. The variation in time to death of trees may reflect underlying variation in site conditions or neighbourhood competition that vary the stress experience by the dying individual (e.g. Battaglia and Williams 1996) or it may reflect tree to tree variability in the ability to withstand stress that may result from differences in tree age, genetics or the life history of the individual (Cregg and Zhang 2001, Martinez-Vilalta and Pinol 2002, Martinez-Vilalta et al. 2002, Yan et al. 2012). Effectively this means that there are not one but many mortality thresholds and that in fact the summation of these individual tree susceptibilities results in cumulative mortality being a result of the within stand distribution of these thresholds (This is represented diagrammatically in Fig. 1). The processes driving these separate events, all possibly recorded as different levels of stand mortality, may be driven by quite different processes. In the case of accelerated self thinning, or 'salt and pepper' death it might be the carbon-starvation of already suppressed trees, or alternatively it might be the genetically more vulnerable trees being removed at a lower level of water stress.

In a partial attempt to address this issue of needing physiologically meaningful, and contextually responsive, indicators of plant stress leading to drought mortality Anderegg et al. (2015) correlated stand mortality with a physiological measure of plant water stress (plant hydraulic conductivity), and then correlated this plant water stress measure with a simply derived climatic drought index (cumulative water deficit). The accuracy of prediction is somewhat surprising given issues of wetting and drying, and the possibility that it is the cumulative effects of both drought intensity (potentially measured as cumulative water deficit) and drought duration that probably contribute to tree death (after McDowell et al. 2011).

A second consideration often poorly considered in modelling of forest vulnerability to drought is the complex interaction between changes in forest physiology and resilience. While increases in forest leaf area are almost always observed in response to elevated CO_2 in FACE experiments

(Ainsworth and Long 2005) the implications of this for future forest performance is rarely integrated into assessments. This is despite clear evidence from experimental forest manipulations that affect leaf area (e.g. thinning and fertilisation) affect forest vulnerability to drought death (White et al. 2009). In terms of the schematic in Fig. 1, it is not just the environmental envelope in which trees grow that may be changing but potentially the positioning of the mortality threshold: future conditions may lead to forest states that make them more susceptible to catastrophic drought death (Fig. 2). Simulating future forest vulnerability to climate change in an empirical manner based on past climate and mortality correlations may miss this changing relationship between trees and the environment brought on by rising elevated CO_2. To some extent this is changing resilience of future forests is supported by observations of more intense and rapid greening and drying of parts of the terrestrial surface (Donohue et al. 2009, Donohue et al. 2013).

The talk finishes by proposing an alternative, pragmatic approach that is nevertheless grounded in sound physiology to model tree and stand drought vulnerability and combines this with our understanding of elevated CO_2 responses to build a framework for assessing vulnerability and adaptation strategies to climate change. Use of this to design adaptation in eucalypt and pine plantations is shown.

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Theme One: Precision measurements and modelling of quality and yield

Session Chairs: Pierre Ackerman; Bo Dahlin; Bruce Talbot;

Thomas Seifert

Forest pest and disease monitoring and ecological modelling for better management: case studies from South African forest plantations

I. Germishuizen[1], K. Peerbhay[1], B. Hurley[2], R. Ismail[3]

[1]Institute for Commercial Forestry Research, PO Box 100281 Scottsville 3209, South Africa.

Ilaria.Germishuizen@icfr.ukzn.ac.za

[2]Department of Zoology and Entomology, University of Pretoria, Private Bag X20 Hatfield 0028, South Africa.

[3] University of KwaZulu-Natal, School of Environmental Sciences. Private Bag X01, Scottsville 3209, South Africa.

Introduction

Crop damage, tree mortality and yield loss due to pest outbreaks are serious risks to supply from industrial wood plantations in South Africa. Global trade has increased the pace of new forest pest and pathogen arrivals in southern Africa and global climate change has increased uncertainty around pest impacts for the sector. Spatial technologies and remote sensing offer cost effective tools to improve pest and pathogen monitoring and risk assessment capability in the forestry sector. For instance:

1) Remote sensing can detect characteristic spectral signatures of stand damage.
2) Predictive models using spatial technologies to predict risks of outbreak based on ground observation, biological cycle and environmental parameters.

Both applications allow for targeted ground surveillance using limited resources, to enable efficient implementation of management interventions to mitigate damage impacts.

This paper illustrates the importance of remote sensing and ecological modelling of pests through two case studies. The first study integrates a Landsat-8 derived baboon damage map with a spatially explicit ecological risk model as a tool to quantify the current extent and intensity of baboon (*Papio ursinus*) caused damage to commercial pine stands. Moreover, the ecological risk model highlights potential "hot spots" of baboon damage and describes the environmental factors associated to the presence of baboon damage.

The second study focuses on the Eucalypt gall wasp *Leptocybe invasa* and evaluates two machine-learning techniques for modeling the risk of infestation in eucalypt plantations in South Africa under current and future climate.

Products and outputs from both studies are currently being used by the forestry industry as tools to guide and optimize management interventions.

Material and methods

Baboon study: The study was conducted in the commercial pine plantation of the Mpumalanga province. Monthly Landsat-8 imagery for the period May to October 2014 and May to October 2015 was used for this study. Statistical analysis was performed by applying two machine learning techniques, Random forests (RF) and stochastic gradient boosting (SGB), using the R statistical software (R development Core Team 2008). Variables included in the model consisted of individual Landsat-8 spectral bands and a number of derived vegetation indices.

Field data consisted of a dataset of over 19 000 pine stands that were assessed for baboon damage. Classification accuracy assessment was evaluated by splitting datasets into training data and test data and calculating confusion matrices based on the test dataset and calculating overall accuracies from confusion matrices.

The ecological risk model was also developed using a RF framework and field data whereby the presence and absence of baboon damage were utilized as response variables. Thirty-eight environmental variables were used as predictors of baboon damage and included aspects of climate, topography and stand specific attributes. Model accuracy was evaluated using the true skill statistic discriminant (TSS; Alluche et al. 2006), the F_1 score (van Rijsbergen 1979) and the area under curve (AUC) using the receiver operating characteristic (ROC) curve (Fielding and Bell 1997).

L. invasa study: Model building was performed using the package Dismo (Hijmans et al. 2016) in the R statistical software (R development Core Team, 2008). Two ecological modelling techniques were tested (Bioclim and Maxent), both requiring presence data only. Variables used as predictors were obtained from the Bioclim dataset (Hijmans et al. 2005). Model accuracy was evaluated using AUC after removing "spatial sorting bias" through point wise distance sampling.

Results

Baboon study: Random forests performed better than stochastic gradient boosting in predicting the presence of baboon damage. Normalised Difference Vegetation Index (NDVI) and Disturbance Index (DI) were the most effective variables in predicting baboon damage. Model accuracy varied monthly and was the highest for the month of May (73%). The model was applied to all pine commercial stands of the Mpumalanga province to produce a baboon damage map (Fig. 1).

Random forests was also successful in predicting susceptibility of pine stands to bark stripping by baboons (F_1 score=0.812; TSS=0.708). Susceptibility was mostly related to stand characteristics rather than the surrounding landscape. Age, Site Index (SI_{20}), species planted and altitude were identified as the most important variables for predicting the occurrence of baboon damage. Baboon damage seems to occur mostly on high productivity sites, where resources are abundant and less time spent foraging. The model was applied to all pine commercial stands of the Mpumalanga province to evaluate the risk of baboon damage at the landscape level.

The Landsat-8 derived damage map and the risk map are in the process of being integrated to improve the ability to recognize baboon damage from general "unhealthy" pine stands.

L. invasa: Maxent performed slightly better than Bioclim in predicting the risk of *L. invasa* over the forestry landscape, however, both techniques achieved an accuracy greater than 80%. The model highlighted that *L. invasa* outbreaks are strongly temperature driven and could be favoured by climate change (Fig. 2).

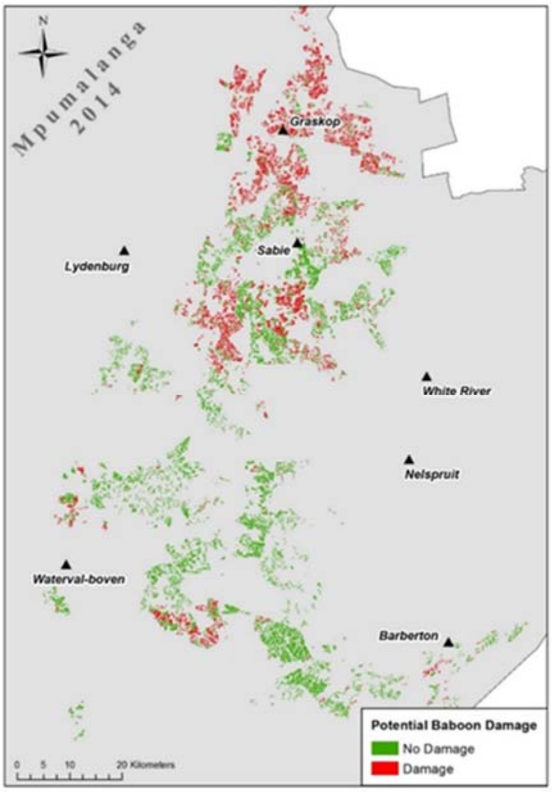

Figure 1: Landsat-8 derived map showing "unhealthy" pine stands. Poor stand conditions are likely to be a result of bark stripping by baboons.

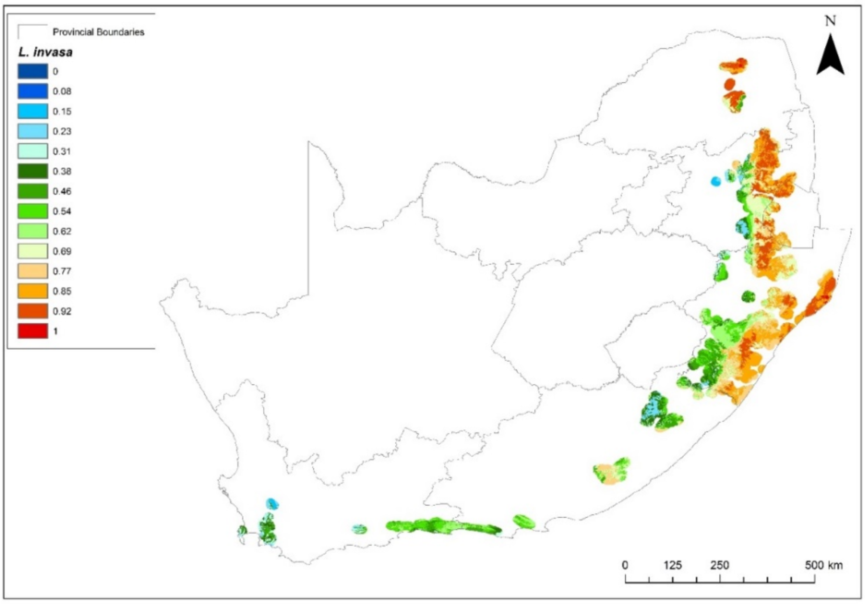

Figure 2: Ecological model (Maxent) showing the risk of L. invasa outbreaks under current climate.

Conclusion

The studies presented provide examples of how forest pest ecological modelling and monitoring contribute towards the development of pest management strategies at different levels:

1) By improving the understanding of the environmental conditions associated to the presence of a pest and defining its ecological niche
2) By providing tools to monitor the extent and intensity of the impact of a pest on plantation forests

These tools can also be applied to optimize management interventions such as the deployment of biological and chemical control and field surveys and promote early detection of pest outbreaks.

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Are sawmills getting what they want? A simulation approach to estimate the value of precise harvester measurements and minimized bucking splits

M. Nordström[1]*, P. Jönsson*[1]*and A .Mörk*[1]

[1] Skogforsk, the Forestry Research Institute of Sweden, Uppsala Science Park, S-751 83 Uppsala, Sweden.

maria.nordstrom@skogforsk.se

Introduction

Swedish sawmills have, over the last decades, transformed from producing commodities to delivering tailored products to key customers and/or markets (Hugosson and McCluskey 2008). As an effect, the demands on harvesting organizations to deliver specific logs with precise dimensions and properties have increased. That in turn demands accurate harvester measurements of diameter and length as input for optimizing bucking alternatives for each stem. A high accuracy of harvester measurements also allows for reduced safety margins in cutting, thus reducing waste. A key success factor in improving harvester measurements is to have a platform for quality-assurance of measurement results. In Sweden, such a system has been in place for around ten years. Skogforsk was involved in setting up the system, and is now a part of developing the system as well as running studies aiming at understanding how different factors impact the measurement quality of a harvester.

Another key factor to ensure that sawmills get the log they need is to keep bucking splits at a minimum. Bucking splits occur when logs are cut hanging freely, exposing the stem to strains. Splits are usually detected in the sawmill once the wood is sawn and dried, and leads to a need to shorten the sawn wood to the next salable length, usually resulting in a loss of at least 30 cm. These losses cause unnecessary losses of raw material for the sawmill together with an in-optimal product mix as compared to what the sawmill is planning on selling.

The work presented here aims at investigating how inaccuracy in harvester measurements and the occurrence of bucking splits at harvesting impact the deliveries to sawmill customers. We chose a simulation approach to the problem to be able to study how different factors interact and how the response changes when the factors are varied within a range.

Material and methods

Bucking simulations were performed using the software Aptan, developed by Skogforsk. Aptan is also used as the core in most bucking systems on the market today. The bucking simulation was performed using a standard set of stems, describing typical conditions at final harvesting in mid-Sweden. To simulate measurement inaccuracy, the diameters and lengths of the bucked logs were imposed with a randomly selected error, distributed around the desired dimension at a standard deviation representative for quality-assured harvesters operating in final felling.

The simulation model used to simulate the occurrence of bucking splits in logs at harvesting was based on data from several Skogforsk studies on the occurrence of bucking splits, and built using the simulation software ExtendSim. The simulation model was run multiple times with a set of stems that was bucked into logs. The logs were then imposed with bucking splits and a measurement error according to defined functions. The model included two levels of bucking splits depending on if split-reducing measures were taken at cutting or not.

Results

Fig. 1 illustrates the effect of inaccuracies in harvester measurements on the lengths of logs produced for a certain sawmill. We chose a level of inaccuracy representative to a Swedish quality-assured harvester, operating in final fellings. In our case, 36% of the logs were cut longer than the minimum 2cm of extra safety margin added to all logs in the simulation. In addition, 4% of the logs were cut too short, thus needed to be shortened in a trimming process to the next salable length. Altogether, this corresponded to yield losses of 0,6% of the total harvested volume. In the described case, no systematic error was added, thus assuming a perfectly calibrated harvester. When an average systematic error of 1 cm was added, the share of logs cut too short increased to 15%, illustrating the importance of good calibration routines.

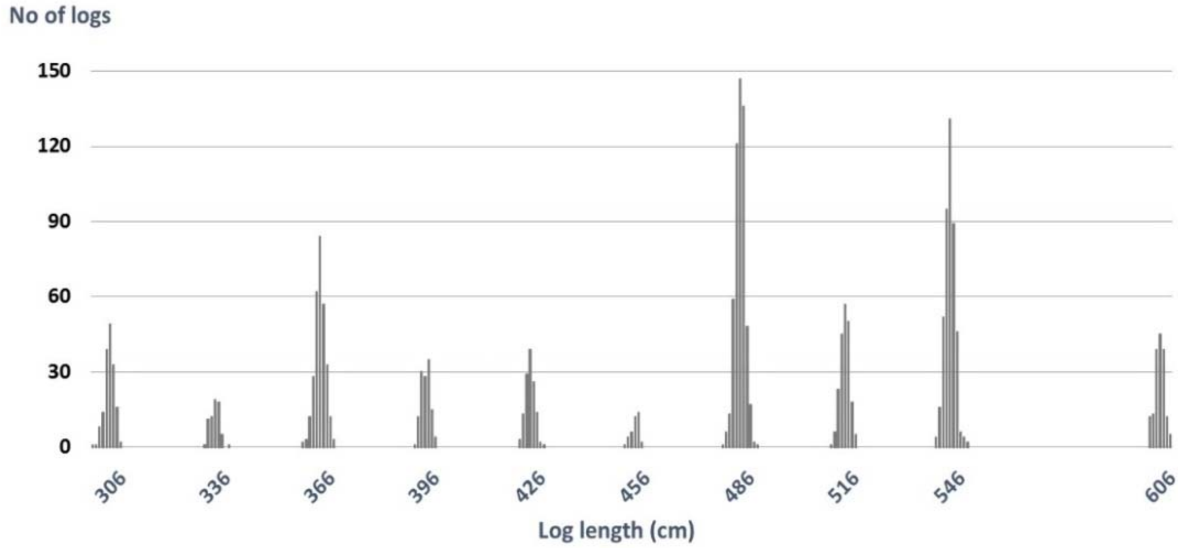

Figure 1: Simulated outcome of bucking a set of stems into logs according to the demands of a specific sawmill. Due to inaccuracy in harvester length measurements, actual log lengths are distributed around the desired length classes. An extra safety margin of 2 cm was added to each measured length before cutting.

Since sawmills describe their log needs as specific combinations of length and diameter (Fig. 2), we also investigated the effect of inaccuracies in diameter measurements. In parallel to the above described reasoning, for a perfectly calibrated harvester with a representative inaccuracy of diameter measurements, 3% of the logs ended up in undesired length-diameter classes and 4% of the logs were too thin to be accepted as timber. These volumes will be sorted out and transported to another sawmill handling smaller dimensions. When an average systematic error of 2mm was added, 4% of the logs ended up in undesired length-diameter classes and 5% of the logs were too thin to be accepted as timber.

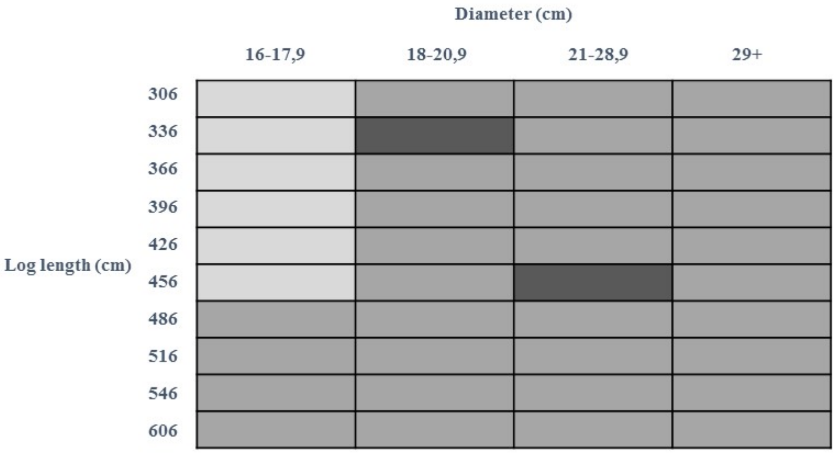

Figure 2: Schematic representation of the case sawmill's demands of logs divided into length-diameter classes. For each class, a desired share of total logs produced is specified. There are restrictions put on undesired classes, in this case the lighter areas (accepted, but not wanted) and the darker areas (not accepted).

Simulations of yield losses due to bucking splits was also run for the case of a perfectly calibrated harvester with an average level of inaccuracy of length measurements. The simulations indicate that in this case, the breakeven point between losses due to bucking splits and due to extra safety margin at cutting was at slightly less than 7cm. The losses quantified as volume to be cut off in the sawmill trimming process were in thin case 8% of total harvested volume. If split-reducing efforts like ground support at cutting or using new cutting technology (Hannrup et al. 2015) were taken, the breakeven point decreased to slightly less than 2cm of extra safety margin. The losses in this case were 2,5% of total harvested volume.

Conclusions

From the work presented here we conclude that there is a large potential in working with improving the accuracy of harvester measurements of diameter and length as well as applying methods and cutting technology reducing the occurrence of bucking splits. Given the large volumes of timber harvested each year, also smaller yield improvements scale up to substantial values. The decreased yield losses in the value chain will benefit both forest owners getting more timber out of their forests and forest industries getting desired proportions of specified length-diameter combinations to fit their planned production.

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Improving forest inventory by quantifying error propagation, DBH-Height representivity, introducing new diameter height models and procedures for improved selection of height samples

G. Lindner[1], D. Drew[2] and C. Ham[2]

[1]Microforest (www.microforest.co.za), Broadacres, Johannesburg, 2021, South Africa. gerard@microforest.co.za

[2]Department of Forest and Wood Science, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa

Introduction and Problem Statement

As the starting point for growth model calibration and estimation of plantation growing stock, Forest Inventory is a critical step in the process of plantation forest planning. Inventory is, however, subject to multiple sources of error and bias which have the potential to propagate throughout the entire planning system. Conventional ground-based forest inventory is based on a two stage process whereby diameter at breast height (DBH) values are captured within plot samples and a sub-sample of DBH and heights pairs is measured throughout the entire stand. The DBH-Height regression is then used to determine the volume of the full stand diameter distribution. Currently, the relationship between the error in the DBH-Height regression and the sampling error of the plot measurements is not well understood. Furthermore, representivity and accuracy of the height sample is not guaranteed and is a potentially large source of error. Inventory practitioners do not have in-field tools to assist with the selection of appropriate DBH-Height sample trees and rely on intuition and training, which may not guarantee representative selection of samples and accurate estimation of key inventory variables.

The purpose of this study is to quantify the relationship between error sources of different inventory strategies and to determine a methodology to estimate the final error in an inventory for volume and stand level calibration variables. The second objective is to find methods of decreasing this error through: a.) improving the DBH-Height regression model by implementing alternative models and introducing stochastic estimation of heights around the model b.) Introducing a systematic way of determining the optimum height to be measured within a plot which would act as an aide for inventory practitioners.

Methodology

The study requires a relatively large stand which has been fully measured (all DBH's and Heights) for comparison. As such a dataset is not currently available, an approach was taken where stands were simulated to represent realistic stands, representing various sizes, ages and variability. For each stand, a sequence of grid based plot samples was also created to simulate sampling procedures of varying sizes and locations within the stand (which ultimately cover the entire stand). For each sample, varying methods of volume estimation were created; a.) Plot DBH measurements with all heights measured, b.) Plot DBH measurements with a sub-sample of heights measured, c.) measurement of all DBH's in the stand with a sub-sample of heights measured and d.) measurement of all heights in a stand with some DBH's measured (to simulate a Lidar-based ground-truthing scenario). Each was compared to the fully measured stand to estimate the actual sampling error. The varying levels of error were mapped and visualised for comparison techniques, which included boxplots, significance tests and residual analysis. Finally, a relationship between error structures of the different steps of the inventory was analysed to understand the interaction of the errors to the final estimation of volume and stand estimates.

As a possible solution to the defined problem, a process was followed where improved DBH-Height models were introduced along with a measure for quantifying representivity of sample. These were used to create a procedure for improved DBH-Height sample selection. The first step includes a comparison of various equations for the modelling of DBH-Height and the introduction of variability into the prediction by including stochastic functions into the equation. This included the estimation of variance relationships of Height along the independent variable (DBH) and to best determine the structure of the variance distributions. For this purpose, fully measured trials and enumerations were used to determine the realistic stochastic Height relationships. The Kolmogorov Smirnov test was analysed as a candidate test to quantify the representivity of the height sample to the inventory plot measurements, which can be used to test whether Height samples are accurate for the known measurements of diameter in the inventory. Finally, a procedure for selecting the optimal tree to measure within a plot was created to meet the objective of improving representivity in a DBH-Height sample and improving overall accuracy of the model.

Preliminary results and discussion

Preliminary analysis has shown that errors in height samples propagate through the estimation of volume by interacting with the sampling error of the plot DBH measurements. Introducing stochasticity into the DBH-Height equation significantly decreases the error associated with volume estimation and could be valuable for inclusion into a growth model. Tests have shown that the Kolmogorov Smirnov test for comparison best quantifies representivity of DBH-Height samples and can be used in inventory systems. A prototype model for the selection of Height samples on a plot-by plot basis has been shown to significantly improve the representivity of height samples and improve the accuracy of the height prediction and ultimately, volume prediction in a stand. This procedure performed well against a random selection of height pairs for measurement (Fig. 1), and was shown to consistently decreases the mean squared error (MSE) of height estimations. However, the effectiveness and practicality of this procedure needs to be tested in-field.

We believe that the improved estimation of errors will significantly improve decision making by mapping and quantifying error structures in an inventory and will provide insight into alternative inventory systems such as Lidar, which involve different error relationships. Improved DBH-Height models and solutions for the improvement of DBH-Height measurements in-field will also introduce novel improvements to the field of forest inventory in plantation forest inventory systems, which in turn will improve the accuracy of variable estimation forest planning applications (such as growth prediction, harvest simulations and forest valuation methodologies). Insights into the problem of error propagation in the rest of the planning system will also be gained, which need to be studied further for various steps in growth prediction procedures.

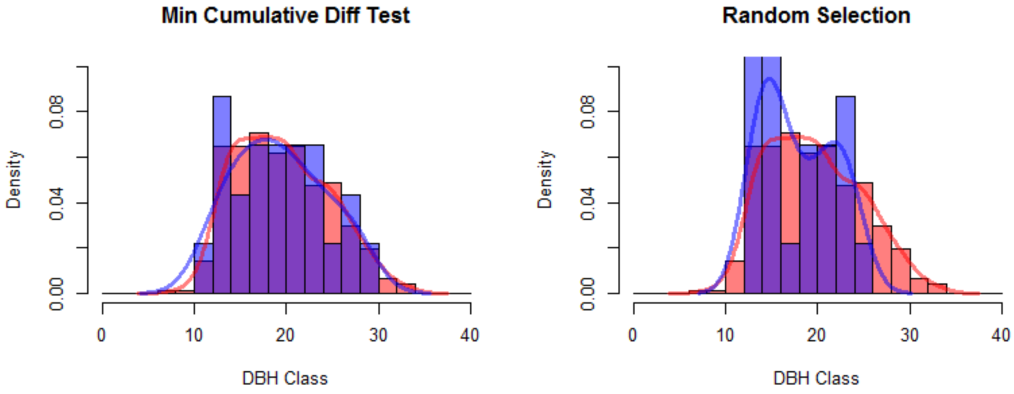

Figure 1: Illustration for the comparison of the representivity of the DBH's of DBH-Height samples and plot Dbh measurements of an inventory. The blue line represents the percentage frequency of the diameters of a height sample, the pink bars represent the percentage frequency (diameter distribution) of the full inventory (smoothed lines represent the overall trend respectively). The left graph is the result of a selection procedure for selecting DBH-Height pairs as data is captured, the right hand graph shows the result of randomly selecting pairs from an enumeration (by plot). The height pair selection procedure consistently improves the representivity of DBH's in the data tested.

Automated volumetric measurement of truckloads through multi-view photogrammetry and 3D image processing software

M Acuna

Australian Forest Operations Alliance, University of the Sunshine Coast, Sippy Downs, QLD, Australia

macuna@usc.edu.au

Introduction

Given that wood represents on average about 1/3 of the delivered cost, it is key to adopt correct measurement procedures and technologies that provide better wood volume estimates. Poor measurements not only impact the revenue obtained by haulage contractors and forest companies, but also might affect their contractual business relationship (Siry et al. 2006). Although laser scanning has become a mature and more affordable technology in the forestry domain, it still remains expensive to adopt and implement in some real-life operations (Eitel et al. 2012). In this study, multi-view photogrammetry and commercial 3D image processing software were tested as an innovative and alternative method for automated volumetric measurement of truckloads. The study also investigated the accuracy in truck volume calculations that can be obtained with photogrammetric methods and 3D reconstruction software in comparison to manual methods, and it proposed guidelines for the implementation of the technology in real life operations.

Material and Methods

Data collection

The data used in this study are digital images from 10 truckloads, which were collected with a drone (DJI Phantom 4) from different angles and heights (10-15 above the trucks) to cover the whole load of pulplogs carried on semitrailer trucks. The drone has an in-built GPS system, so all the photos were geotagged with their corresponding latitude, longitude, and altitude information.

Multi-view 3D reconstruction

Multi-view 3D reconstruction is a technology that uses complex algorithms from computer vision to create 3D models of a given target scene from overlapping 2D images obtained from a digital camera (Thoeni, 2014). It is an inexpensive, effective, flexible, and user-friendly photogrammetric technique for obtaining high-resolution datasets of complex topographies at different scales. There are a number of commercial software solutions that implement algorithms for multi-view 3D reconstruction. In this study, the solution of choice was the software Agisoft PhotoScan Professional™. In conjunction with Agisoft PhotoScan, mesh analysis and frame volume determination of each truckload was performed with the software Autodesk Remake™.

The reconstruction with Agisoft PhotoScan consisted of the following steps: 1. Photo Alignment, 2. Dense cloud building, 3. Mesh building, 4. Texture building, and 5. Tiled model building. The object model was then exported to Autodesk Remake where the mesh was edited and adapted to allow for frame volume calculation of each truckload (Fig. 1). Subsequently, the truckload frames volumes generated from multi-view 3D reconstruction of the truckloads were compared to those obtained from a pair of photos taken from each side of the truckloads. Finally, a regression model was developed between frame volume calculated from multi-view 3D reconstruction and the actual solid volume calculated from manual measurements (logs physically measured on the ground) using the Smalian formula (Fig. 2).

Figure 1: Multi-view 3D reconstruction of the truckloads

Results

Table 1 presents the summary statistics of the 10 truckloads measured for solid volume and frame volume (multi-view 3D reconstruction). In addition, the summary table provides data of the gross vehicle mass (GVM), tare and net payload of the trucks.

Table1: Summary statistics of the truckloads including frame volume calculated from multi-view 3D reconstruction

Truck #	GVM (tonnes)	Tare (tonnes)	Net payload (tonnes)	Net volume (m^{3}s)	Frame volume (m^3)	Net-to-Frame volume ratio
1	29.04	14.95	30.95	29.04	43.73	0.66
2	28.53	15.35	30.20	28.52	45.92	0.62
3	31.64	16.10	34.25	31.64	47.56	0.67
4	26.20	14.75	26.80	26.20	40.85	0.64
5	29.09	15.65	30.35	29.09	45.40	0.64
6	29.13	15.70	30.30	29.13	45.15	0.65
7	28.86	14.95	30.40	28.86	45.97	0.63
8	28.73	15.15	30.95	28.73	45.95	0.63
9	27.15	17.85	28.60	27.15	43.13	0.63
10	28.80	15.50	29.85	28.80	44.83	0.64

Net volumes ranged between 26.20m^3 and 31.64m^3, with an average of 28.54m^3 and a standard deviation of 1.46m^3. Likewise, frame volumes calculated from Multiview 3D reconstruction ranged between 40.85m^3 and 47.56m^3, with an average of 44.85m^3 and a standard deviation of 1.87m^3. The average net to frame volume ratio was 0.64.

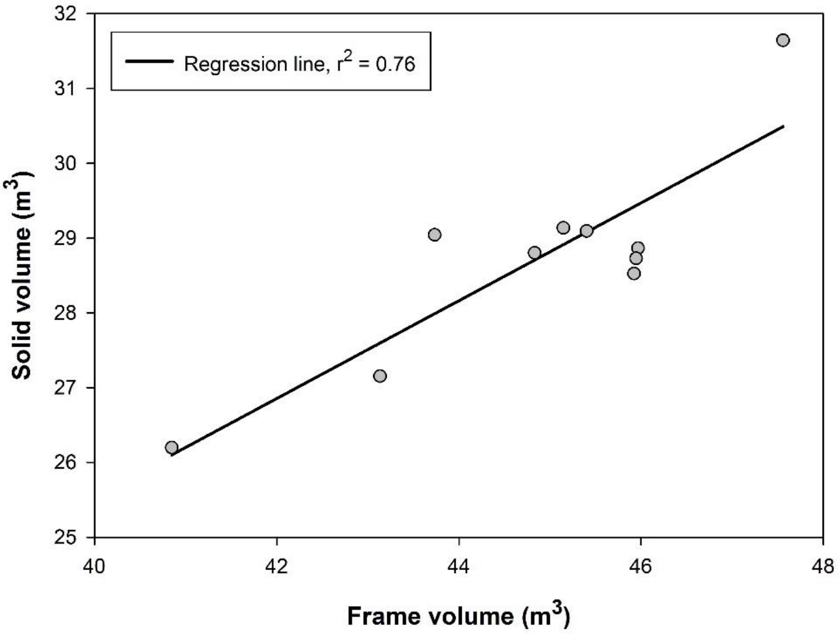

Figure 2: Regression model between frame volume calculated from Multiview 3D reconstruction and actual solid volume calculated from manual measurements.

About 76% of the variation of solid volume was explained by the frame volume calculated from Multiview 3D reconstruction. Given its high coefficient of determination, this model might be implemented in real life operations to estimate solid volume from frame volume calculations.

Conclusion

In this paper, a novel approach to estimate frame volume of truckloads from Multiview 3D reconstruction has been proposed. Multi-view 3D reconstruction is an inexpensive, effective, flexible, and user-friendly photogrammetric technique for obtaining high-resolution datasets of complex topographies at different scales. Our preliminary tests show promising results for the future implementation of this approach in real life operations, and more tests will be conducted to validate our approach.

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Updating stand-level growing stock information using airborne LiDAR data

A Wise[1]*, H.W. Kassier, K. Tasker, N. Rampersad, N. Hattingh*

Sappi Forests, Victoria Country Club Estate, Pietermaritzburg, South Africa.

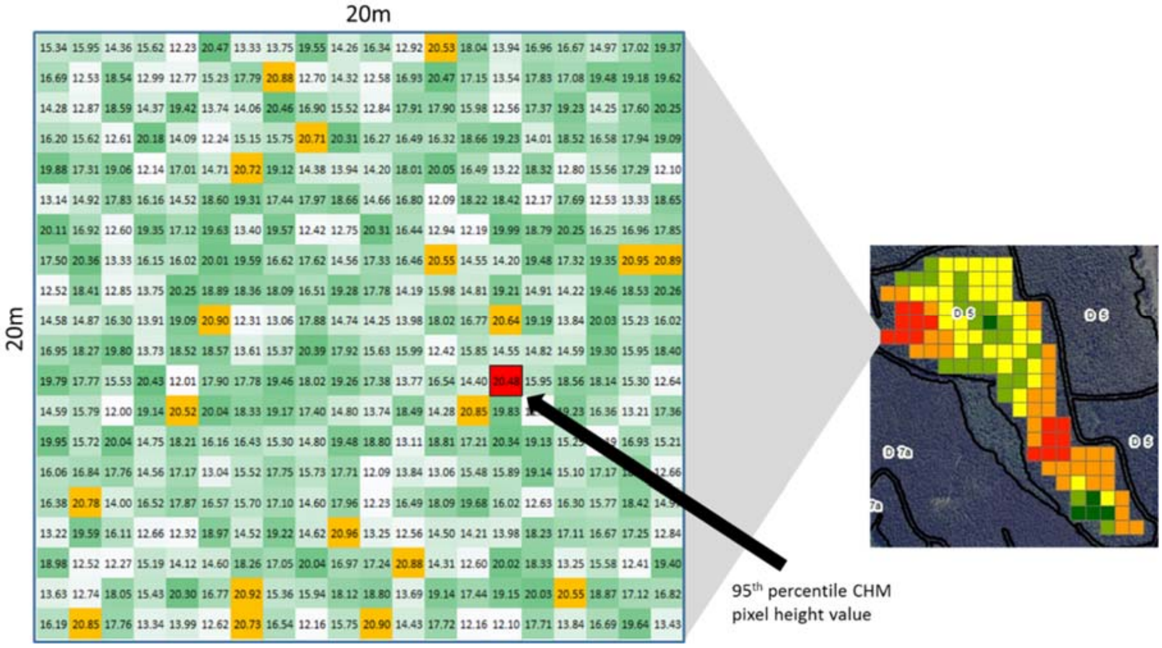
andre.wise@sappi.com

Due to the serious drought conditions in Zululand over the past two to three growing seasons, permanent sample plot (PSP) and enumeration data have shown a significant reduction in tree growth in Sappi's *Eucalyptus* plantations in this region. Since the current growth models do not take climatic conditions into account, future growth projections for compartments enumerated before the onset of the drought will not show the impact of the drought. Similarly, the model predictions for the young, non-enumerated compartments, calibrated with a historic long-term average Site Index (SI) will not reflect the drought impact. In both cases, long-term final harvest volumes will be over-estimated.

Airborne LiDAR data (acquired January 2016), available for all Zululand plantations, were used to obtain an accurate average tree height estimate for all planted compartments older than 3 years. The process of extracting compartment tree height data from LiDAR-based canopy height models (CHM).

Using these data as basis, it was then possible to obtain an accurate dominant height and SI estimate for abovementioned compartments. These outputs, in conjunction with current growth models, were used to update the previously enumerated stand basal areas. Subsequent adjustments to compartment volume estimates were then possible. Additionally, LiDAR-modelled SI could be used to replace all the general SI estimates of the young, non-enumerated compartments in a similar fashion, incorporating the effects of the recent drought conditions.

The experimental work covered in this project included the process of extracting compartment mean tree height from LiDAR-based CHM using height percentiles. Various canopy height percentiles were evaluated on a species level to find the percentile to best represent mean tree height for a grid cell as shown in Figure 1. Acceptable correlations were found between enumerated and LiDAR-extracted dominant tree height (Figure 2).



15.34	15.95	14.36	15.62	12.23	20.47	13.33	13.75	19.55	14.26	16.34	12.92	20.53	18.04	13.94	16.96	16.67	14.97	17.02	19.37
16.69	12.53	18.54	12.99	12.77	15.23	17.79	20.88	12.70	14.32	12.58	16.93	20.47	17.15	13.54	17.83	17.08	19.48	19.18	19.62
14.28	12.87	18.59	14.37	19.42	13.74	14.06	20.46	16.90	15.52	12.84	17.91	17.90	15.98	12.56	17.37	19.23	14.25	17.60	20.25
16.20	15.62	12.61	20.18	14.09	12.24	15.15	15.75	20.71	20.31	16.27	16.49	16.32	18.66	19.23	14.01	18.52	16.58	17.94	19.09
19.88	17.31	19.06	12.14	17.01	14.71	20.72	19.12	14.38	13.94	14.20	18.01	20.05	16.49	13.22	18.32	12.80	15.56	17.29	12.10
13.14	14.92	17.83	16.16	14.52	18.60	19.31	17.44	17.97	18.66	14.66	16.80	12.09	18.22	18.42	12.17	17.69	12.53	13.33	18.65
20.11	16.92	12.60	19.35	17.12	19.63	13.40	19.57	12.42	12.75	20.31	16.44	12.94	12.19	19.99	18.79	20.25	16.25	16.96	17.85
17.50	20.36	13.33	16.15	16.02	20.01	19.59	16.62	17.62	14.56	17.33	16.46	20.55	14.55	14.20	19.48	17.32	19.35	20.95	20.89
12.52	18.41	12.85	13.75	20.25	18.89	18.36	18.09	16.51	19.28	17.78	14.19	15.98	14.81	19.21	14.91	14.22	19.46	18.53	20.26
14.58	14.87	16.30	13.91	19.09	20.90	12.31	13.06	17.88	14.74	14.25	13.98	18.02	16.77	20.64	19.19	13.84	20.03	15.23	16.02
16.95	18.27	19.80	13.73	18.52	18.57	13.61	15.37	20.39	17.92	15.63	15.99	12.42	15.85	14.55	14.82	14.59	19.30	15.95	18.40
19.79	17.77	15.53	20.43	12.01	17.90	17.78	19.46	18.02	19.26	17.38	13.77	16.54	14.40	20.48	15.95	18.56	18.14	15.30	12.64
14.59	15.79	12.00	19.14	20.52	20.04	18.33	19.17	17.40	14.80	13.74	18.49	14.28	20.85	19.83	[illegible]	19.23	16.36	13.21	17.36
19.95	15.72	20.04	14.75	18.21	16.16	16.43	15.30	14.80	19.48	18.80	13.11	18.81	17.21	20.34	19.13	[illegible]	[illegible]	16.93	15.21
16.06	16.84	17.76	14.56	17.17	13.04	15.52	17.75	15.73	17.71	12.09	13.84	13.06	15.48	15.89	19.14	15.10	17.17	[illegible]	12.66
16.38	20.78	14.00	16.52	17.87	16.57	15.70	17.10	14.60	17.96	12.23	16.49	18.09	19.68	16.02	12.63	16.30	15.77	18.42	[illegible]
13.22	19.59	16.11	12.66	12.32	18.97	14.52	19.22	14.62	20.96	13.25	12.56	14.50	14.21	13.98	18.23	17.11	16.67	17.25	12.84
18.98	12.52	12.27	15.19	14.12	14.60	18.26	17.05	20.04	16.97	17.24	20.88	14.31	12.60	20.02	18.33	13.25	15.58	12.41	19.40
13.63	12.74	18.05	15.43	20.30	16.77	20.92	15.36	15.94	18.12	18.80	13.69	19.14	17.44	19.15	20.03	20.55	18.87	17.12	16.82
16.19	20.85	17.76	13.34	13.99	12.62	20.73	16.54	12.16	15.75	20.90	14.43	17.72	12.16	12.10	17.71	13.84	16.69	19.64	13.43

Figure 1: Extracting tree heights from a LiDAR data-generated grid using relevant height percentiles. In this example, canopy height model values within a 20x20m grid cell are shown on the left hand side, with the selected pixel representing the 95th percentile height value within that grid cell. This height is then selected to represent the mean tree height for that particular grid cell within a compartment context (right).

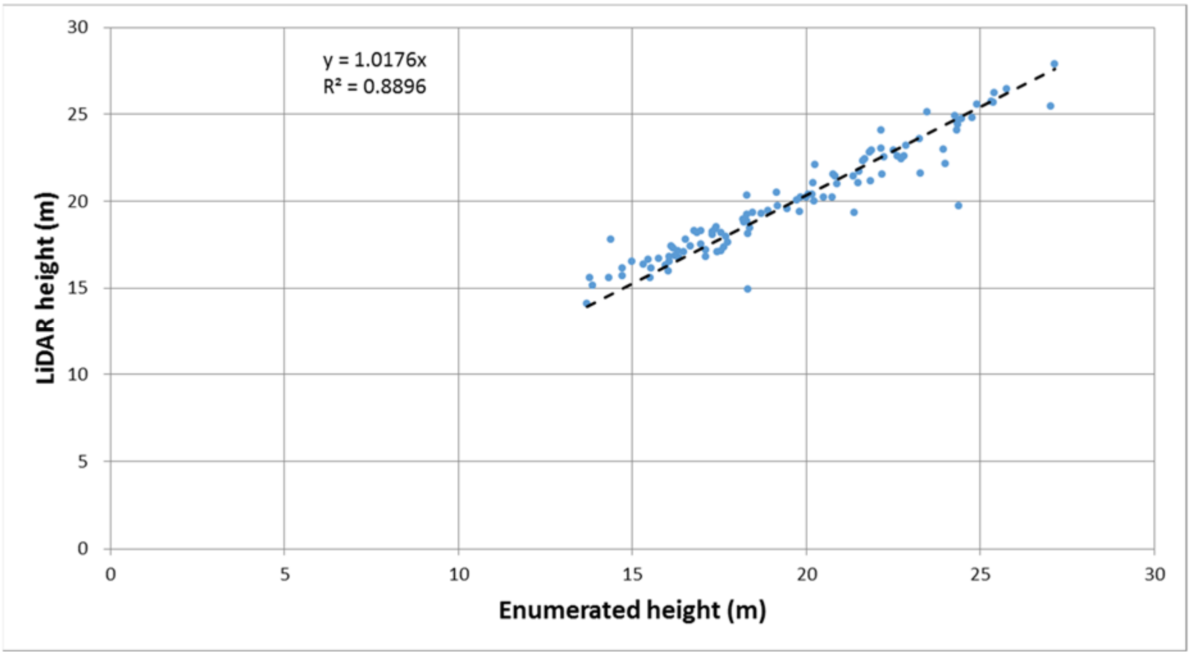


Figure 2: Relationship between dominant tree height as extracted from LiDAR data and dominant height from the same, recently enumerated compartments.

With the updated enumeration data and SI values, the current standing volume, as well as the future volume predictions, could be recalculated for all Zululand plantations. This work was extended to cover the rest of Sappi growing areas. Further work was carried out to quantify within-compartment variability and expected product at harvesting. Various advantages in terms of financial and operational efficiencies from using LiDAR-based, census level data for growing stock measurement are now possible.

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LiDAR Forest inventories in pulpwood stands in Mondi, South Africa

H. Kotze[1], M. Norris-Rogers[2], K. Lim[3] and M. Chauke[4]

[1]Mondi Limited, 380 Old Howick Road, Hilton, 3245.

Heyns.Kotze@mondigroup.co.za

[2]Lim Geomatics Inc., P.O.Box 628, Msunduzi,3231.

[3]Lim Geomatics Inc., 343 Preston Street, 11th Floor, Ottawa, Ontario, K1S 1N4, Canada.

[4]Mondi Limited, 380 Old Howick Road, Hilton, 3245.

Introduction

Mondi has flown its entire land-holdings with LiDAR, primarily to obtain detailed Digital Elevation Models (DEM). The first flights started in 2012 with the Melmoth area and ended in 2016 with coastal Zululand. Canadian and Scandinavian researchers have made significant progress in using the LiDAR data in association with field plots to develop models for Airborne Laser Scanning (ALS) Inventory Predictions (LiDAR Inventories). In 2015, Mondi working with Lim Geomatics, successfully developed LiDAR Inventory prediction models for *Eucalyptus dunnii* in Piet Retief. This exercise was repeated in 2015 for *E. dunnii* and *E. grandis* in the New Hanover area and in 2016 for *E. grandis x urophylla* in Coastal Zululand. In 2016, Mondi held a training workshop with Lim Geomatics, together with acquiring the LAS Tool Kit (LTK), in order to build capacity to run the modelling technology in-house. Mondi developed custom software to summarize the LiDAR Inventories on a compartment level and process it further to be consistent and compatible with its MicroForest planning system.

Background

LiDAR is an acronym of 'Light Detection And Ranging', which is a remote sensing technology that measures distance by illuminating a target with a laser pulse to produce a 3D point cloud in which every return signal has an x; y; and elevation record. A number of technologies are used together in a LiDAR system, as shown in Fig. 1. The basic products generated from the LiDAR point cloud include the Digital Elevation Model (DEM), shown as a grey hill shade in Fig. 2, a Digital Surface Model (DSM), not shown in Fig. 2, and a Canopy Height Model (CHM), shown in Fig. 2. The CHM is generated by subtracting the DEM from the DSM.

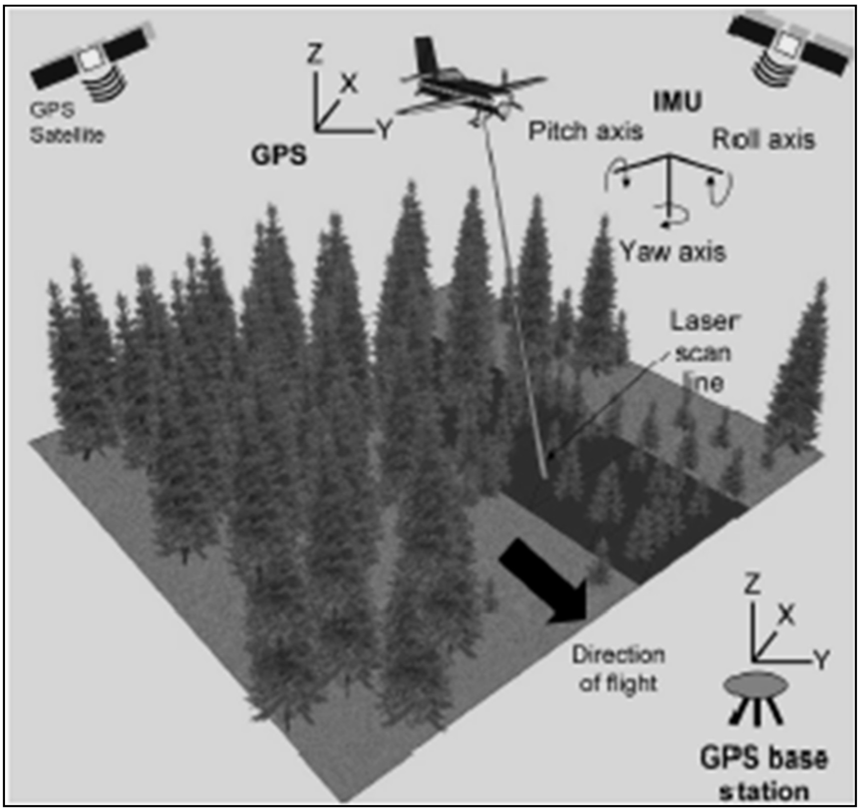

Figure 1: Schematic of a LiDAR system.

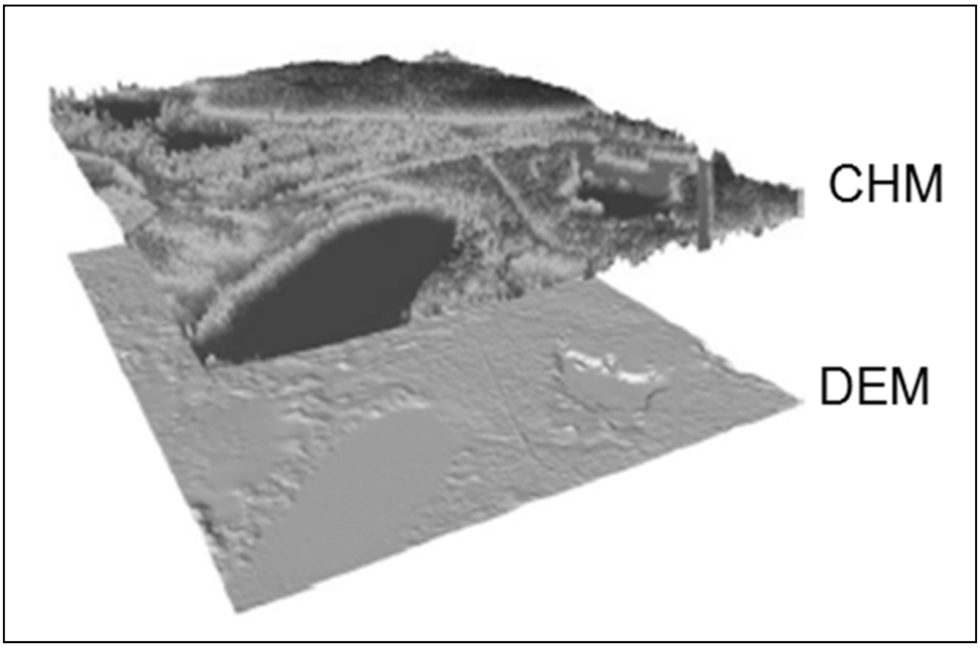

Figure 2: LiDAR base products, includes the DEM and CHM.

Materials and Methods

The LiDAR data was collected using a Leica ALS50-2 multi-pulse LiDAR sensor mounted in a Cessna 208 fixed wing aircraft. Average flying height was 800m above ground level with 50% overlap in flight lines to produce the target point density of 6 points per square meter.

Using the Global Navigation Satellite System (GNSS) and Inertial Navigation System (INS) data collected simultaneously during the flights, the raw Lidar point data was georeferenced in Terrapos software. The georeferenced point data were then classified based on the industry-standard ASPRS LAS1.2 classification using Terrascan software. The data was then referenced against the SAGeoid2010 geoidal model to produce mean sea level heights. Positional accuracy of the point cloud was tied into ground-surveyed points to ensure positional accuracy met the required specification. All this pre-processing work was done by Land Resources International (LRI) prior to supplying the completed point cloud product in a LAS format.

About 50 field sample plots were selected for each species prior to each LiDAR flight. The plots were selected to represent ranges for age, site quality and stand density. A 500m^2 plot size was adopted towards the end of the study. Plot centres were captured to sub-metre accuracy using a Leica GG03 antenna logging data onto a Leica Zeno 5 data logger. The GG03 antenna can receive both GPS and GLONASS signals in the L1 and L2 bands. The Zeno 5 was fitted with a SIM card so that it could receive Real-Time Kinematic (RTK) correction signals broadcast over the internet by the TrigNet RTK base station signal network. Where no cell phone signal could be received, the data was post-processed in the office to apply the necessary correction factors to the GNSS data.

A number of area based LiDAR metrics can be generated from the LiDAR point cloud. The LTK software is used to extract the LiDAR predictors for the field plots. These predictors can be used to predict forest inventory variables, as measured in field plots. The following variables can be predicted with reasonable success: Dominant height, Mean height, Basal area per hectare, Quadratic mean Dbh, Standard deviation of Dbh, Total volume per hectare. The models are fitted for each species and LiDAR flight using stepwise regression procedures in the Statistical Analysis Software (SAS). The models are applied to the LiDAR point cloud using LTK, and predictions for each of the variables are made in a 20m x 20m grid for the compartments within the LiDAR flight area.

Mondi's custom software, the ALS Inventory Processor (ALSIP, (Kotze, 2016)) was used to summarise and further process the LiDAR inventories for all compartments, so that it is compatible and consistent with the MicroForest planning system.

Results

The results from the LiDAR Inventory Prediction modelling exercise for *E. dunnii* in Piet Retief are documented in Lim (2015); the results for the modelling exercises for *E. dunnii* and *E. grandis* in New Hanover are documented in Lim (2016a) and the results for the *E. grandis x urophylla* exercise are documented in Lim (2016b).

The LiDAR Inventory Predictions data can be viewed in context of the compartment maps and ortho-photos in a custom Mondi website for LiDAR Enumerations.

Repeat LiDAR flights have demonstrated the technology's ability to quantify growth loss due to drought and other factors.

Discussion

It was confirmed that sub-metre accuracy of the field plot centres was critical to the success of the study. The ALSIP software was used to compare the results from LiDAR inventories with our traditional forest inventories. The prediction accuracy was convincing and Fig. 3 and 4 show the results for dominant height and total volume per hectare for *E. dunnii* in New Hanover.

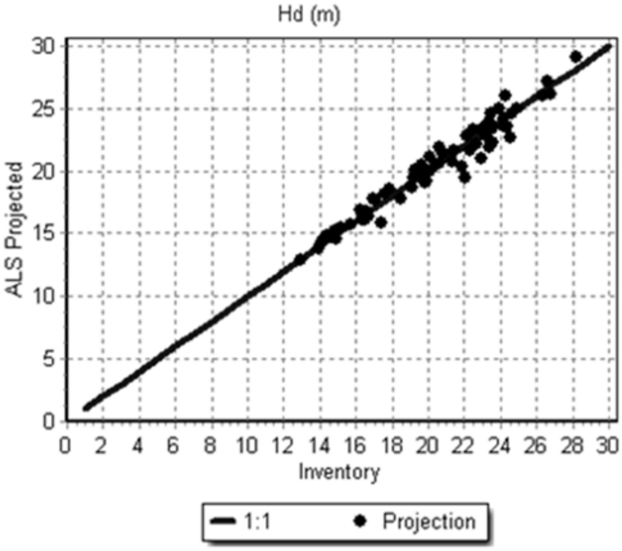

Figure 3: LiDAR Inventory prediction accuracy for dominant height of E. dunnii in New Hanover.

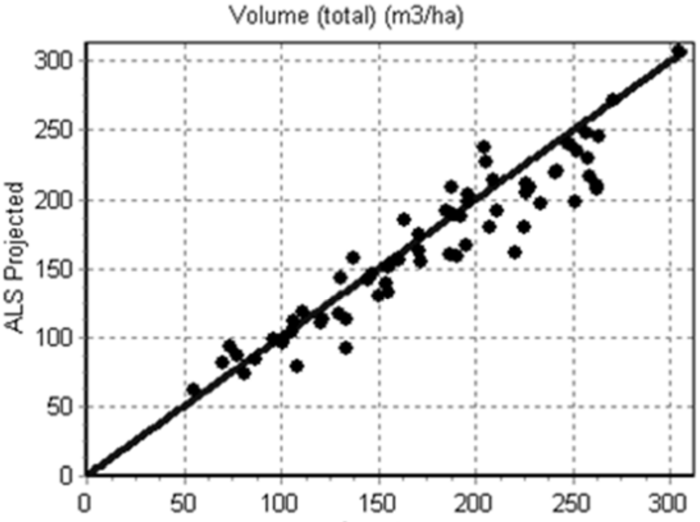

Figure 4: LiDAR Inventory prediction accuracy for total volume of E. dunnii in New Hanover.

Conclusions and Recommendations

LiDAR flights provide a number of base products like the DEM, DSM and CHM. The case studies showed that LiDAR inventories can also be done with reasonable success. Full LiDAR inventories can be done in most compartments older than 2 years where the dominant height is greater than 12m. For the rest of the compartments, the dominant height estimate can be used for a site-index based calibration.

It is our recommendation that we do LiDAR inventory predictions as a routine, when new LiDAR flights are done. Routine LiDAR flights will add value by improving the accuracy of our estimates of standing timber and Net Stocked Area.

Acknowledgements

We acknowledged the contributions of Dave Borain and his field team (from Nguni Forestry Services) for their dedicated work in ensuring accurate plot centres and forest metrics. Kendall James from Leica Geosystems for providing submetre GPS equipment and post-processing the GPS data, James Brodie from LRI for providing quality LiDAR data products.

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Estimation of compartment-level mean wood density and stem diameter in Australian radiate pine plantations using a hybrid modelling approach

D. Drew[1] *and G. Downes*[2]

[1] Department of Forest and Wood Science, Stellenbosch University, Private Bag X1,
Matieland 7602, South Africa.

drew@sun.ac.za

[2] Forest Quality, Franklin, Tasmania, Australia.

Introduction

In managed industrial forests it is important to be able to simulate forest growth and future yield for a variety of purposes. Forest managers might want to understand future risk profiles for a forested estate in a changing climate, or what changing silviculture might do to yields, for example. There is also an increasing need to predict the properties of the wood, and hence products derived from the forest. In that context, a model that predicts not only potential future product quantity, but also quality would be of great value. A promising approach is to use a "hybrid"-type model, such as the highly successful and flexible 3PG (Landsberg et al. 1997). Drew and Downes (2015) previously proposed a hybrid approach in concert with 3PG or the CaBala (Battaglia et al. 2004) model. But the complexity and slowness of iteration of the approach meant that application in a managed forest was still impractical. A new model was developed to (a) reduce complexity and depth of iterations and (b) make use of readily available streams of data at sufficiently high precision, with a daily stem step and modelling at the compartment level or finer. We report here on this new precision modelling framework as tested on a wide variety of *Pinus radiata* plantations in south eastern Australia.

Materials and methods

A modelling framework was developed that incorporates two distinct components. The first, which was developed from the 3PG model (Landsberg & Waring 1997) estimates daily net primary productivity, carbohydrate allocation and water balance at the stand level. Daily increment in mean tree height is calculated as a direct function of NPP. The second component simulates stem growth rate and xylem formation for the putative "mean tree" in the stand at any position in the stem below the currently estimated mean tree height.

A set of 124 *P. radiata* study sites (some sites were at the same location, but managed under different regimes) from across south- eastern Australia were used for model calibration and validation (Fig. 1). It was important for model simulations to make use of readily available, standardised site-descriptive data at sufficiently high precision for management decision making to be both practical and useful. Weather data were obtained from the Australian Scientific Information for Land Owners (SILO) interpolated daily weather grids for the location. Soil information for each site was obtained from the Australian Terrestrial Ecosystem Network (TERN) interpolated soils grid. Regime information for each compartment/research plot was obtained directly from the relevant forestry companies involved in the research.

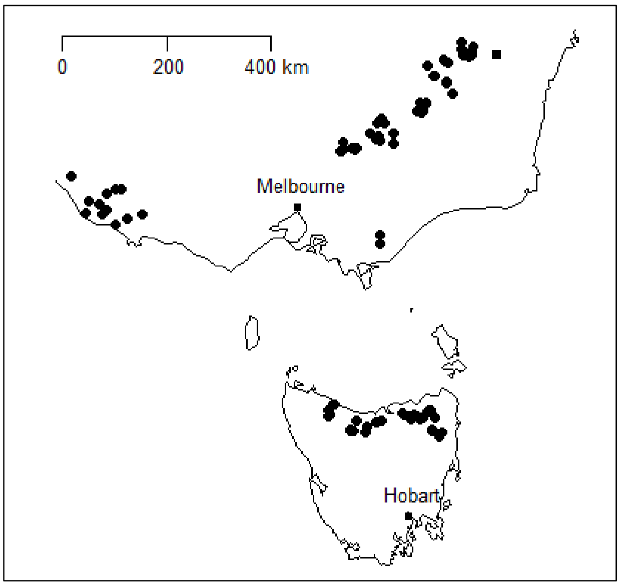

Figure 1: Map of study site locations in south eastern Australia

Of the sites available, a random set of 60% of the sites were used to reach the best parameter estimates for parameters that could not be obtained from the literature or physiological measurements. This was done by varying the selected parameters until the best model fit for outer mean wood density and mean DBH for the stand was achieved by means of the coefficient of determination, RMSE and the Akaike's Information Criterion (AIC). The fitted model was then applied to the validation set which consisted of the remaining 40% of sites, against which parameters had not specifically been optimised.

Results

Using a single set of parameters, the model framework explained about 67% ($p < 0.001$) of the variance in observed mean wood density in a 5 cm outerwood core sample for sites used to estimate parameters. For the remaining sites, not used for the parameter estimation, the model estimated over 50% ($p < 0.001$) of the variance in observed data. It is notable that one site in represented an important outlier, and its removal increased R^2 against the validation dataset to more than 60% ($p < 0.001$). The model explained about 50% ($p < 0.001$) of DBH variation in both calibration and validation datasets.

Conclusions

The modelling framework proposed here allows estimation of both mean tree size as well as mean wood density based on actual weather and site data that is readily available. One of the reasons the model did not explain more of the observed variation is that interpolated, spatially explicit and readily available soil data, particularly relating to fertility, is still not sufficiently accurate at many sites. The modelling framework does provide, however, a spatially and temporally precise approach to stratifying sites for low or high density, or tree size classes, and makes it possible to explore scenarios around changed future climates and altered regimes, and the interaction between these two factors.

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Applications and prospects of terrestrial LiDAR and drones for an improved forest inventory: a review based on current literature

E. Seifert[1,2]*, S. Seifert*[2]*, A. Kunneke*[1]*, D. Drew*[2]*, J. van Aardt*[3]*, T. Seifert*[1,2]

[1] Department of Forest and Wood Science, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa.

e.seifert@scimond.com

[2] Scientes Mondium UG (haftungsbeschränkt), Scientific Services, Ruppertskirchen , 85250 Ruppertskirchen, Germany.

[3] RIT: Center for Imaging Science, Digital Imaging and Remote Sensing Group, 54 Lomb Memorial Drive, Building 76-3124, Rochester, NY 14623, USA.

The development of novel technologies always has the potential to lead to a step change in a scientific field or in commercial application. With the advent of terrestrial LiDAR (TLS) and drones (UAVs) in the past years two very promising technologies have become available for precision forestry applications. Both technologies have created a lot of interest in the application for forest mensuration and inventory in particular. A bibliometric review showed a total of 331 articles addressing TLS and 274 articles addressing drones, respectively. An exponential increase of publications for both was recorded since the start of the century.

With their advent both technologies had weaknesses on the hardware and the software side, which initially largely prohibited their productive use in forests. The flight times of drones were limited as were their capacities to carry sophisticated sensors, which in turn were quite heavy. The first terrestrial laser scanners were too heavy and bulky and suffered from several technical teething troubles. However, as the technology has matured, the hardware and the algorithms have been substantially improved and a totally new generation of hardware and software is now available. Based on these novel developments and mounting scientific evidence on the applicability, reliability, and accuracy of drones and TLS, it appears appropriate to review existing precision forestry solutions based upon these technologies and revisit their uptake in commercial forestry.

Terrestrial laser scanners have been successfully applied for the detection of tree diameters and tree heights (Simonse et al. 2003, Seifert et al. 2010, Klemmt et al. 2015) as well as tree positions (Simonse et al. 2003) covering major variables of forest mensuration. First trials have been conducted to determine tree species based on bark structure via LiDAR as well (Haala et al. 2004). Beyond that, variables were successfully detected through TLS that could not be easily measured before in inventories. Examples are stem form (Thies et al. 2004, Seifert et al. 2010, Hackenberg et al. 2014, Barnett and Murphy 2015), pruned stem height (Seifert et al. 2010, Kankare et al. 2014), branch diameters (Seifert and Seifert 2008), crown surface (Seifert and Seifert 2008, Pretzsch et al. 2011, Seifert 2012), and bark scars that allow for the modelling of knots (Schütt et al. 2004, Stängle et al. 2014). While these methods are still in a scientific domain they raise the expectation that forest inventory information can be substantially extended by the application of TLS. An example application was presented by Seifert and Seifert (2010) who demonstrated how trees can be scanned and virtually sawn into timber products even before harvesting (Fig. 3, left). The benefit is an improved knowledge about the resource, which provides a large potential for management optimisation. Additionally, ground surface, slope, and obstacles, such as rocks, have been successfully detected (Biber et al. 2013, Chhatkuli et al. 2016), which could deliver important information for harvest planning. However, TLS application also has its limitations. One limitation certainly is that crown penetration is limited. This often leads to an insufficient coverage of the upper crown, which impedes the accurate determination of tree heights (Ducey et al. 2013).

Another drawback of TLS is the fact that it is a ground based method, making it expensive if larger areas should be covered. Thus, it practically remains a sampling technique, less suited for mapping entire stands tree by tree.

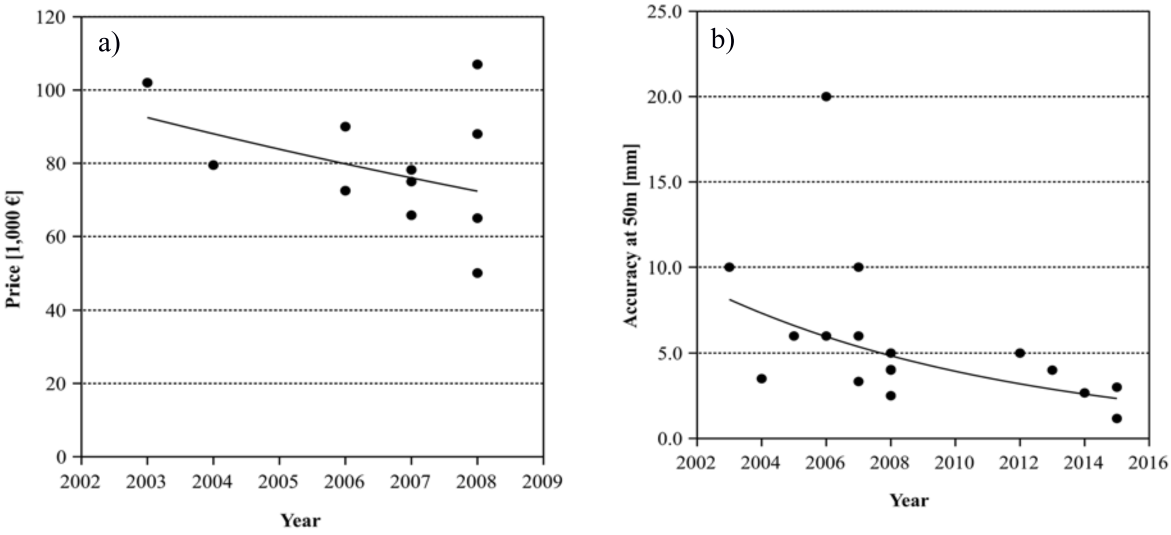

Figure 1: Analysis of development trends in (a) prices and (b) accuracy of terrestrial laser scanners.

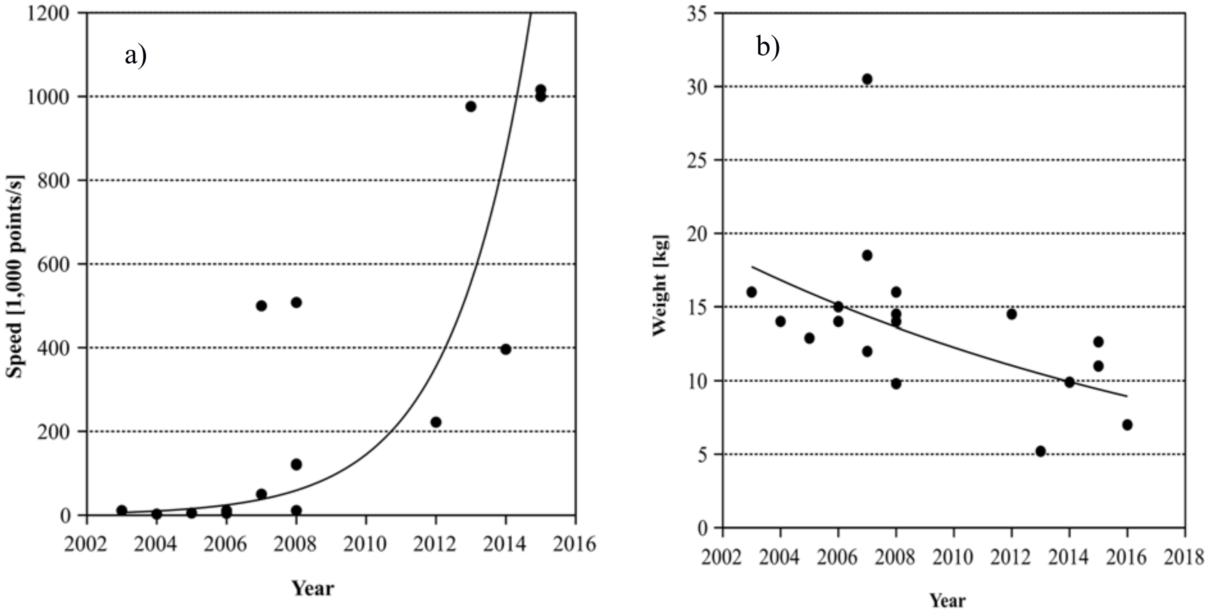

Figure 2: Analysis of development trends in (a) detection speed and (b) weight with batteries of TLS hardware.

Drones in contrast can cover full stands and have been used in forest inventory for classical mapping to delineate stand borders. Further applications comprise the estimation of biomass (Ota et al. 2015), tree stem mapping (Fritz et al. 2013) and the measurement of tree heights and crown dimensions (Zarco-Tejada et al. 2014). Torresan et al. (2016) also mention applications for tree species classification, quantification of spatial gaps in forests, as well as forest health and fire monitoring. The big advantage of drones is their ability to cover larger areas in a wall-to-wall mapping and the multitude of sensors. They can be equipped with digital RGB cameras (Dunford et al. 2009), multi-spectral sensors (Mäkynen et al. 2012), thermal sensors (Zarco-

Tejada et al. 2012), LiDAR (Wallace et al. 2012), and even RADAR (Li and Ling 2016). Thus, important variables such as tree species can be detected, which are difficult to determine by TLS. Drones also offer a good coverage of the upper crown, which is necessary for reliable height measurements. The software has developed rapidly, driven by newer approaches, such as Multi View Geometry (Fig. 3, right).

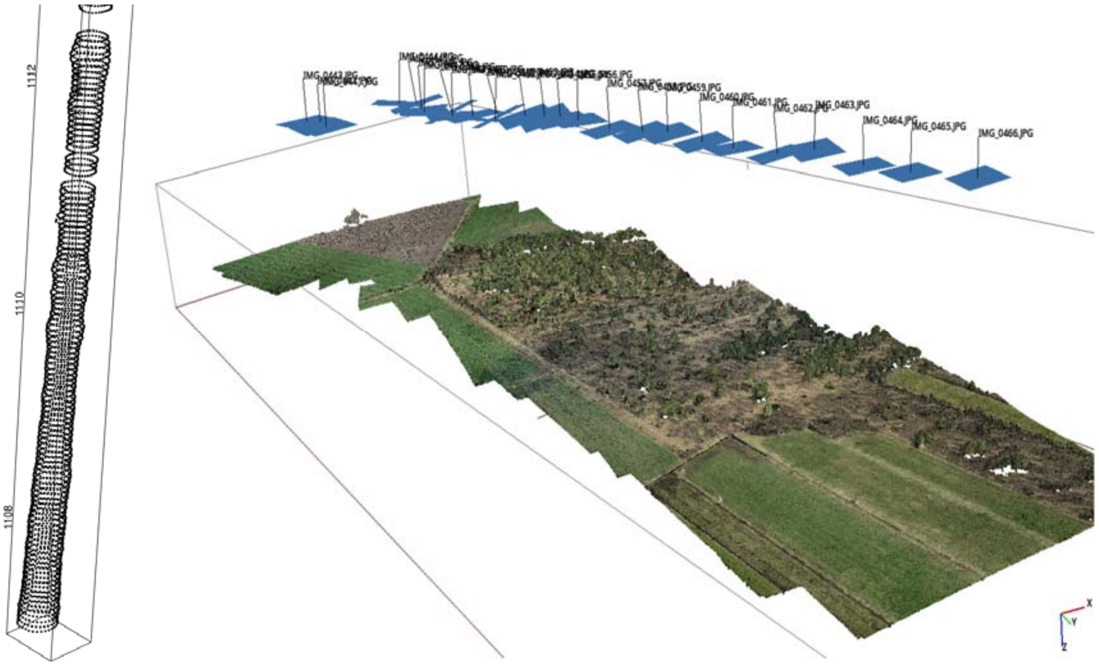

Figure 3: Surface model of a stem acquired with TLS (left) and 3D model and camera positions reconstructed from UAV pictures (right).

To date TLS and drones present themselves as highly sophisticated technologies with an increasing uptake in forest inventory. However, commercial software products for forest inventory are still in an early development stage. Despite this identified shortcoming it is already obvious that these new technologies will augment and amend existing mensuration and inventory systems in the near future and will lead to major advances in precision forest management.

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Implementation of computer vision algorithms for automated detection and diameter estimation of logs on trucks

M. Acuna [1] and A. Sosa[2]

[1] Australian Forest Operations Research Alliance (AFORA), University of the Sunshine Coast, Sippy Downs, Australia

macuna@usc.edu.au

[2]School of Biosystems Engineering, University College Dublin, Ireland

Introduction

Manually measurement of logs stacked at the roadside or on trucks is time consuming and labour expensive. Common features of interest include, but are not limited to, number of logs, diameter distribution, and volumes (Galsgaard et al. 2015, Norell 2010, Sosa et al. 2015). Recently, a number of computer vision algorithms and software solutions have been developed and implemented in real life applications. In this study we tested a solution method based on OpenCV computer vision algorithms, which were implemented in a tool named LogVision, using the Qt/C++ programming framework. Preliminary results show that our solution method has the potential to detect and estimate diameters of logs on trucks quickly and with a relatively high accuracy, which makes it suitable for use in operational conditions.

Materials and Methods

Data Acquisition

The data used in this study are digital images of end faces from logs carried on trucks and collected at the weighbridge of sawmills. The images size of each image was 640 x 480 pixels. In total, the data consisted of 22 digital images containing a total of 252 Radiata pine logs. The diameter of each log was measured manually with a measuring tape.

Image pre-processing

The background of the images was cropped using a grab-cut algorithm to remove noise from the sections of interest (end face of the logs). Another pre-processing step consisted in applying a contrast enhancement technique called convolution. These pre-processing techniques improved the quality features to be analysed and also the computation accuracy (Fig. 1).

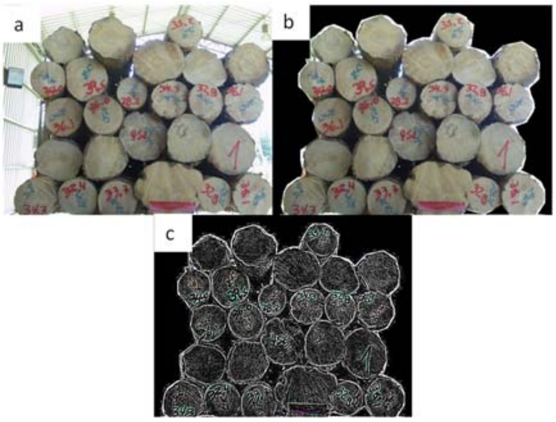
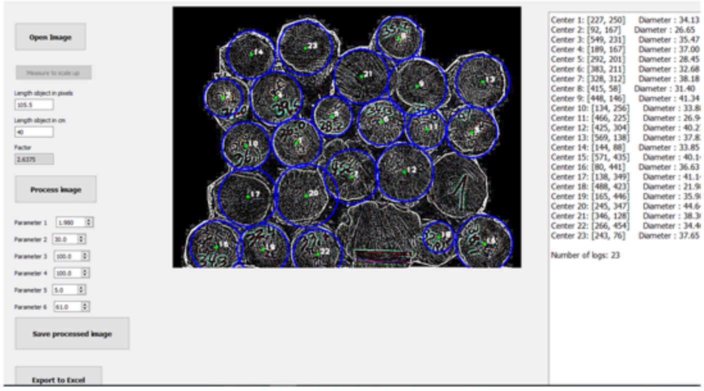


Figure 1: Images from the back of trucks carrying logs a) original b) with cropped background and c) convolved.

Image Analysis

The processing for the automated detection and diameter estimation of logs included the following functions/algorithms: 1. 2D filtering with a 5x5 kernel, 2. Changing of colour channels, 3. A Gaussian Blur algorithm, 4. A Hough Circles algorithm, and 5. A function to draw circles around the faces of the logs. All these algorithms and functions were implemented in a software named LogVision, which counts the number of logs and estimates diameters of the logs in the image (Fig. 2). The tool also allows data export to MS Excel and the image (jpg format) with the diameters calculated. The Hough Circles algorithm is the core of the detection system and makes it use of the Circle Hough Transform (CHT) technique, which is a feature extraction algorithm used in digital imagery to find circles in imperfect image inputs (Mukherjee et al. 2016).



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Length object in pixels
105.5
Length object in cm
40
Factor
2.6375
Parameter 1   1.980
Parameter 2   30.0
Parameter 3   100.0
Parameter 4   100.0
Parameter 5   5.0
Parameter 6   61.0
```

```
Center 1: [227, 250]    Diameter : 34.13
Center 2: [92, 167]    Diameter : 26.65
Center 3: [549, 231]    Diameter : 35.47
Center 4: [189, 167]    Diameter : 37.00
Center 5: [292, 201]    Diameter : 28.45
Center 6: [383, 211]    Diameter : 32.68
Center 7: [328, 312]    Diameter : 38.18
Center 8: [415, 58]    Diameter : 31.40
Center 9: [448, 146]    Diameter : 41.34
Center 10: [134, 256]    Diameter : 33.8
Center 11: [466, 225]    Diameter : 26.9
Center 12: [425, 304]    Diameter : 40.2
Center 13: [569, 138]    Diameter : 37.8
Center 14: [144, 88]    Diameter : 33.85
Center 15: [571, 435]    Diameter : 40.1
Center 16: [80, 441]    Diameter : 36.63
Center 17: [138, 349]    Diameter : 41.1
Center 18: [488, 423]    Diameter : 21.9
Center 19: [165, 446]    Diameter : 35.9
Center 20: [245, 347]    Diameter : 44.6
Center 21: [346, 128]    Diameter : 38.3
Center 22: [266, 454]    Diameter : 34.4
Center 23: [243, 76]    Diameter : 37.65

Number of logs: 23
```

Figure 2: Log diameter measurement tool developed in this study.

Results

The diameters measured and recorded in the forest were compared with the diameters calculated by the LogVision tool. The difference (cm) between the diameters calculated manually and with the algorithm was on average 0.52cm, with a maximum of 9.3cm and minimum of -8.9cm (Fig. 3). Approximately 71% of the variation was less than 3cm (Fig. 4).

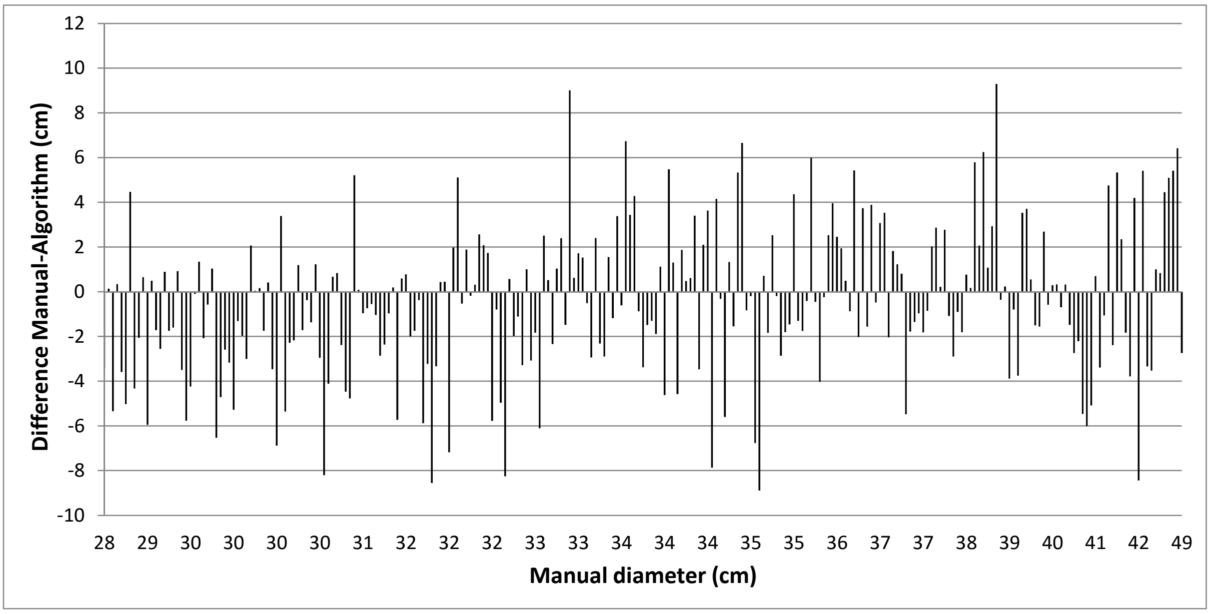

Figure 3: Variation (cm) between the manual and digital measurements of the diameters.

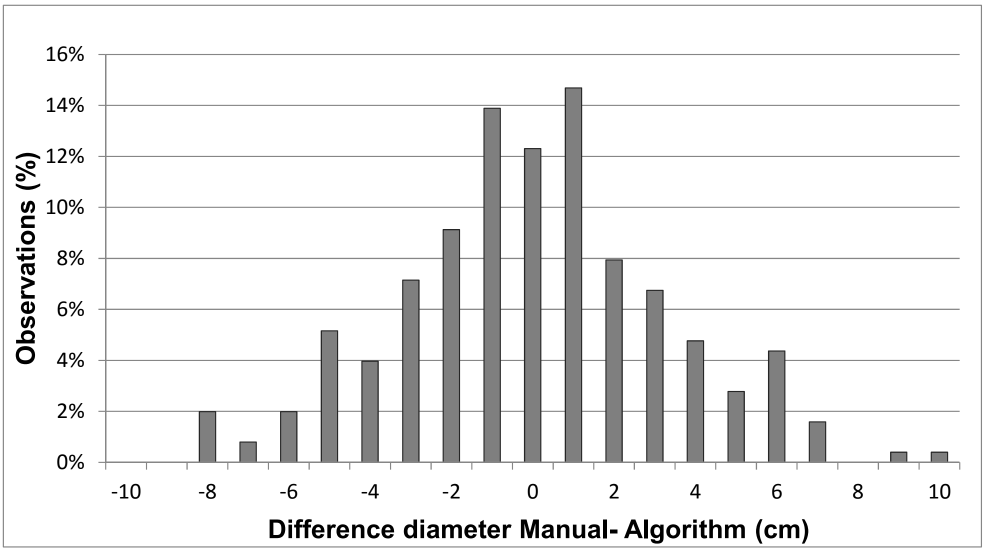

Figure 4: Distribution of the difference between the diameters measured manually and with the LogVision software.

Conclusion

In this paper we have presented a novel approach for detection and estimation of diameters of logs on trucks. The image processing and detection algorithms have been implemented in a tool named LogVision, based on OpenCV algorithms and developed with the Qt/C++ framework. Our preliminary results show the potential of the tool for log detection and diameter estimation in real life operations. Further studies will compare different image capturing and pre-processing techniques, and also different measurement algorithms to enhance the quality of the images. It is expected that the improved tool is fully functional before the end of the year.

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Physiological tree growth model for future model-aided optimal thinning operations

P. Fransson[1], *Å. Brännström*[1,2] *and O. Franklin*[3,4]

[1]Department of Mathematics and Mathematical Statistics, Umeå University, SE 901 87 Umeå, Sweden

peter.fransson@umu.se

[2]Evolution and Ecology Program, International Institute for Applied Systems Analysis, Laxenburg, A-2361 Austria

[3]Ecosystems Services and Management Program, International Institute for Applied Systems Analysis, A-2361 Laxenburg, Austria

[4]Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, SE-901 83 Umeå, Sweden

Introduction

In thinning operations, trees are removed to improve the development of a forest stand. Removal is normally based on rule of thumbs, to achieve e.g. spatial evenness. However, using such rules one may not necessarily find the optimal selection of individuals to remove, in order to maximize the harvest potential of a stand. To investigate this further, one would need to predict the future growth of the remaining individuals, through computer aided modelling. In the model, the growth of an individual is dependent not only on the abiotic environment and the state of the individual, but also on the state of its surrounding neighbors and the spatial relation to each other. With the additional information about operational aspects such as strip roads and spatial specific logging costs, such a model can be used as a decision-support to harvester operators, as well as a steppingstone towards autonomous thinning operations.

In this paper, we take the first step towards such a fully automated model-aided decision tool. Specifically, we develop a physiological tree growth model suitable for predicting the changes in carbon allocation, in a single tree, due to changes in the surrounding environment. We compere this model against the standard method Dynamic Programming, (Bellman 1954).

Methods

Our physiological model is built on the foundation of two principles, the well-known pipe model (Shinozaki et al. 1964) and the light-use efficiency model (Medlyn 1998). The pipe model states that the sapwood area, is proportional to the leaf mass. The light-use efficiency model is used to model the photosynthetic acquisition. These two principles enable us to express the growth of the whole tree in terms of crown size growth and stem height growth.

Based on the work of Fridman and Ståhl (2001) we introduce a size dependent mortality, which affects the individual tree.

We introduce a new biomass allocation model which consist of two strategies to cope with two different types of light conditions. One for shaded conditions below the canopy and one for near canopy light conditions. In the shade strategy, allocation should first prioritize crown size expansion until an optimal crown size is reached when priority is shifted to steam height growth. Finally, near the canopy, allocation is shifted towards crown-size growth until reproductive production starts. The allocation model was designed based on the assumption that every single tree tries to maximize its life-time reproductive output (seed production), which we take as a proxy for the fitness of an individual; provides a schematic scheme for our model.

We compare our model against the standard method Dynamic Programming (DP). DP is a method for solving complex decision-making-problems by dividing the main problem into smaller sub-problems and solve those in a recursive manner; in principle the method will find the allocation that maximizes the fitness by trying all possible allocation decisions. The two methods are compared by simulating the growth path and fitness of a single tree in different light environments with each method.

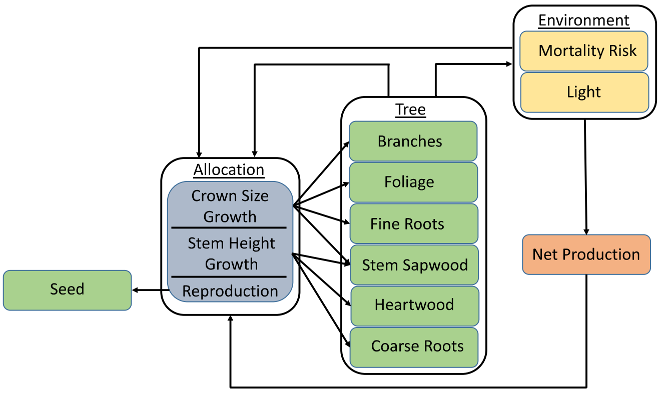

Figure 1: Schematic scheme of the system. The size of the six compartments of the tree and the light environment determine the net production. The net production is allocated to the six different compartments and seed production. Allocation is divided into crown size growth and stem height growth; the environment and tree size determines the partition.

Results

The heuristic allocation model approximates well the optimal trajectory, in terms of fitness value and the final tree height and basal area. The relative difference between the two methods does not surpass 2 percent.

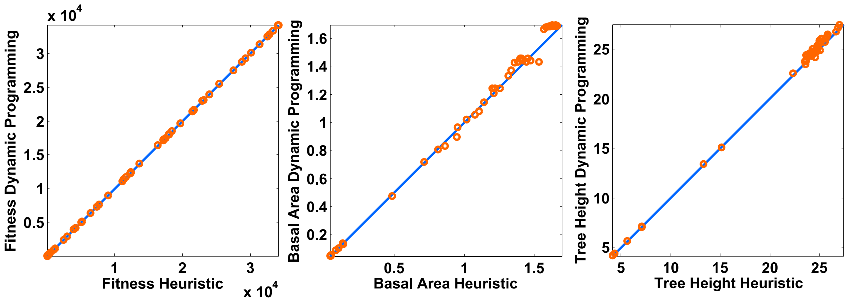

Figure 2: Fitness, tree basal area and tree height calculated by Dynamic Programming and the biomass allocation model.

Conclusions

We found that the growth path that maximizes a tree's fitness over its life time is not necessarily the one that will maximize the momentary growth, but instead one that strives for a balance between high photosynthetic gain and low mortality, and which appropriately invests for the future in terms of height growth to reach the canopy.

One emerging property from our model is that it predicts multi layered forest. The type of vertical forest structure predicted by our model is consistent with what has been observed empirically (Batista et al. 2014, Èermák 1998).

Our model is able to predict growth paths close to those predicted by Dynamic programming without suffering its draw back like heavy computational load.

The benefit of our allocation model, compared to traditional allocation methods like static allometric functions, lies in its ability to predict changes of growth due to changes in the surrounding environment. This aspect of our model is important to realistically simulate the impact of a thinning operation on the remaining tree community and thus it is a vital piece in creating an automated model-aided decision toolbox

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Precise localization and Mapping in forest with 6DOF SLAM

M. Pierzchala, P. Giguère and R. Astrup

Norwegian Institute for Bioeconomy Research, Postboks 115, 1431 Ås,
Marek.Pierzchala@nibio.no

Introduction

Advanced technology is forestry allows for precise data capture with use of onboard sensors. Most important tasks are conducted with support of automatically aquired data for example processor head or airborne data. There is a big need for spatial reference to ground tasks and due to poor GNNS reception under storey, this solution is not sufficient, therefore simultaneous localization and mapping (SLAM) algorithms are needed (Siciliano and Khatib 2008). Some studies with use of SLAM were conducted before for forest inventory (Tang, Chen et al. 2015) and for machine localization (Miettinen, Ohman et al. 2007). This study aims in generating 3D map of forest area with use of small 3D scanner VLP 16 and validating the accuracy of generated stem map.

Material and Methods

In our this approach, a mobile platform, 4 wheeled rover Superdroid 4WD IG52 DB is used to carry the sensor frame with microcontroller Pixhawk, VLP 16, stereo camera and GPS for global reference. Selected area represents homogenous Norway spruce stand with mature trees with no understorey. Mapping and localization is performed with near real time simulation on the recorded dataset to allow for flexible parameter configuration. For this a graph based SLAM approach is used with solely laser as odometry where ICP (Iterative Closest Point) algorithm is used to compute odometry (Minguez, Montesano et al. 2006). Resulted graph is optimized whenever a loop closure is detected and for optimization GTSAM (Dellaert 2012) algorithm is used. Optimized robot poses are used to assemble scans from Lidar and a 3d point cloud is generated.

Point cloud is processed in order to segment out the ground points and compute signed distance (SD) between the reconstructed ground mesh and points respresenting tree trunks, similarly to method proposed by Pierzchala (Pierzchała, Talbot et al. 2016). In order to validate the data set, points with SD between 1,2 and 1,4m are projected on 2D plane representing DBH. In order to detect single trees a Dbscan clustering method is applied (Ester, Kriegel et al. 1996). Ultimate step is to extract diameter by circle fitting and generating 2d position of a tree. Results are verified towards real measurements and trunk reconstruction quality is assessed.

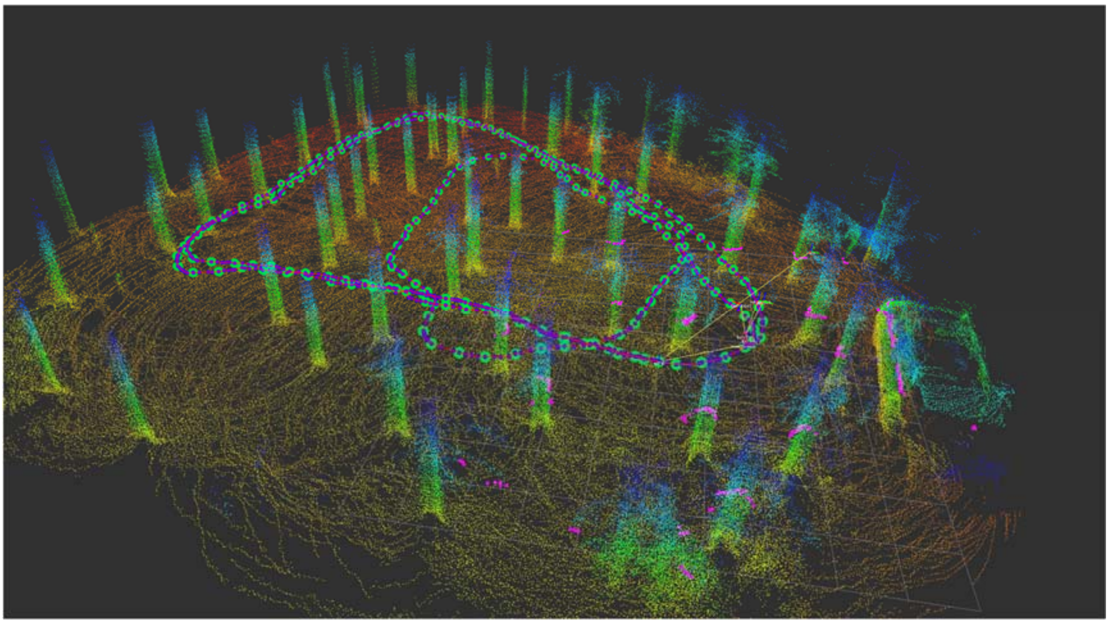

Figure 1: Generated 3D map with robot trajectory.

Results

With use of 6DOF SLAM a 3D point cloud was generated and single clusters were extracted. In total there were 67 clusters out of which 59 can successfully describe DBH and the rest of clusters represent other object (car) or cannot provide sufficient information due to occlusion caused by low suspended branches covering the stem. Comparison of the cluster centroids with fitted circle centers is a good indicator for stem recognition and error assessment. In this map standard deviation of this parameter is 0.05m which means that in most cases circles are fit well thus confirming the quality of the mapping.

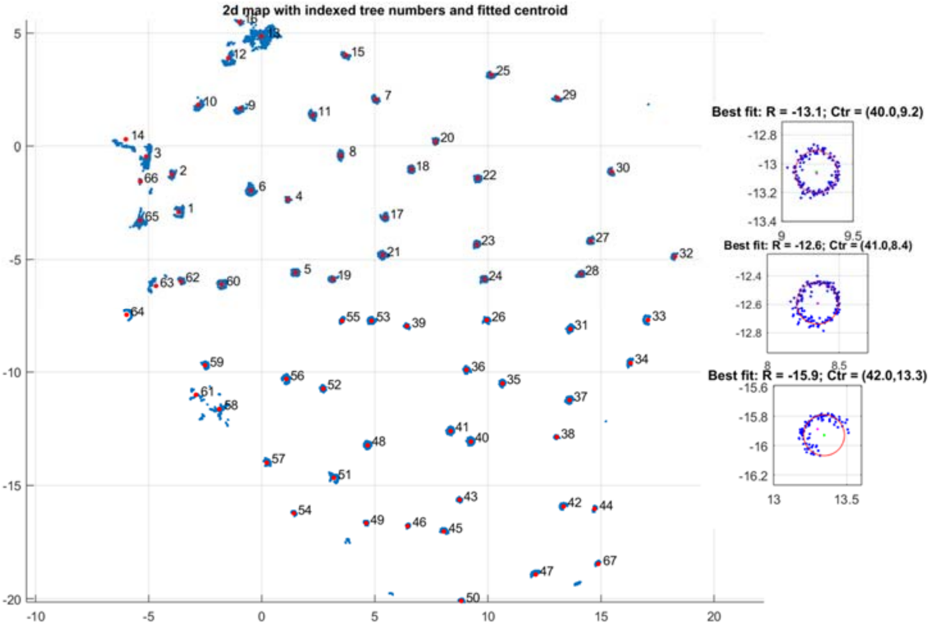

Figure 2: Projected trees with 3 selected examples of extracted clusters with fitted circles.

Conclusions

Use of 6DOF SLAM for machine positioning and forest mapping is an interesting and promising method. With this approach it is possible to provide supplementary underground information to ALS data with generated maps as well as position data that is important for machine localization. Successful localization is a fundament for autonomous operations. More attention should be put in developing forest specific mapping applications particularly adapting different parameter setup for various forest conditions.

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Inherent wood property mapping at the individual tree and landscape level for better utilization of the forest resource

M. Leitch and S. Miller

[1]Faculty of Natural Resources Management, Lakehead University, Thunder Bay, Ontario

mleitch@lakeheadu.ca

Introduction

The Canadian forest industry has undergone a major shift in how it conducts business due mainly to increase competition from other regions of the world, in particular the Southern Hemisphere. The forest sector in Canada needs to be more responsive to global demands. This requires a science-based understanding of the useful characteristics and limitations of the harvestable wood at the individual tree and landscape level. Lakehead University Wood Science and Testing Facility (LUWSTF) has developed non-destructive evaluation of wood properties (NDE) methodologies that fit into existing Forest Resource Inventory (FRI) Calibration Plot Specifications so that forest technologists can collect additional wood attributes data in tandem with core FRI field collection activities; without the need for specialized expertise. Employing NDE procedures LUWSTF and their industry research partners have developed Decision Support Tools (DST), which uses FRI and NDR field data, to optimize forest operation and planning activities, attract new investment and increase the value of the forest resource.

Materials and Methods

The materials and methods have 4 main sections.

Section 1 – Collecting inherent wood properties through destructive means – this was accomplished by destructively collecting the large, quadratic mean and small trees from a specific ecosite and then repeating this for all ecosites a species grows on. This was completed for all Boreal species growing in Northwestern Ontario. Sample trees were randomly selected and harvested with stem bolts from every 10% of total tree height then from 0%, 25%, 50%, 75% and 100% of merchantable tree height. Change in sampling intensity was based on initial studies where we found we could cut back to the 0%, 25%, 50%, 75% and 100% of merchantable tree height sampling with no loss in information. These were brought back to the LUWSTF for processing and testing of physical and mechanical properties following ASTM standards (which were also followed for representative sampling). This produced the base information about the trees main stem wood properties from pith to bark and base to crown for each species across its growing conditions (ecosites).

Section 2 – Developing a non-destructive methodology for inherent wood properties - this was accomplished using acoustic technologies combined with large diameter increment cores. The data collected during destructive sampling was used to calibrate the predictions for inherent wood properties of the acoustic tools. Some destructive samples were cut to confirm the predictions were accurate. This was accomplished by acoustically testing trees in the field and predicting all stem properties, followed by harvesting those trees and testing all the wood to compare the prediction to actual numbers. Once we were convinced the predictions were accurate we continued to collect data with the acoustic machine on all species. Large diameter increment cores were taken to get density profiles that are used in conjunction with the acoustic data to predict mechanical properties (i.e. MOE). From this lumber grades can be assigned.

Section 3 – Development of the LUWSTF Wood Science App – this was accomplished by hiring a programmer consultant to write the programming for the App to be used in all field sampling. This section occurred at the same time as Section 2 research. The App is a product of the LUWSTF and will be made commercially available in 2017. All field data (including acoustic data, site data, tree data including defects, stand composition etc) is inputted into the App (on field tablets) during field data collections and when workers return to the labs the data is uploaded through a wifi connection to the LUWSTF MS Access Database. The testing machines in the labs also use the App to control data so it is taken directly from the testing machines into the database and related to the field data. From here maps or data queries can be made.

Section 4 – Field testing of the App and methodology – this was accomplished through several field tests for several projects. The main one being a recent study to test the viability and operational efficiency and feasibility of the App on a 100,000Ha block in Northwestern Ontario for the provinces Forest Resource Inventory (FRI). This is an inventory the province does every 10 years to provide industry with information so they can write their management plans for their forest licence. This involved conducting 100 Forest Resource Inventory plots across the landscape and collecting the information traditionally collected in an FRI and using our system of information collection with our App. The 100 FRI lines conducted included all data collected from a traditional FRI cruise plus our additional information to allow wood quality attributes to be placed on the FRI as well. The study was to compare the two methods and see if the LUWSTF method produced the information requested by government and was operationally and economically feasible.

Results

The main results from Section 1 shows that the opportunity to increase value of each tree is possible by recognizing the inherent wood properties and potentially segregating the main stem into lengths that could then be sent to appropriate mills to maximize the utilization and therefore value. It was found that by mapping this information at this level of detail we could increase the value of each tree by as much as 30%. Fig. 1 shows a break-down of a trees inherent properties and where they change along the stem length and from pith to bark.

Section 2 and 3 describes the non-destructive method we use to predict the inherent wood properties from pith to bark and base to crown and at the same time were developing the Wood Science App and testing it. This was accomplished by using the acoustic values taken on the periphery of the tree and combing this with the density values from the large diameter increment cores and the acoustic testing of destructively harvested trees to compare. The destructively harvested trees were also used to acquire pith to bark acoustic profiles in order to use the density data to determine MOE values from pith to bark and up the main stem. This information was then produced for all species across their growing conditions (ecosites) and used for all subsequent predictions where only acoustic and density data was retrieved in a non-destructive manner. Fig. 2 shows the relationship between test properties allowing us to predict properties based on acoustic velocity, density and MOE. Section 4 was a large scale field test of the Wood Science App and our non-destructive methodology for collecting resource information for managers etc. Fig. 3 and 4 display some of the maps we have produced using our methodology.

Conclusions

The whole tree and landscape mapping program in the LUWSTF has been shown to be effective at collecting information relating to inherent wood properties at the individual tree and landscape levels. This is in part due to the Wood Science App developed by the LUWSTF where all data needed to produce the maps is collected through the App and then produced through the App. Our research has shown this to be an effective and accurate method of collecting field data without errors from data input in the field and in the lab. The App also allows all field data to be uploaded from the field tablets eliminating the chance of errors when inputting field data into the LUWSTF database. In a recent study the App was used to map a 100 000Ha block in Northwestern Ontario where it was proven that our non-destructive methodology for mapping could be added to the Provincial Forest Resource Inventory methodology and is operationally feasible and economic. This is a significant improvement for the industry and government. For industry it means a better description of the resource across the landscape and for government it means an increased ability to promote our resources to new investment.

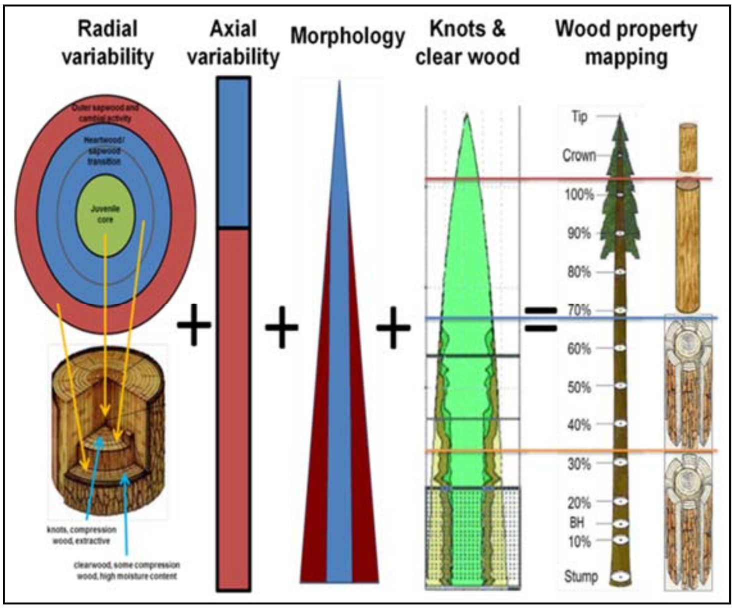


Figure 1: Wood Property Metrics.

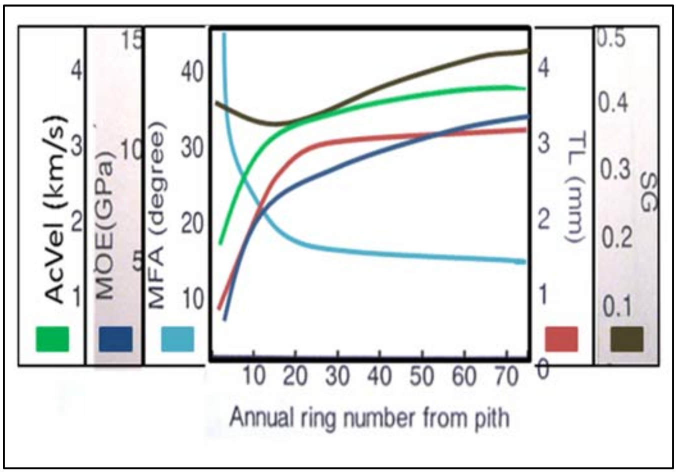


Figure 2: Relationship between test properties.

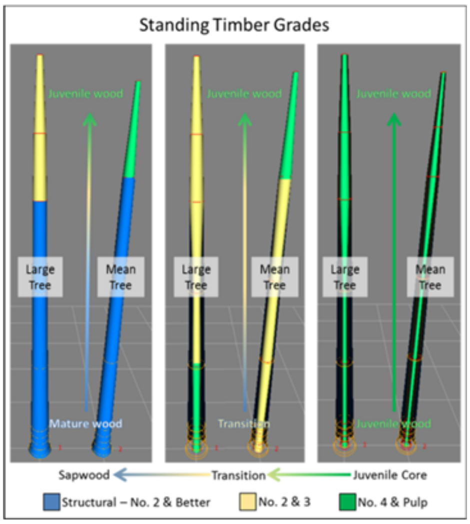
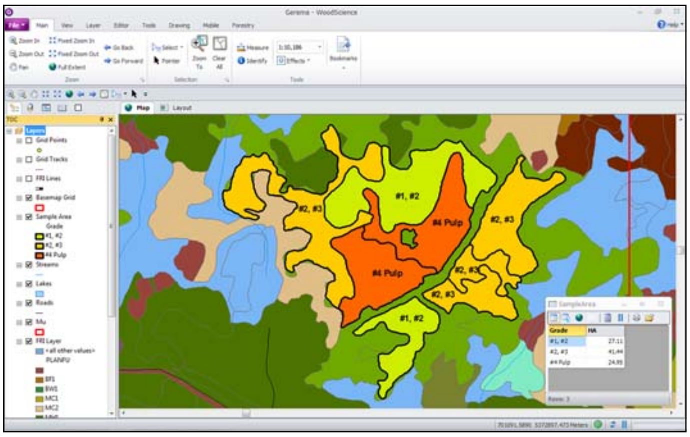


Figure 3: WS App 3D representation of standing timber grades prediction.



Grade	HA
#1, #2	27.11
#2, #3	41.44
#4 Pulp	24.95

Rows: 3

Figure 4: Integration of WS App plot data wood metrics with Gerema mapping functions.

A pedagogical interface for developing production management practices in Norwegian wood supply

D. Fjeld[1], E. Skagestad[2], N. Opsahl[3], B. Vennesland[1] and M. Fønhus[2]

[1]NIBIO, Norwegian institute for bioeconomy research, 1430 Aas, Norway
dag.fjeld@nibio.no

[2]Skogkurs, Norwegian forestry extension institute, 2836 Biri, Norway

[3]Nortømmer AS, 2411 Elverum, Norway

Introduction

The paper presents the development of a pedagogical interface for training production managers in Norwegian wood supply. Production management balances a trade-off between two different planning goals; market-orientation to fulfill mill delivery plans and a production-orientation to maximize capacity utilization. The goal for the development of the pedagogical interface was to provide a virtual planning environment where students and practitioners could experiment with the trade-off between planning approaches.

Development of the interface

The work started with mapping production management processes at three forest owners associations. This provided a basic process model for the sponsor organization which was dramatized in an instruction video. Harvesting data was collected from CTL harvesting teams over a period of 3-months including both initial contract volume data as well as the final scaled yield per assortment (Fig. 1).

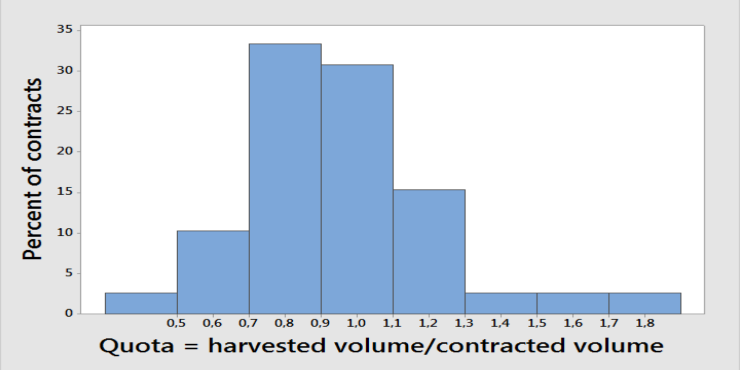


Figure 1: Distribution of quotas between actual harvested volume and expected volume per harvesting contract.

The planning goal given to the participants is to maximize a net surplus for monthly planning periods. In this context the net surplus is based on the sum of 1) bonuses for meeting assortment-specific delivery plans, 2) penalties for deviating from stipulated machine utilization and 3) costs for relocation. Rut repair costs are also included for sites harvested without the necessary bearing capacity for the scheduled season. Productivity models from earlier studies were used to forecast time consumption per site for harvesters and forwarders.

The interface is created in an Excel spreadsheet so participants can add a simple integer-programming solution for selection of sites for the coming planning period, using the same goal function and restrictions as the manual planning solutions. A site selection module is linked to a scheduling module to visualize site location, arrange relocations and present gantt-charts of site and machinery schedules.

The pedagogical approach

So far the exercise has been used to introduce new employees and forestry students to production planning. After a first (manual) planning cycle participants are divided into two groups with instructions to prioritize the one of the two planning goals (market- vs. production-orientation). After each planning cycle (spanning winter, spring and summer months) the KPIs are compared between groups. For the third planning cycle participants compare results between manual and optimized planning.

During all 3 cycles participants base their planning on the initial contracted volumes (expected yield for the stands harvested at each harvesting site). After the third cycle they enter the actual assortment yield (scaled volume) to examine the change in KPIs for both manual and optimal solutions. The exercise concludes with their own evaluations of the merits and weaknesses of the different planning approaches given varying levels of precision for harvesting contract data.

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New Values to the Bio-based industry by Precision Wood Characterization and Delivery

L. Wilhelmsson and J. Arlinger

Skogforsk, The Forestry Research Institute of Sweden, Uppsala Science Park, SE-751 83 Uppsala, Sweden

lars.wilhelmsson@skogforsk.se

Introduction

In Europe as well as in other parts of the world there is a scientific understanding and a growing public support towards the need for sustainable solutions on supply and use of material, energy and services (e.g. OECD 2009, Staffas et al. 2013, de Besi and McCormick 2015) as well as sustainable systems for food and feed. Politically, in Europe, research, development and innovation targeting less exploitation of fossil based and non-renewable resources towards renewable bio-based materials and energy solutions, cascading use (Sokka et al. 2015) and minimized waste i.e. “bio-economy” is clearly supported by the EU Framework Program for Research and Innovation - Horizon 2020.

Wood is a variable raw material and used for many different purposes and considerably larger than other non-food bio-material resources of the EU (EUROSTAT 2016). The currently growing stock in Swedish forests are 3465 million cubic meter total stem volume over bark, with an annual increment of 128 million (National Forest Inventory 2016). Main species are *Picea abies* 41%, *Pinus sylvestris* 39%, other conifers 1%, broad-leaves (*Betula, Populus*, *Alnus, Quercus* and *Fagus*) 19% in growing stock respectively. According to analyses and scenarios made by the Swedish forest agency (SKA15) a prolongation of the current intensity of silvicultural and environmental considerations in Swedish forestry accounts for a sustainable annual harvesting of 100 million cubic meter solid stem wood during year 2016-2029. The variation in growth speed and different wood characteristics are caused by combinations of genetic reaction norms including variation between and within species (Zobel and van Buijtinen 1989) over cambial maturity from pith to bark and root to top over time (Larson 1996) causing different rates and forms of cell divisions with response to climate, weather, soil and competition for available water, nutrients, light and space.

Different patterns of biotic and abiotic damage between and within species, between and within different regions are other important sources of variation in wood properties. The Swedish National Forest Inventory (2007) showed that on around 20% of the productive forest land at least 30% of the mature trees had at least one visible damage and on 7% of the land more than 50% trees with at least one such damage causing some kind of lower timber value and/or growth reduction. Undetected but rot (mainly spruce but logs) add some damage upon this. Despite the considerable percentage of stems with presences of damage a very high proportion of the sum of produced stem lengths remain undamaged. Nevertheless the result of all this variation may commonly reduce the possibilities to develop efficient precision manufacturing.

Precision wood characterization in the forestry biorefinery

Today, efficient measurements, including airborne and mobile terrestrial LIDAR, standardized production files from Cut-To-Length harvesters (Arlinger et al. 2012), imputation (Holmgren et al. 2012) and models for predicting wood and fiber properties (e.g. Wilhelmsson et al. 2001, Ekenstedt et al. 2003, Moberg 2006, Moberg et al. 2006) provide knowledge concerning the sources of wood variation, their magnitude and interactions. These means are comparatively inexpensive and can now be efficiently utilized into precision deliveries with respect to different parallel and consecutive value chains. The ability to characterize different forest resources, harvesting conditions, costs for harvesting and logistic operations and environmental concerns should all be included in a "Precision customer communication". We hypothesize that fully utilized this precision wood characterization will have a great potential to add considerable economic, environmental and societal value for boosting a forest-based bio-economy. Indications are presented in e.g. Wilhelmsson (2005), Nurminen et al. (2009), Wilhelmsson et al. (2011), and Larsson et al. (2016).

Material and methods for characterizing the Swedish forest resources

The predicted variations in a set of wood and fiber properties were analyzed by simulated CTL-harvesting and bucking of 114 677 diameter measured pine and spruce sample trees mature for final cut distributed over 4069 sample plots from all Sweden (Swedish National Forest Inventory 2005-2009). Tree heights and tree ages were measured on a subset of totally 39 032 sample trees for extracting height curves and tree ages for all diameter measured trees (Lundström and Nilsson, pers. com.) before the bucking simulation. A set of wood and fiber properties were then predicted by models and procedures described by Wilhelmsson et al. (2011).

Results and discussion

Fig. 1 shows the distribution of predicted basic density, thickest average branch/whorl and heartwood content of Scots pine sawlogs from entire database. Precision in LIDAR, CTL-harvester measurement, tree age accuracy and strength of the models indicate that 40-80% of this variation in wood properties, i.e. the fixed part of the explained variation by mixed models, can be controlled by means of existing technology. This include pre-harvest forest inventories, bucking simulation, stand segregation, based on combinations of imputation and prediction models into precision production control (CTL-harvester) and smart logistics.

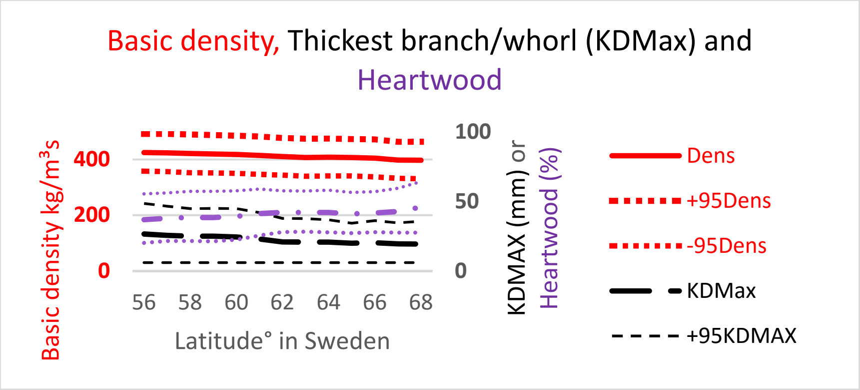

Figure 1: Example of precision communication on the existing forest resources in Sweden. Results from bucking simulation and prediction of wood properties of Scots pine (Pinus sylvestris) sawlogs (54133 logs). Averages (thick lines) and 95 percent confidence limits (thin dotted lines) over latitudinal gradients (56-68°) of predicted basic density, log averages of thickest knot diameter/whorl (KDMax) and heartwood content (%) are presented.

Straight and transparent precision communication, precision value chain analyses resulting in precision economic and environmental weights with respect to the impact of each wood characteristic on each industrial process, goal products, by-products and delivery accuracy and the cost and environmental load for actions needed are fundamental prerequisites to take advantage of the existing variation.

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Sawing optimization based on X-ray computed tomography images of internal log attributes

I. Duchesne[1]*, D. Belley*[2]*, S. Vallerand*[3]*, J. Barrette*[1] *and M Beaudoin*[4]

[1]Natural Resources Canada, Canadian Wood Fibre Centre, 1055 du P.E.P.S., Québec, QC G1V 4C7, Canada.

isabelle.duchesne@canada.ca

[2]Département des sciences du bois et de la forêt, Université Laval, 2405 rue de la Terrasse, Québec, QC G1V 0A6, Canada. Now with Ministère des Forêts, de la Faune et des Parcs. 5700, 4e Avenue Ouest, Québec, QC G1H 6R1 Canada.

[3]Département des sciences du bois et de la forêt, Université Laval, 2405 rue de la Terrasse, Québec, QC G1V 0A6, Canada. Now with Global Optimality, 34, boul. Champlain, Québec, QC, G1K 4H7 Canada.

[4]Département des sciences du bois et de la forêt, Université Laval, 2405 rue de la Terrasse, Québec, QC G1V 0A6, Canada.

Introduction

Current sawing optimization strategies in softwood sawmills are mainly based on external log characteristics. Yet, knots are one of the major defects affecting stem quality and lumber structural performance (e.g. Oyen et al. 1999, Longuetaud et al. 2012). Knowledge of internal log attributes is important to adapt sawing processes to the characteristics of fibre supply. The main objective of this research was to evaluate whether knowledge of internal knottiness combined with optimized log rotation could increase white spruce (*Picea glauca* (Moench)) and jack pine (*Pinus banksiana* Lamb.) lumber value yields. Three different sawing optimization strategies (*sweep up*, *shape optimized* and *knot optimized*) were used to compare lumber value yields in spruce and pine stems.

Methods and materials

Thirty-one white spruce (WS) and 22 jack pine (JP) trees were selected for the study. The 32-year-old trees were harvested in a Nelder Spacing Experiment, which was established in 1977 near Woodstock in New Brunswick (46.16^0 N, 67.58^0 W), Canada. The circular plantation design had a gradient of initial spacings ranging from 0.87m by 0.91m to 3.84m by 4.02m (12,000 stems/ha to about 600 stems/ha; see Belley et al. (2013)). Stems were scanned at 5cm intervals using FPInnovations true-shape laser scanner to obtain their external form in 3D. Before proceeding with the X-ray scanning, all stems were cut into 2.5 m logs, after which each log was joined for stem reconstruction in CT2Opti software. Each log was scanned with an X-ray computed tomography (CT) Siemens Somatom Sensation 64 medical scanner (Siemens Medical Solutions USA, Inc.) which is based at the Institut National de la Recherche Scientifique in Québec (Canada). The X-ray scans were performed every 2mm along the logs, producing a consecutive series of approximately 2,500 CT images by log. All CT images obtained from the scanned logs were then fed into CT2Opti software for stem reshaping and knot detection analysis. CT2Opti detects and extracts stem, pith and knot shapes from a sequence of CT images, and then reconstructs sawlogs with internal knots (Fig. 1; Vallerand et al. 2011). Thereafter, the data can be exported to Optitek to simulate different sawing optimization strategies. In the first *sweep up* strategy tested, the log's maximum deflection or sweep was placed in the vertical axis before primary breakdown. In the *shape optimized* strategy, the log was rotated to maximize lumber value recovery according to one simulated rotational angle. The log was first placed in the *sweep up* position and then rotated every 12 degrees to achieve the best solution (i.e. maximum lumber value). After completing 30 rotations, Optitek provided the optimal solution generating the highest lumber value recovery. After finding the best log position, the information on internal knottiness of each sawlog was fed into Optitek to extract lumber grades and values of sawing simulations. The third *knot optimized* strategy considered the internal knottiness information at the beginning of the simulation rather than after. Once again, the logs were rotated every 12 degrees and Optitek provided an optimal solution generating the highest lumber value recovery. Simulated pieces of lumber produced with this strategy were graded and valued the same way as for the first two optimization strategies.

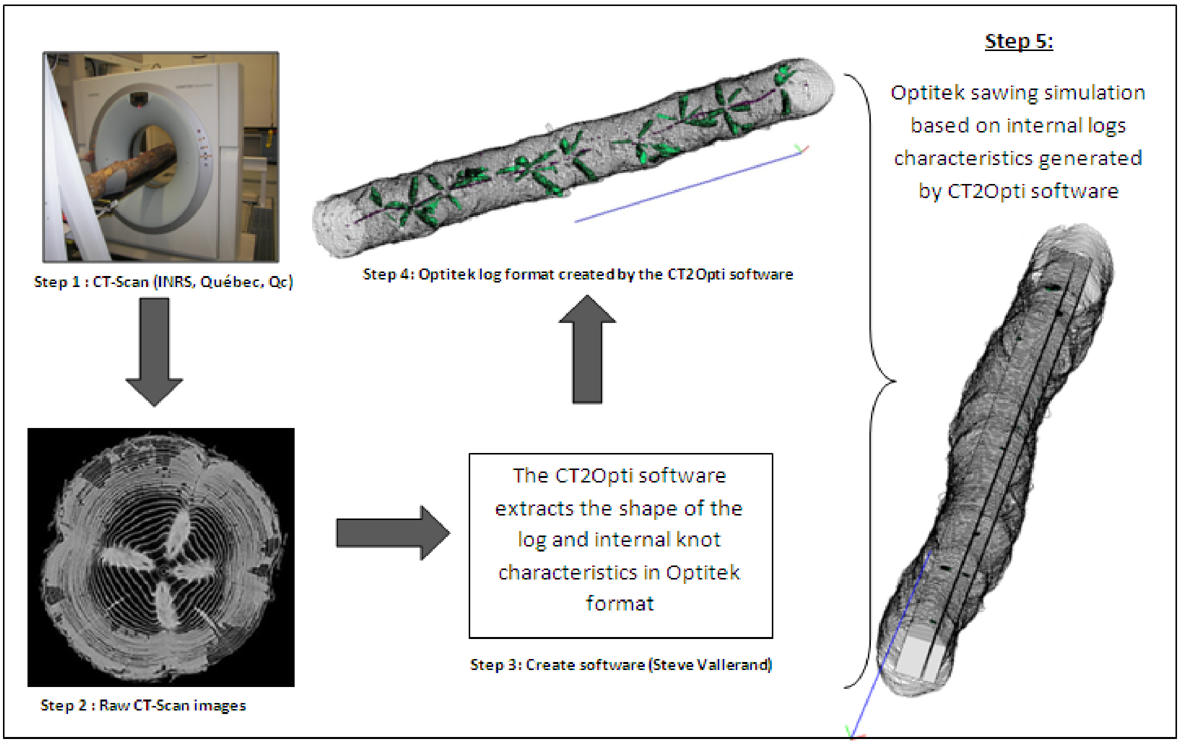

Figure 1: Log CT-scanning, CT2Opti image analysis for stem reshaping and knot extraction, and sawing simulation using Optite

Results- Sawing simulations in lumber value

The average scanned length of pine (10.3m) was higher than that of spruce (6.9m). Taper was larger in spruce (1.2cm/m) than pine (0.6cm/m) whereas sweep was smaller in spruce (0.5cm/m) than pine (1.0cm/m). On average, diameter at breast height and stem merchantable volume was larger in pine (18.1cm and 174.5 m^3) than in spruce (16.2cm and 99.4dm^3). In terms of lumber value, results from the ANOVA testing the significant difference between the two tree species (WS and JP) and the three levels of optimization (*sweep up*, *shape optimized* and *knot optimized*) showed a significant interaction between species and optimization levels (Table 1). Contrasts on this interaction reveal significant differences between sawing optimization strategies for each species (Table 2a). Looking deeper, the protected LSD multiple comparisons revealed that each sawing optimization strategy was significantly different from one another in jack pine and that both *knot optimized* and *shape optimized* were significantly different from the *sweep up* position in spruce (Table 2b). However, no significant difference arose between the *knot optimized* and *shape optimized* strategies in white spruce. The *sweep up* optimization strategy provided the least benefit in term of lumber value recovery (WS = \$253.40; JP = \$268.60) while the *knot optimized* strategy provided the highest lumber value recovery in both tree species (WS = \$291.60; JP = \$330.40). The *shape optimized* strategy fell between the two others (WS = \$277.00; JP = \$304.10), meaning that more flexibility in terms of log positioning, based on the external shape of the logs, can provide additional monetary benefits. The increase in lumber value recovery from *sweep up* to *knot optimized* was 23% in JP and 15% in WS, while the increase between *shape optimized* and *knot optimized* was 9% for JP and 5% for WS. In summary, the sawing strategies can be ranked as follows:

WS lumber value recovery: Sweep up < Shape optimized = Knot optimized
JP lumber value recovery: Sweep up < Shape optimized < Knot optimized

Table 1: Split-plot ANOVA table testing the effect of tree species (white spruce and jack pine) and sawing optimization strategies (sweep up, shape optimized, knot optimized) on sawing simulation in lumber value (\$).

Effect	**Num. DF**	**Den. DF**	**F Value**	**Pr > F**
Species	1	48	2.12	0.1515
Optimization	2	93	26.82	<.0001
Species*Optimization	2	93	5.58	0.0052

Table 2a: Contrasts on the interaction terms to test differences in lumber value (\$) between the three levels of sawing optimization strategies within each species.

Slice	**Num. DF**	**Den. DF**	**F value**	**Pr > F**
Species (WS)	2	93	31.31	< 0.0001
Species (JP)	2	93	15.04	< 0.0001

Table 2b: Protected LSD multiple comparisons of lumber value ($) among the three levels of sawing optimization strategies for each species. LS-means with the same letter are not significantly different.

Slice	**Sawing optimization strategies**	**LS-means**	**Std Error**	**Grouping**
Species (WS)	*Knot optimized*	2.1335	0.1482	A
	Shape optimized	2.1116	0.1482	A
	Sweep up	2.0473	0.1481	B
Species (JP)	*Knot optimized*	2.5377	0.1694	A
	Shape optimized	2.4202	0.1694	B
	Sweep up	2.3125	0.1694	C

Conclusion

By considering internal knots before log sawing, 23% more lumber value was generated for jack pine and 15% for white spruce compared with the *sweep up* sawing strategy. These encouraging results indicate a good potential to increase mill profitability by implementation of the CT-scan technology.

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Cable logging operation supported with sensor fusion

M. Pierzchala, K. Kvaal and S. Grigolato

[1]Norwegian Institute for Bioeconomy Research, Postboks 115, 1431 Ås,
Marek.Pierzchala@nibio.no

Introduction

Cable yarding operations, which are actively used in many countries, are often based on old systems that do not possess advanced sensors. A standalone system that both contains sensing and computing resources is a cheap and efficient alternative for getting valuable information from the machines that are not self-equipped with any data logging device. Sensor system works independently and evaluates the operation based signal processing. Cable yarding operations are executed in a schematic way and despite of being a semi manual system, they follow automated routines. Cable logging has easy to distinguish phase cycles that always follow the same order which can be explained by state machine concept. Numerous studies were done to analyze machine performance with use of field computers(Spinelli, Maganotti et al. 2015). But instead of manual interpretation ,there are attempts to do it automatically (Gallo, Grigolato et al. 2013). This work presents a workflow for real time sensor fusion together with wireless communication between independent machines as well as automatic process phase prediction using sensor readings.

Material and methods

In cable logging, we distinguish process phases that occur in every turn. In following, the time study method (Huyler and LeDoux 1997) after slight modification we can list the following elements for every cycle: outhaul empty, lateral out, hook-up, lateral in, inhaul unhook.

For process monitoring, a peer to peer connection is established between the tower and carriage with use of two TP-Link (WA5210G) access points. On cable carriage, single board computer with peryferical android device and 2 cameras is used to record data.

With this setup it was possible to record different sensor data at different frequencies: GPS, IMU (Linear acceleration, Angular velocity and orientation), Images. IMU data was filtered using Kalman Filter and Images were processed in order to obtain motion vectors from optical flow (Farnebäck 2003). Second step was the offline data analysis with attempt to predict phases using principal component analysis with 5 cycle phases to be distinguished.

Figure 1: Konrad Woodliner carriage with access point facing the tower, android device and single board computer - raspberry pi at the bottom with attached camera.

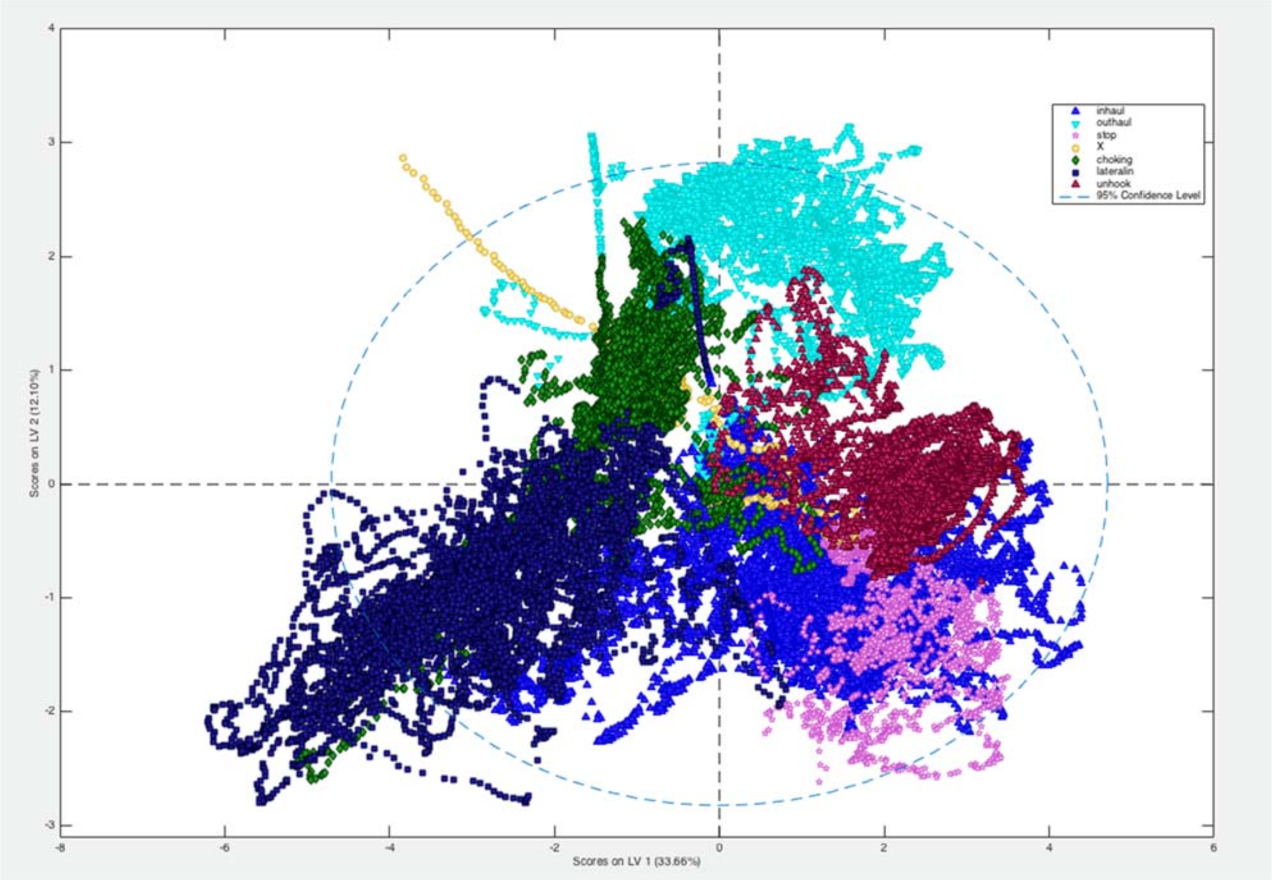

Figure 2: Score plot for distinguishing different operational phases.

Results

This setup allowed getting a stable wireless connection between the tower and cable carriage. No significant latencies were present and compressed images were successfully streamed to the landing. Confusion table shows a great share of correctly predicted phases (Table 1).

Predicted as:	**Actual**					
	Inhaul	**Outhaul**	**Stop**	**Choking**	**Lateral In**	**Unhook**
Inhaul	11066	0	103	65	234	275
Outhaul	0	5930	0	81	0	357
Stop	1092	83	6295	24	81	798
Choking	730	750	0	16803	1327	0
Lateral in	1231	0	0	998	7290	0
Unhook	1198	1	26	0	0	5497

Conclusions

This study shows that automatic cycle segmentation is successful with use of onboard sensors. Wireless communication allows for incorporating other machines that participate in the logging process providing with productivity data. Clear distinction of operational phases based on sensor reading can support reporting of such activities. Also, integrating sensor devices should facilitate autonomous forest operation allowing for robust auto control.

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Mapping the South African pulpwood supply chain

S.A. Ackerman, D.N. Rietz and LW Titshall

Institute for Commercial Forestry Research, PO Box 100281, Scottsville, 3209

Simon.Ackerman@icfr.ukzn.ac.za

Summary

Plantation management involves a cycle of operations that are often viewed and managed as separate and discrete events. This can lead to miscommunications, inefficiency of spending and the focus of resources that do not benefit the overall supply/value chain. By investigating the interaction of parts of the South African supply chain, and in particular the interaction of harvesting and silviculture, it is evident that cost-effective operations are a priority. These operations generally do not involve large scale mechanisation (in harvesting or silviculture) but requires a re-focussing of what is done and how work it allocated and managed. This work has led to further analysis of the pulpwood value chain and identified the connections between particular aspects and nodes (or operations) where further efficiencies can be achieved. This identification and analysis of the pulpwood supply chain was achieved through inter-company collaboration and is a first for the South African forestry industry.

Introduction

The focus of many companies on the improvement of supply chain efficiency and responsiveness is from the recognition that supply chains compete more than companies do with one another (Cox 1999). In essence, companies that improve the total performance of their supply chain will be more successful than those that optimise discrete components but with no integration (Cox 1999). A supply chain contains the full range of activities that are undertaken to take a product from its most basic form to the sale of the final product (Cox 1999). Historically, the South African forestry supply chain was divided up into discrete sections, usually nurseries, silviculture, harvesting, transport and processing, with each being managed separately to optimise operational and financial efficiency of a given section. However, when viewed from a full supply chain perspective, optimisation within sections often results in loss of efficiency in other sections and possibly even losses in production. This recognition has prompted the forestry industry to look at their supply chain in a more holistic manner, and to develop the understanding of how the optimisation of an operational section (e.g. nursery, silviculture, etc.) impacts on other sections in the supply chain, and ultimately on the value realised from the full supply chain (Rietz et al. 2015).

This paper details the results of the first South African Forestry led ‘brown paper’ mapping for the South African pulpwood supply chain. It details current challenges, possible solutions and any opportunities typical for the South African forestry industry.

Materials and methods

An initial map (or framework) of the eucalypt pulpwood supply chain was utilised to give a basis for the workshop. This initial map was based on a basic system for plantation forestry production from stock production to mill-gate and adapted based on engagement with various stakeholders prior to the workshop. The draft supply chain map was presented and a consensus as to where to begin analysing the supply chain was obtained. All steps and options within each component, as well as any links between steps or options, of the supply chain were then discussed and key points captured for these.

This was done through a brown-paper exercise aims to map a supply chain as it currently operates (not as it should operate), to identify challenges and opportunities and to understand the relationships between various sectors and markets (Brown Paper Process Flow Analysis 2016). To fully capture the information in the forestry supply chain, process owners of the different operational sections (e.g. planning, harvesting, silviculture, nurseries) within each of the major pulp-processing companies were engaged.

Results and discussion

The results of the exercise yielded a conceptual map of the South African forestry supply chain (Fig. 1). This included understanding the different parts of and the interaction of these parts on each other. Details of the main criteria, interventions, opportunities and potential for new investigations and research are also discussed and highlighted.

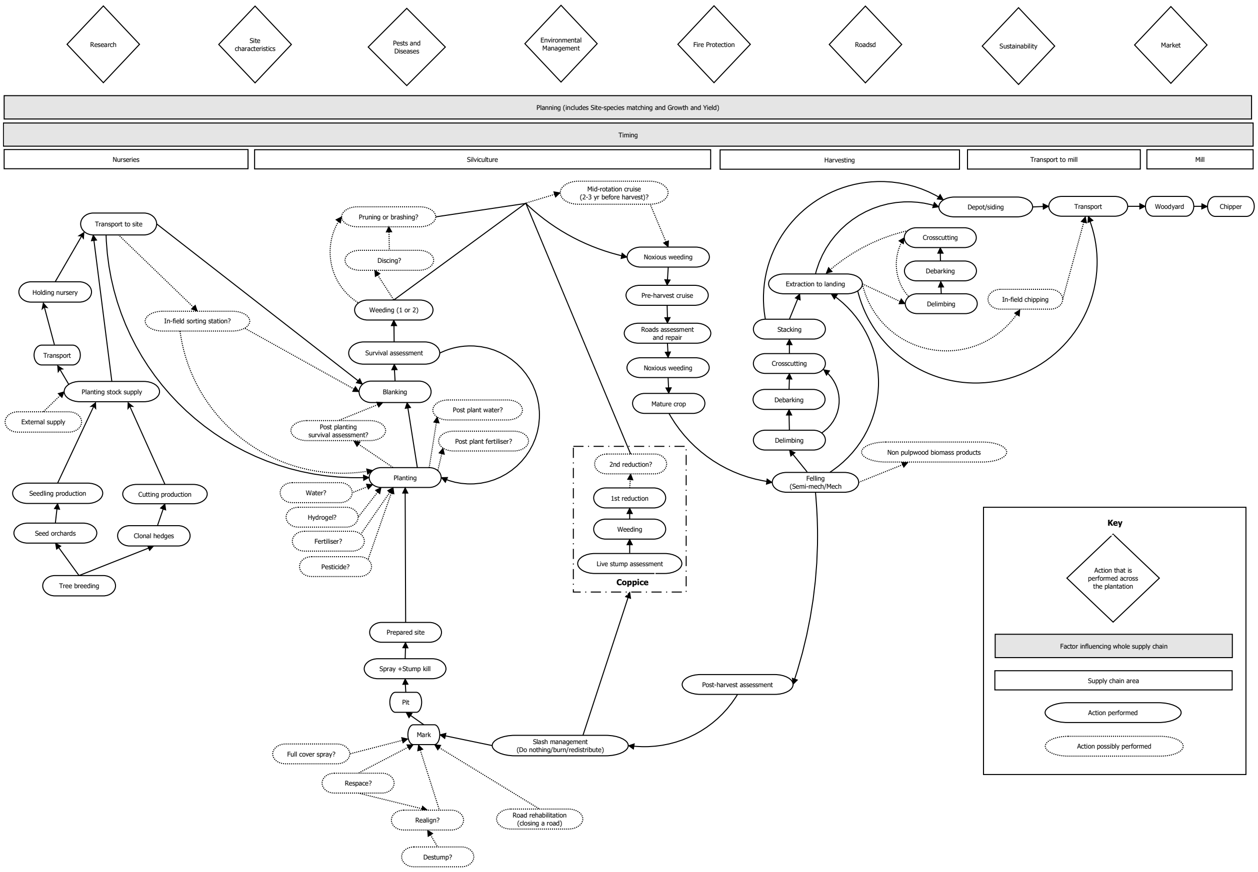

Figure 1: The South African pulp wood supply chain.

Conclusion

The results of the workshop show that there are many areas within the eucalypt pulpwood supply chain that could be optimised, some of which would be through a change in management, others require research to determine if they would result in improved efficiency or productivity. The next step would be to identify the variables required, mathematical relationships and potential measures/indicators of various steps and options within the supply chain. This process will highlight the priority of research needs for the supply chain by giving an indication where there is little or no information available. Once the various variables are linked together using the mathematical relationships in a decision support framework and system, the costs and resultant revenue of various options can be applied to assist companies or individuals to make informed decisions.

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Theme Two: Utilising precision data for efficient forest management and operations

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Session Chairs: Dave Drew; Dirk Längin

Time of arrival variations for short-sea shipping of roundwood and chips within the Baltic Sea

D. Fjeld[1,2], B. Talbot[2]

[1]Swedish University of agricultural sciences, Umeå, Sweden. dag.fjeld@slu.se

[2]Norwegian institute for bioeconomy research, Aas, Norway. Bruce Talbot@nibio.no

Introduction

The Nordic wood supply import has varied considerably over the last 15 years. For Sweden these volumes decreased from 13 million m^3 in 2000 to just under 8 million m^3 in 2009, rebounding thereafter to approximately 11 million m^3 in 2013. Although these volumes are marginal for many mills, predictable deliveries are important for reliable wood supply. For sources in the Baltic Sea region, these volumes are delivered with small bulk vessels (under 10 000 DWT). Although typical cargo sizes for roundwood shipments are small in relation to other bulk products, one vessel carries the same volume as 100 trucks or 3-4 trains. An overview of the current level of arrival precision is therefore important for efficient coordination of supply with domestic sources.

An overview of import sourcing from 2000 to 2013 shows the main volumes from Latvia, Estonia and Russia, with Russian volumes later being surpassed by Estonian and Norwegian volumes after 2008. Given that Norwegian volumes were delivered primarily by rail, this leaves the same three sources as the dominant sources for shipping of import volumes. The goal of the study was therefore to quantify the cargo-level arrival precision for short-sea shipping of roundwood and chip deliveries from the three main sources to Sweden.

Material and methods

Data was made available from Vesselplan (www.vesselplan.com) for 335 roundwood and chip shipments during 2013. The Vesselplan system provides an online platform for storing, exchanging and updating wood flow plans and delivery information for all members companies based on a common cargo identification. The flows selected were from Latvian (4), Estonian (2) and Russian (8) ports of lading (PoL) to ports of dischange (PoD) in south (11), southeast (16) and north Sweden (17). The distribution of cargoes is shown in Table 1.

The variables examined included aggregate voyage time (including delays before leaving PoL, voyage time and delays before discharging at PoD) as well as the estimated and actual times of arrival (ToA) at the port of discharge. Data on all cargoes was anonymous without specification of seller, vessel or customer.

Table 1: Number of cargoes per selected flow from port of lading to port of discharge.

		No. of cargoes to Port of Discharge		
	Port of lading	S SWE (11)	SE SWE (16)	N SWE (17)
	LV (4)	38	76	76
	EST (2)	11	46	29
	RU (8)	0	32	27

Results

Vessel cargo sizes were divided into classes of under 2000mt (class 1), 2000-4000mt (class 2) and over 4000mt (class 3). Class 2 cargoes dominated for the PoDs in the south (11, 16) while class 3 dominated in the north (17). Class 3 cargoes were most frequent during january-march (Q1), declining through april-june (Q2) to the lowest proportion during july-september (Q3), thereafter increasing through october-december (Q4).

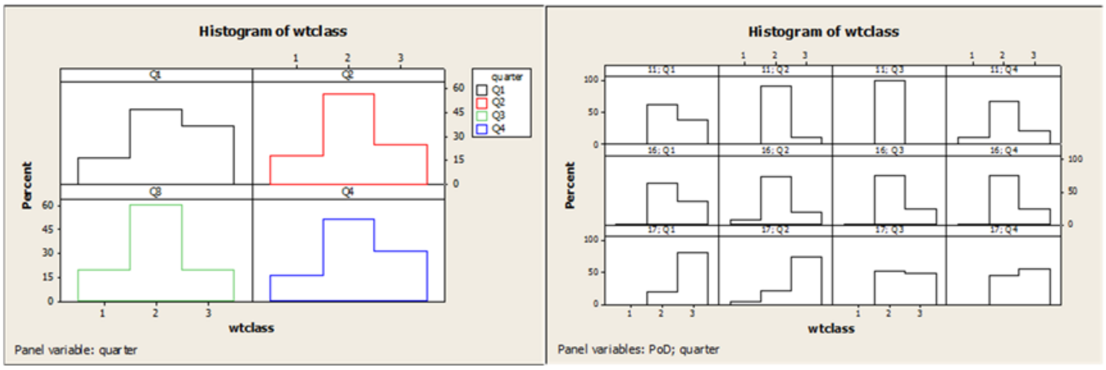

Figure 2: The distribution of vessel cargo weight classes (wtclass) per quarter (Q1-Q4) on left and per port of discharge (PoD 11, 16, 17) on right.

The average time between loading and discharging was just over 60 hours. This time consisted of 59% voyage time, 36% delays before leaving PoL and 5% delays before discharging at the PoD. The average time between PoL-PoD combinations ranged between 26 and 66 hours.

Overall, 85% of cargoes arrived within 5 hours of their estimated time of arrival. The deviations between estimated and actual time of arrival (ToA) show the expected right-skewed distribution with a higher frequency of late arrivals than early arrivals (Fig. 3). The smallest ToA deviations were for PoDs in southern Sweden (11) where cargoes come predominantly from PoLs in Latvia (4). The largest deviations were for PoDs in the southeast and north where a higher proportion of cargoes come from Estonia (2) and Russia (8). The percent of on-time arrivals was highest for cargoes from Latvia (4) and Estonia (2) and lowest from Russia (8).

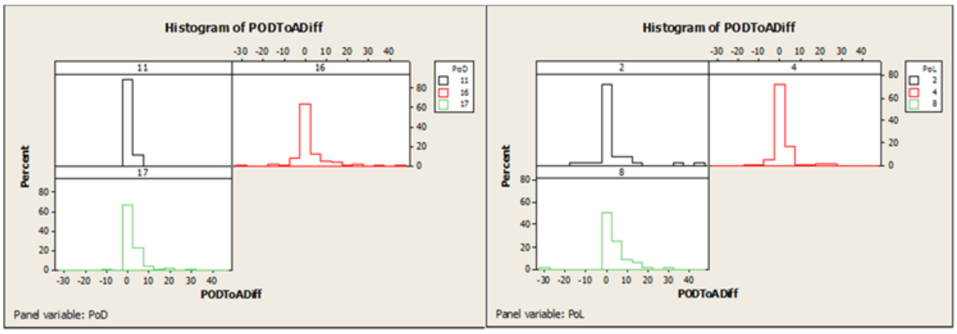

Figure 3: The distribution of deviations between estimated and actual times of arrival at port of discharge (PoD_ToA_Diff in hours). The figures on the left and on the right are the distributions per PoD and PoL, respectively.

Discussion

The follow-up of delivery data via Vesselplan served as a useful source for quantifying risks for delayed arrivals via short-sea shipping for the various PoL-PoD combinations. While experienced shippers have an intuitive understanding of these, such quantitative measures are useful for further OR work.

The overall distributions of deviations between latest estimated and actual time of arrival showed a relatively high proportion of on-time arrivals (85 % within 5 hours of estimated ToA). Figure 3 visualizes the longer delays associated with northern shipping routes such as RU (8) to N SWE (17). Surprisingly, the study did not quantify any increase in delays during the winter. This is presumably due to the mild mid-winter ice conditions during study period where both the Gulf of Finland (PoL 8) and Gulf of Bothnia (PoD 17) had primarily drift ice conditions with limited amounts of fast ice. This, in combination with the more frequent use of larger ice-classed vessels to ports in north Sweden (Fig. 2) limited the adverse effects of winter conditions.

Import statistics since 2000 show a gradual increase in the number of countries exporting roundwood or chips to Sweden until 2004-2007. Since then, volumes have become increasing consolidated to fewer sources. The initial period was also associated with more frequent use of general purpose bulk vessels (min-bulkers or coasters). With later reduced import volumes and consolidation of sources, there has been an increasing use of specialty wood-shuttles, with wider and shallower hull profiles enabling larger deck loads and easier access to more marginal ports. Given the larger vessel cargo sizes for the northern PoL-PoD flows (Fig. 2), this trend for specialized vessels is most relevant for the shorter southern routes.

Acknowledgements

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Utilisation of high resolution harvester production data for improved forest operations and management

J. Arlinger, J.J. Möller and J. Söderberg

Skogforsk, The Forestry Research Institute of Sweden, Uppsala Science Park, SE-751 83 UPPSALA, Sweden.

john.arlinger@skogforsk.se

Introduction

Detailed standardized production data (hpr- or pri-files) is collected by all modern CTL harvester computers during harvesting. All data are stored in standardized StanForD files (Anon 2013, www.skogforsk.se/stanford2010). This data can be utilized in order to improve forest management and operations, feedback to operators and forest owners.

There is a large number of new implementations based on harvester data under introduction, including follow up of machine productivity and reliability, automatic thinning evaluations, regeneration planning after final felling, forest residue estimation etc. The objective of this presentation is to present two of the latest fields of applications based on harvester data, in order to illustrate the possibilities that are available today:

- improved pre-harvest assessments (yield estimations)
- monitoring of harvester operator quality (manual decisions vs optimization)

Detailed harvester data

Measuring data for each stem and log are registered continuously, including e.g. dimensions, species, coordinates, time, operator decisions etc. These data can be used in order to re-construct the trees and the forest that was felled (Fig. 1 and 2). When reconstructing stems a number of filtering algorithms has to be implemented in order to e.g. handle stem breakage. Algorithms have been developed (Bhuiyan et al. 2016) in order to calculate the harvested area using coordinates of the stems as well as segmenting the site into sub-areas with more homogenous trees based on the dominant height.

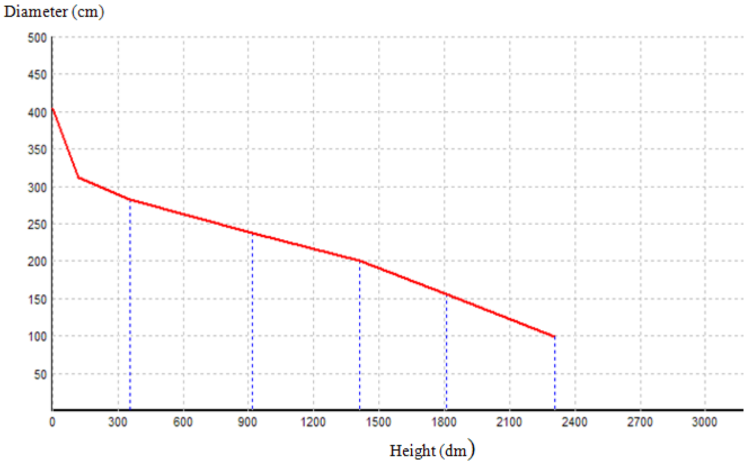

Figure 1: Harvested stem with 5 logs

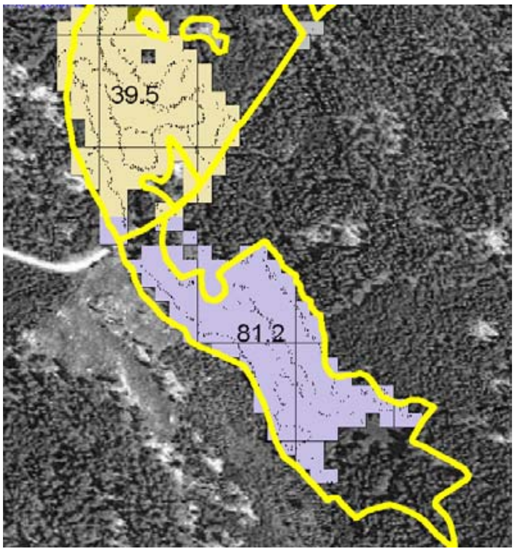

Figure 2: Site segmented into 2 separate sub-areas based on variation in dominant height.

It is possible to calculate a receipt on the harvested volume and the value, area, average stem size, DBH distribution, damage frequency etc. when the harvesting operation is completed. Today modern software versions have functionality for automatic hourly production reporting which means that tools using harvester data are almost on-line applications.

Improved pre-harvest assessment (yield estimations)

Implementation projects are carried out by Skogforsk together with three large Swedish forest companies in order to develop a new pre-harvest assessment/planning system for improved yield estimations. The system is based on a calculation of a number of key figures per harvested sub-area (Fig. 2 and 3) that are stored in a database.

Figure 3: Examples of harvested sites (white polygons) 300 km west of Stockolm, Sweden, used in imputation to find harvested sites as similar as possible to planned sites that are not yet harvested.

When planning a new harvesting site the same key figures are collected using field measurements, remote sensing and existing stand inventory data. Using an imputation method (Söderberg, 2015) the most similar harvested sub-areas are selected. The results from the imputation can then be used for predicting the outcome of the planned site based on what was harvested on other sites (Fig. 4) or a new synthetic stem database can be created in order to make bucking simulations. The imputation method is under development and testing.

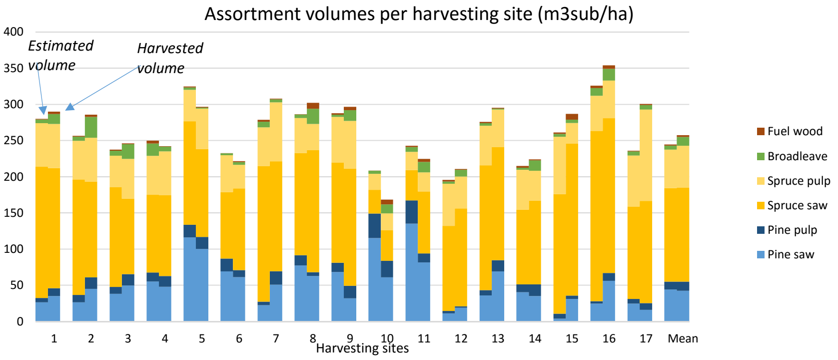

Figure 4: Preliminary imputation results from tests at 17 different harvesting sites in the south-east of Sweden. The first bar describes the estimated volumes based on an imputation while the second bar describes the harvested volumes as measured by the harvester.

Monitoring of harvester operator quality (manual decisions vs optimization)

All StanForD compliant control systems optimize the bucking of stems into logs in order to maximize the value of each stem. However the operator can always override the bucking decisions of the control systems, e.g. due to stem defects, root rot or sharp bends. It is automatically registered if a log was cut based on the decision of the control system or if it was a manual decision by the operator (illustrated in Fig. 5).

It has been observed by forest companies that the harvested outcome per assortment varies more than expected between different teams and different operators. When studying a large number of harvester production reports it has been noted that there can be a huge difference in operator behavior for the same machine and site. In one study two different operators were driving the same harvester in the same final felling stand. The results from this study (Table 1) illustrates the fact that different operators interact with the optimization in significantly different ways when studying the frequency of manual cuts. The number of manual cuts can have a significant effect on the outcome regarding both assortment volumes as well as length distribution of saw logs (Arlinger et al. 2014).

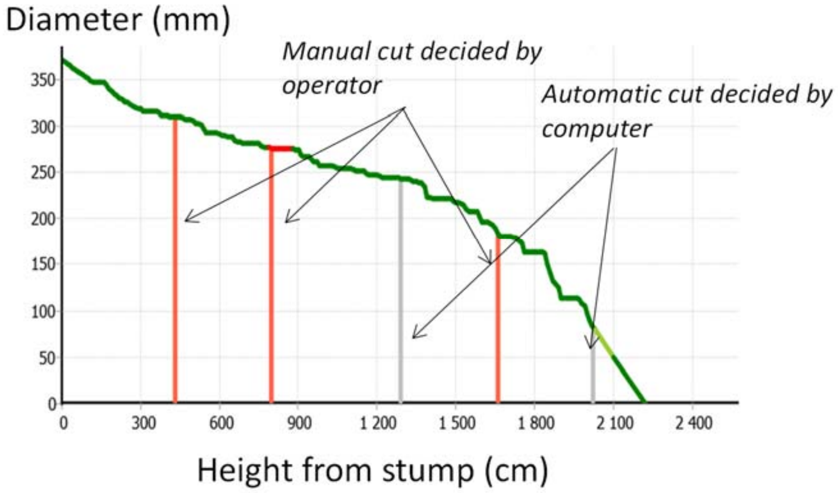

Figure 5: Felled Scots pine with five logs, three manual and two automatic log cuts.

Table 1: Comparison of two operator on same harvester (John Deere 1470E) regarding proportion of manual cuts and some other properties.

Operator	Manual cuts (% of saw logs)	Mean length saw logs (cm)	Relative volume of saw logs (%)	Mean stem volume (m3sub)
A	60.2	441	56.1	0.281
B	0.3	476	68.8	0.292

These results, as well as more recent studies of harvester teams in normal logging operations, indicate the importance of considering operator behavior when analyzing the production results. It is not uncommon to find operators that basically put the value optimization out of play by cutting almost all logs manually. It is common that these operators are not aware of the effects of this practice, e.g. that it affects both output/value recovery and productivity.

Discussion and conclusion

Soon basically all StanForD compliant CTL harvesters are able to report detailed production data. This means that the harvesters are sending the same data that are actually measured in the machines, consequently the receiver of data has full flexibility in analyzing the data. It is worth pointing out that this is basically the only time from planting to and industrial use that we measure each individual stem and log.

There are few limitations in the possibilities of improved utilization of harvester data as long as we limit ourselves to the present measuring techniques. However there are some important factors that always need to be considered when planning to upgrade information systems:

- Harvester control systems need to be regularly updated
- Mobile communication solutions must be able to handle quite large amounts of data
- Operator skills/experience and training has to be at the right level
- Measuring system needs to be well calibrated and continuously controlled

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Estimating thinning results based on standardised harvester data

J.J. Möller, N. Bhuiyan, J. Arlinger, B. Hannrup and M. Nordström

Skogforsk, The Forestry Research Institute of Sweden, Uppsala Science Park, SE-751 83 UPPSALA, Sweden.

johan.moller@skogforsk.se

Introduction

A model has been developed in order to calculate key stand data after thinning based entirely on standardized harvester data. The model has been evaluated for all types of sites in Sweden using more than 10 different thinning harvesters.

The objectives of thinning follow-up on a stand level are to monitor thinning operations, making it possible to update databases for forestry planning systems, increase thinning quality, decrease costs and increase total productivity. It is important to focus further development on giving the logging teams more rapid updates as well as increasing the quality of the estimations of the remaining stand.

Figure 1: Thinning harvester felling strip road trees.

Materials and methods

Skogforsk has developed a model for calculating key stand level data, based on harvester data (Möller m. fl. 2011, 2015). The model has been extensively tested in practice. A demonstration software for use in harvester computers has been developed, giving operators feedback on important thinning quality parameters and data for the remaining stand (Fig. 2). A total of 60 different thinning stands from all over Sweden have been evaluated.

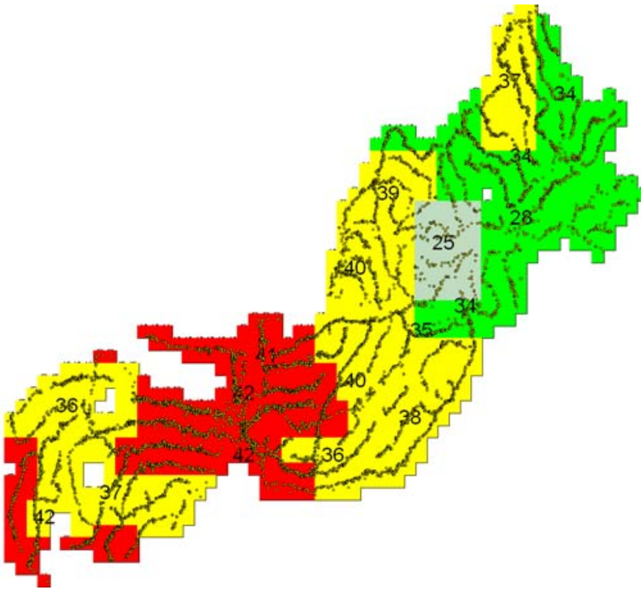

Figure 2: Degree of thinning (felled basal area / pre harvest basal area) calculated based on harvester data, example of user interface in harvester. Red color indicates very intense thinning (>40%), yellow indicates intense thinning (35-40%), green normal (25-34%) and light green a low degree of thinning (<25%). Black dots indicate harvester positions when felling.

Results

Comparisons of manual field measurements of thinning intensity to the automated follow-up by harvester data showed a good correspondence with a standard deviation of 2.8% (Hannrup et al 2011, 2015). The study also showed that strip road trees can be identified using crane angle data and thereby making it possible to estimate the thinning quotient with high precision. This means that the thinning quotient can be continuously monitored in an automatic system, which has not previously been possible.

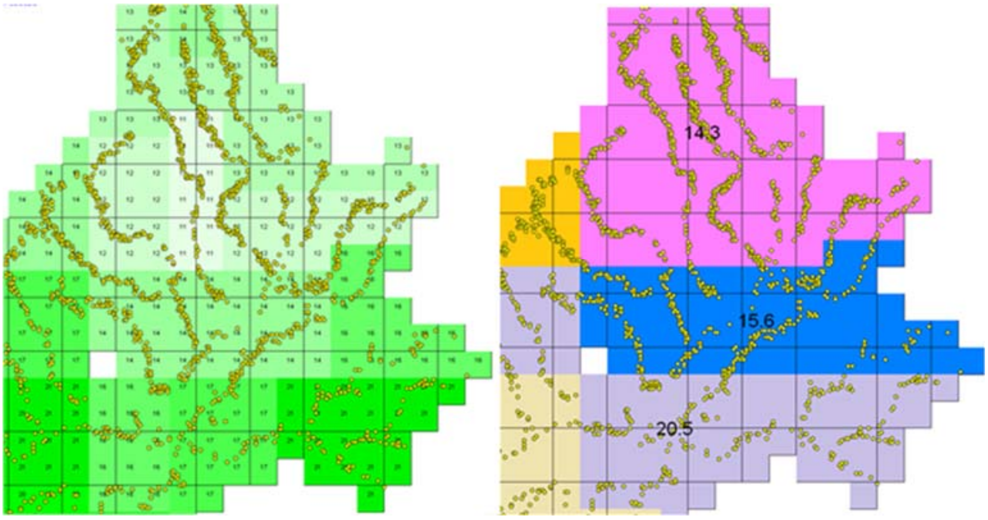

Figure 3: Automatic segmentation of harvesting site based on dominant height as measured by harvester, illustration to the left. Estimated basal area (m^2/ha) after thinning based on harvester data, figure to the right. The basal area is estimated for each segmented sub-area.

The systematic deviations for stand parameters like basal area, volume, DBH, number of stems and dominant height were small (<2.2%) when comparing manual reference measurements with the figures estimated based on harvester data (Hannrup 2015). Standard deviation for the differences between reference measurements and harvester based estimations were 12-13% for basal area and volume after thinning. The corresponding values for basal area weighted DBH and dominant height were four and eight percent, respectively. Also the results for number of stems also gave a quite low standard deviation (15%). The species distribution based on harvester data corresponded well with the reference assessment on approximately 85% of the stands. Significant deviations regarding species distribution occurred in cases with dramatic differences between the distribution before thinning comparing with what was harvested (e.g. if all trees of a certain species were felled).

The precision of harvester based estimation of basal area and volume was on the same level as earlier noted for inventories carried out with areal laser scanning (Naesset 2007). The most significant differences in precision between these methods are probably when estimating basal area weighted DBH and species distribution where both of these parameters can be estimated with a significantly higher precision using harvester data.

Discussion

Taken together our study indicates that the methods for estimating stand variables based on harvester data is of general usage and can be expected to give a high precision in practical forestry under most normal conditions that occur in Swedish thinning stands. Based on this study it is concluded that the methodology has been sufficiently validated and that the method can thus be widely implemented by Swedish forestry. The future development therefore ought to be focused on implementations of the method and, of course, further fine-tuning. Today (August 2016) approximately 200 harvesters in Sweden use the presented methods in on-board software and several forest companies are integrating the methods in their own information systems.

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Striving for excellence – moving towards precision forestry in South African plantation forestry operations, the Mondi Forests approach

D. Längin[1], D. da Costa[1], J. Eggers[1], S. Ackerman[2]

[1] Mondi, 380 Old Howick Road, Hilton, 3245,

dirk.laengin@mondigrouo.co.za

[2] ICFR, PO Box 100281, Scottsville, 3209

Introduction

Fast growing plantation forestry is the key supplier of fibre for the pulp and paper industry internationally. This is mainly due to short rotations with high yields, leading to a cost effective source of raw material for the sector. With a significant increase in *Eucalyptus* plantation area especially in Southern America and Asia, a limited market demand increase resulting in stable and or declining international pulp pricing, increasing cost pressures on labour costs, equipment costs and land prices as well as socio-economic challenges in the Southern Hemisphere, the competitiveness of fast growing eucalyptus plantations is becoming increasingly under pressure. For this reason the South African forestry industry is going through a phase of re-inventing operations and operational forestry techniques to refine processes and develop cheaper and safer operations. Part of this being the critical review of the pulpwood supply chain by gaining a better understanding of how new operational techniques fit into and enhance this supply chain to reduce the delivered cost of timber to remain internationally competitive (Rietz et al. 2016).

Background

To improve the plantation forestry sector's competitiveness a new wave of innovation is required according to Pöyry (2014), with a focus on operational excellence and applied R&D. To achieve best practice with a focus on maximising the true growth potential of a site, Pöyry identified three gaps, namely (a) the productivity gap, (b) the technological gap and (c) the gap due to operational conditions (Fig. 1).

To achieve maximum potentials from a plantation over its rotation (m^3/ha), focus on best practice and standardisation is required to close the gap between theoretical return and actual return. The South African forestry sector has taken major steps in terms of eg. clonal developments and silviculture improvement over the last 30 years through excellent forest research and development, further improvements mean focussing on the finer details and optimizing smaller elements in terms of technology development as well as productivity improvements along the elements of the plantation forestry value chain.

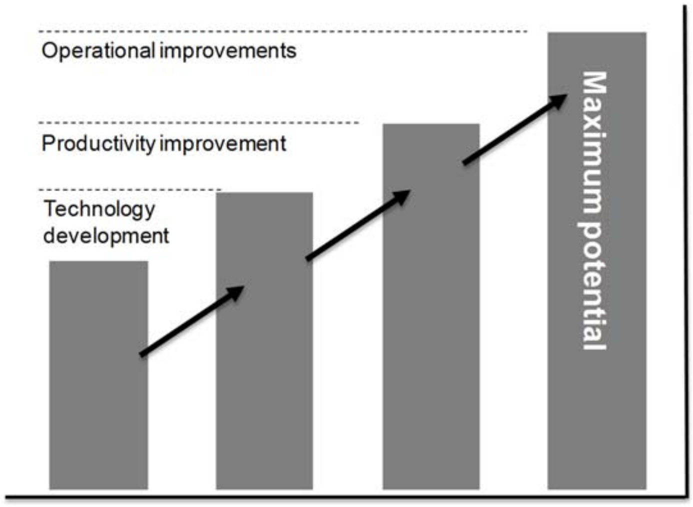


Figure 1: Gaps identified in order to achieve maximum site potential (adapted from Pöyry, 2014)

When comparing South Africa to its biggest competitors overseas, South Africa has lower growth potential, specifically due to marginal rainfall, steep and often rough terrain, pests and diseases and socio-political challenges. It is therefore important to close the gap on technology and precision to improve on efficiencies, increase productivity and maximise site productivity on a reducing land base. In addition, the pressures of an increasingly fragmented plantation landscape due to land restitution pressures, which are not unique in the international context, add additional complexity. This necessitates a change in mindset towards continuous improvement and adaptive management to counter these external factors and influences.

The Mondi Forests approach

To cater for these South African business challenges and to maintain its international competitiveness, Mondi Forests is focusing on value chain perspectives to ensure that commercial forestry remains dynamic and efficient as well as moving towards a precision forestry approach in order to achieve maximum returns, by taking incremental but significant improvement steps on Mondi's continues improvement journey. This includes a strong focus on standardisation of operations and value chains under specific climate and terrain conditions.

The initial steps for this continues business improvement has been Mondi's mechanisation drive in harvesting operations, moving from mainly motor-manual harvesting to over 95% mechanised cut-to-length harvesting operations with its contract partners. In silviculture as well as fire prevention and fire fighting Mondi Forests has been implementing modernised operations since 2013, focusing on reduced health and safety exposure of its contract workforce, implementation of advanced site preparation and establishment technologies as well as modernised maintenance activities (Fig. 2) (da Costa, 2013). Only by closing this technology gap through modernisation and mechanisation is Mondi in a position to focus on closing the gap due to operational conditions and closing the gap on productivity. This does allow closing the gap between theoretical gains and actual yields, by improving stand uniformity, reducing waste and improving the overall quality of silviculture and harvesting operations.

Figure 2: Closing the technology gap - modernisation of planting operations in Mondi

Mondi's applied precision forestry approach

Mondi Forests is focusing on implementing practical precision forestry and operations research steps with a strong focus on value chain optimisation. This initiative has been strongly driven by benchmarking international best practice, close co-operation with national and international research and development partners, as well as the company's drive for constant innovation through a continuous improvement initiative. Across its value chain Mondi has been implementing and is in the process of implementation various precision forestry tools and approaches. In the following some examples are given.

From a planning perspective Mondi in co-operation with Land Resources International is using LiDAR data to improve harvesting operational planning by supporting its contractors and foresters with detailed information on compartment conditions (Kotze & Norris-Rogers, 2016). LiDAR data is further used for improved extraction route and secondary transport road planning (Fig. 3) and forms the base for 3D modelling in forest road construction (Fig. 4).

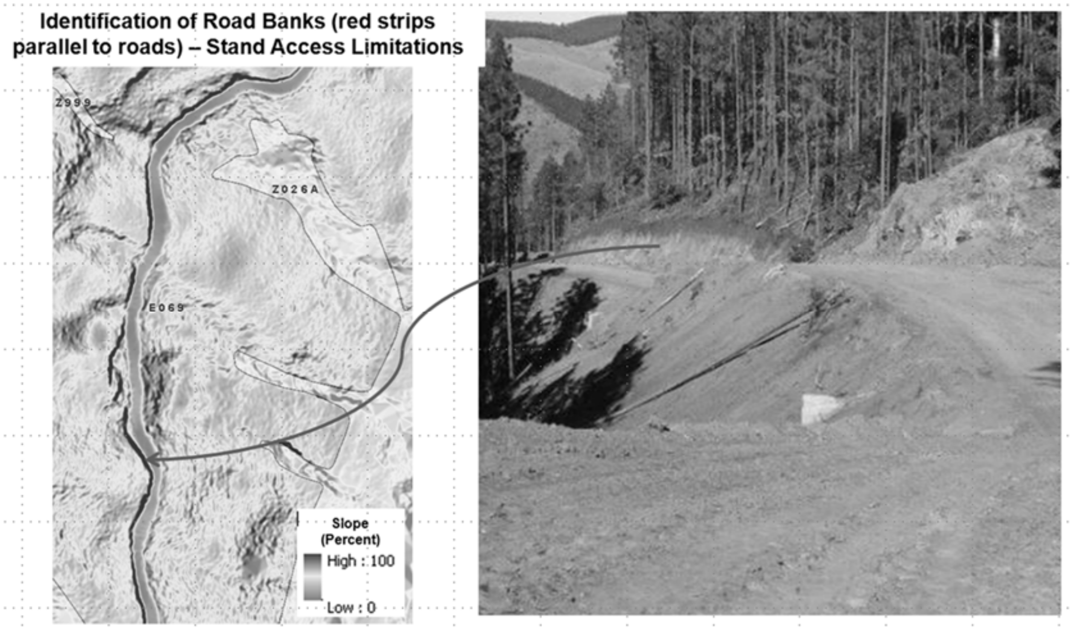


Figure 3: Improved extraction routes and secondary transport road planning

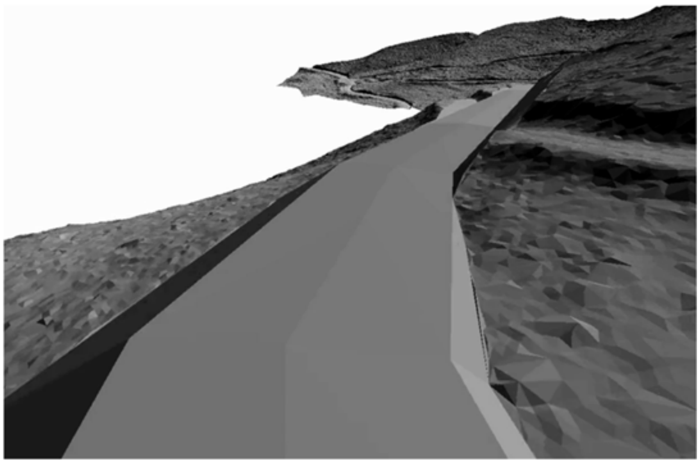
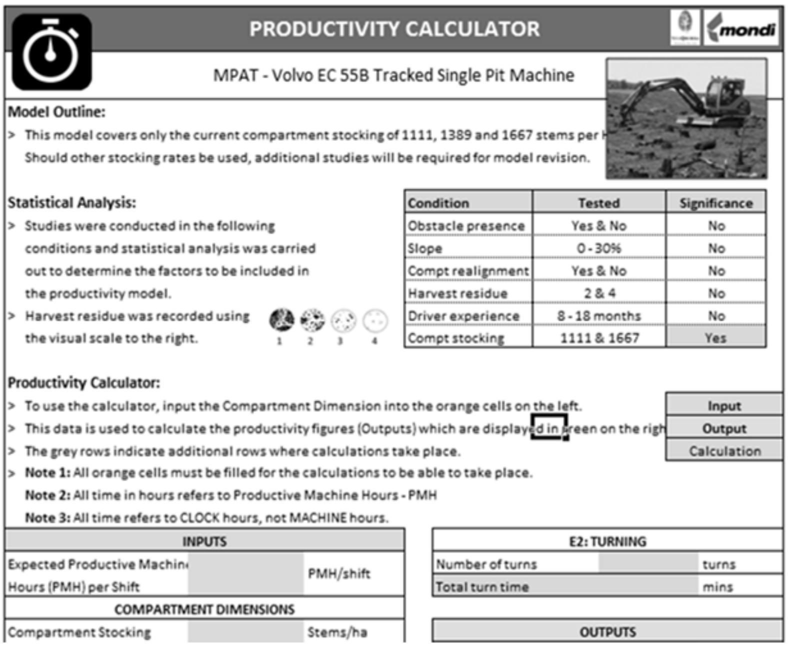


Figure 4: 3D modelling in forest road construction

Through an industry wide co-operation project with the ICFR the pulp wood value chain is currently being modelled with the ultimate aim to develop a decision support tool, allowing for informed optimization of individual elements of the value chain, with the decisions being driven by growth, cost, quality as well as safety and environmental optimization (Rietz et al. 2015).

From an operational perspective, Mondi is applying a strong focus on improving operational efficiency through intensive productivity studies carried out through the support of applied technologies as well as onboard tracking solution for equipment, developing hands on productivity calculators for operational staff (Fig. 5). Through the implementation of mechanised pitting and semi-mechanised planting operation, Mondi is able to achieve improved planting quality and uniformity, with a further potential of improvement through onboard GPS systems (Fig. 6).



PRODUCTIVITY CALCULATOR

MPAT - Volvo EC 55B Tracked Single Pit Machine

Model Outline:

> This model covers only the current compartment stocking of 1111, 1389 and 1667 stems per
Should other stocking rates be used, additional studies will be required for model revision.

Statistical Analysis:

> Studies were conducted in the following conditions and statistical analysis was carried out to determine the factors to be included in the productivity model.
> Harvest residue was recorded using the visual scale to the right.

Condition	Tested	Significance
Obstacle presence	Yes & No	No
Slope	0 - 30%	No
Compt realignment	Yes & No	No
Harvest residue	2 & 4	No
Driver experience	8 - 18 months	No
Compt stocking	1111 & 1667	Yes

Productivity Calculator:

> To use the calculator, input the Compartment Dimension into the orange cells on the left.
> This data is used to calculate the productivity figures (Outputs) which are displayed in green on the righ
> The grey rows indicate additional rows where calculations take place.
> **Note 1:** All orange cells must be filled for the calculations to be able to take place.
Note 2: All time in hours refers to Productive Machine Hours - PMH
Note 3: All time refers to CLOCK hours, not MACHINE hours.

Input
Output
Calculation

INPUTS		
Expected Productive Machin Hours (PMH) per Shift		PMH/shift
COMPARTMENT DIMENSIONS		
Compartment Stocking		Stems/ha

E2: TURNING		
Number of turns		turns
Total turn time		mins

OUTPUTS

Figure 5: Example productivity calculator

Figure 6: Modernised planting operations

From a plantation management perspective and risk perspective, Mondi has developed an innovative approach, combining remote sensing and ground truthing, on how to manage large stock at sidings and deports (Fig. 7) (Woolley 2016). Another example is the current development of a pest and disease App (Figure 8) which will not only give the forester a quick reference guide, but will further allow for assessment of damage levels and infestations to be directly recorded in field, geo-referenced, and update the compartment database (Meyer et al. 2016).

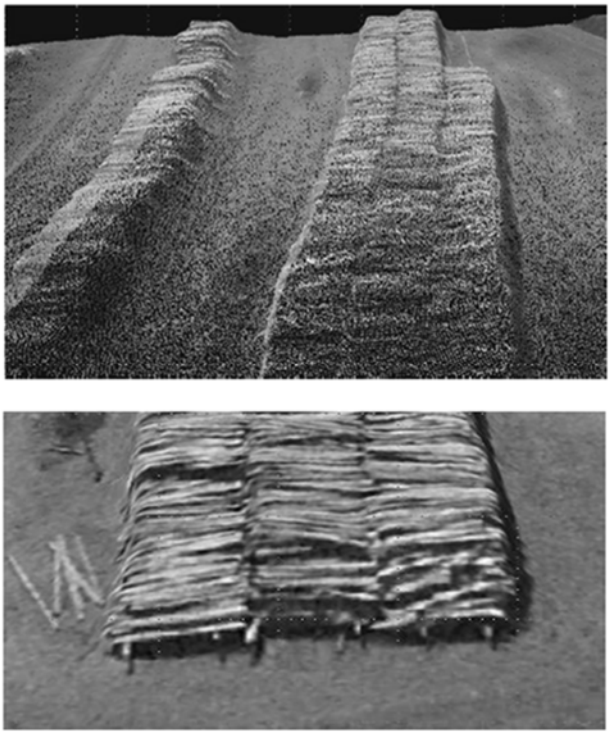
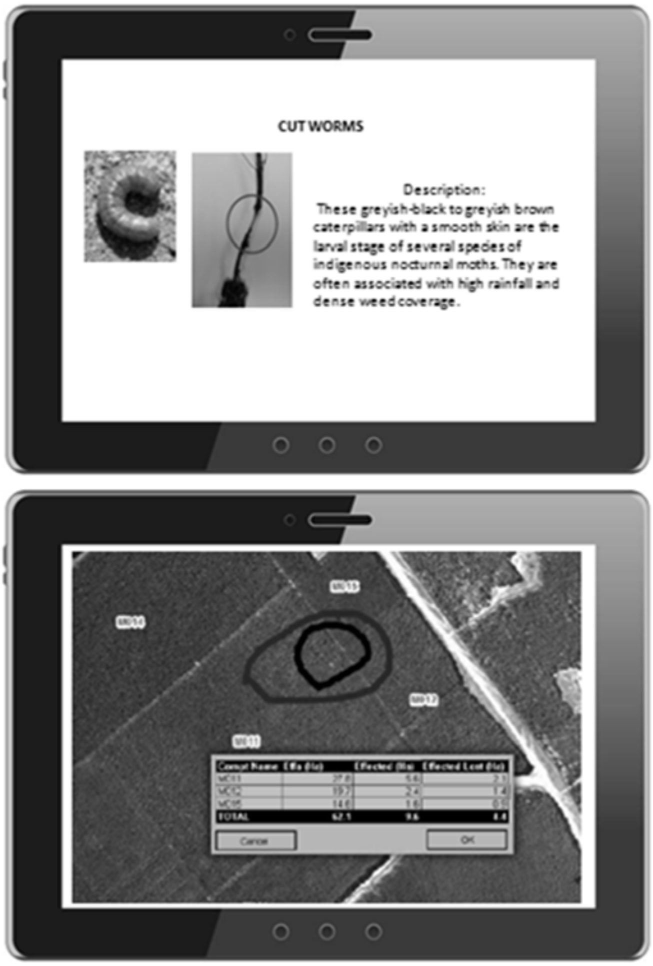


Figure 7: Semi-automated stock taking



CUT WORMS

Description:
These greyish-black to greyish brown caterpillars with a smooth skin are the larval stage of several species of indigenous nocturnal moths. They are often associated with high rainfall and dense weed coverage.

Figure 8: Mondi applied pest and disease App (under development)

Discussion and Conclusion

Mondi's drive in closing the technology gap in harvesting and silviculture operations in line with some of the world leaders in eucalyptus plantation forestry has laid the foundation to aim for best practices and maximise returns of plantation sites through improved yields and operational efficiency. This is a journey Mondi has embarked on by applying a range of precision tools and approaches, allowing for improved operational planning and focused standardisation through increased data collection and better data analysis, to improve the company's decision making processes. At the same time, the increased focus on the overall value chain has allowed to break down traditional silos of eg. silviculture and harvesting, to support a holistic decision making process and a focus on continuous improvement, aiming for maximising the customers benefit.

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Variability in the precision of UAV based surface models in a post-harvest survey

B. Talbot[1]*, M. Pierzchała and R. Astrup,*

Division for Forestry and Forest Resources, Norwegian Institute for Bio-economy Research, NIBIO

bta@nibio.no

Introduction

Images captured from unmanned aerial vehicle (UAV) mounted cameras are increasingly used in enabling a wide range of land-use related assessments. One application to which UAV's are well suited is in carrying out post-harvest assessments, where having to traverse harvesting slash on the ground can be avoided and a better overall spatial reference can be achieved from above. Also, specific features can be accurately measured from aerial imagery (Pierzchała, et al. 2014). However, measurement requires a geo-referenced orthophoto, as do DEMs if they are to be used in specific studies of micro-topography or hydrology. Precise positioning of orthophotos or surface models requires the presence of ground control points (GCPs) in the images, but laying these out on a harvest site is difficult work, and almost impossible where GNSS signal is obstructed. An alternative is to use the data written to the image file from the drone's GNSS, the image geotag. However, models based only on such data are typically less accurate than models corrected with high grade RTK units used in positioning the GCPs. The aim of this work was therefore to investigate how inaccurate such models are when compared with correctly positioned models. The evaluation was done for 6 flights of the same site, and overall model accuracy assessed against using 3 GCPs in the positioning the model.

Materials and methods

We acquired imagery of a clearfell harvest site 6 times over a period of roughly two months using a DJI Phantom 4 drone. The 8ha site had approximately 27m vertical variation and convolution in both longitudinal and lateral directions (Fig. 1). Nine permanent ground control points were laid out, their positions recorded as the mean of three repeated readings using a Topcon GR5 DGNSS, and used as the experimental reference points. The flights were carried out along a route of predetermined waypoints using the Autopilot app from Autoflight Logic. The flight altitude was fixed at 30m above the take-off point (approx. 110m.a.s.l), which was the same point for all flights. This resulted in a flying height above GCPs ranging from 30m to 57m at the lowest point in the terrain. The set of images from each flight was processed in Agisoft Photoscan. The surface models were geo-referenced solely on the basis of the GPS geotag data from the drone, as written to the image EXIF file, and the output orthophoto stored as GeoTiff in UTM32 coordinate system. For one flight, a model was developed using 3GCPs. The evaluation consisted of comparing the positions of GCPs evident in the geotagged orthophotos with the true GNSS derived position of the ground control point in a QGIS environment. The deviations from X (longitude) and Y (latitude) were recorded for all 9 GCPs in each model (Fig. 2).

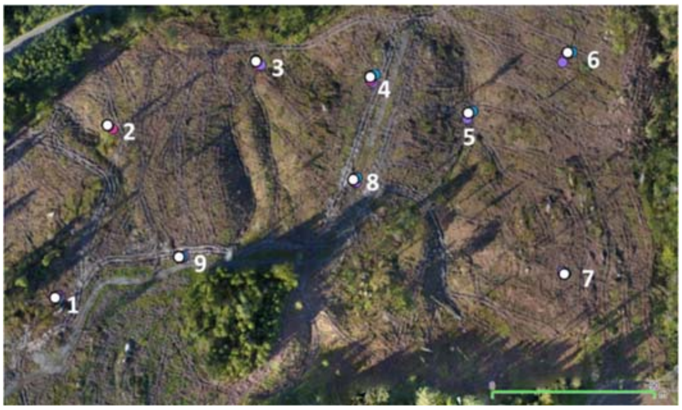

Figure 1: Overview of the 8 ha site, where the white circles show the true position of the ground control points.

Results

Ground control point position estimated mean errors varying between 0.15m and 1.54m in longitude and 0.23m and 1.17m in latitude (Table 1). There was no direct error correlation between longitude and latitude – although GCP 7 was an exception with low mean error in both dimensions. There was however, a consistent positive error in longitude and negative error in latitude with the exception of two GCPs.

Figure 2: Distribution of the estimated location of the GCPs around the true point

The overall mean error for all six flights was 0.83m for X (longitude) and -0.76m for Y, (latitude) giving a mean Euclidean error of 1.12m from any given point. The error breakdown to each of the flights is given in Table 2.

Discussion and Conclusion

The repeated flights tend to give relatively small variation in error despite the size of the site (8ha). The variation seen in this study can likely be attributed partially to the gusty conditions experienced during a number of flights, which would result in some erratic movement of the drone. Also, the fixed altitude resulted in the height above ground varying between 30 and 57m which influences the footprint size of each image and therewith pixel size adopted in the final model. In our case, pixel size never exceeded 2x2cm, but pixel size has been shown to be related to model precision (Küng et al. 2011).

For most post-harvest assessments (identification of trails, environmental condition, location of log piles, biomass etc.) the models derived in this study are considered to be of more than sufficient accuracy. For the accurate measurement of specific features (rut widths, water channels), greater precision may be required. Accuracy in the Z dimension was not addressed in this study, although it would vary to a greater degree than X or Y and would therefore be problematic in relation to e.g. hydrological modelling.

The main conclusion of this work is that Ground Control Points do not seem to be necessary if a model is needed mostly for management purposes (error of 1-2 meters in each plane), such as the following up of general harvesting and extraction quality parameters, but that they would be required if the model were to be used in more detailed analysis.

Table 1: Mean error observed around the GCPs

	Ground Control Point								
GCP	1	2	3	4	5	6	7	8	9
Mean X	1.539	1.289	1.035	0.975	0.427	-0.242	0.153	0.979	1.388
Mean Y	-0.319	-0.982	-1.165	-1.127	-1.152	-1.717	0.278	-0.426	-0.227

Table 2: Mean GCP estimation error (m) for each of the six flights.

Flight	**X**	**Y**
1	1.711	0.348
2	0.763	-1.672
3	1.101	-1.409
4	0.470	0.366
5	0.118	-1.561
6	0.807	-0.760

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A new moisture loss curve for *Eucalyptus dunii* using automated technology

M. Chauke, H. Kotze and D. Borain

[1]Mondi, 380 Old Howick Road, Hilton, 3245, South Africa.
morries.chauke@mondigroup.co.za

Introduction

Timber (pulpwood) sales in South Africa are usually done in tons. On the other hand, volume is measured in cubic metres. Consequently, moisture loss curves derived from wood densities are required to convert m^3 to tons. Previous studies indicated that moisture loss curves differ among species and currently, there is no known study on moisture loss curves for *Eucalyptus dunnii*. Moreover, previous studies involved a manual process of weighing logs over time. This pilot study on the other hand, involves the automated process that uses a trailer equipped with load cells to determine the weight loss curve. This method is new and has not been used elsewhere before.

The first objective of this document is to report on the as-received moisture content (ARMC), the as-received wood density (ARD) and basic wood density (BWD) of the two stands. The second objective is to report on the moisture loss curve for *E.dunnii*, the modeling thereof and derivation of the conversion factor (CF) curve.

Methodology

The study was carried out in two rounds. The first round (Summer) was carried out at Mountain Home (compartment F002), from the 25th of November 2015 to the 17th of February 2016. The second round (Autumn) was carried out at Woolstone (compartment F005), from the 3rd of March 2016 to the 27th of May 2016. In both rounds, 30 trees were selected to represent the diameter distribution. These trees were felled, debarked and cut into 1.0m lengths for the purpose of volume and taper studies, prior to felling of the compartment. The disks were collected, sealed into plastic bags and taken to the Trahar Technology Center (TTC) for analysis of wood properties.

The compartment trees were felled, debarked and cut into 5.5m logs by the harvester. A forwarder was used to collect and offload the logs into the draw-bar trailer provided by Timber24. This trailer was equipped with load cells from LoadTech.

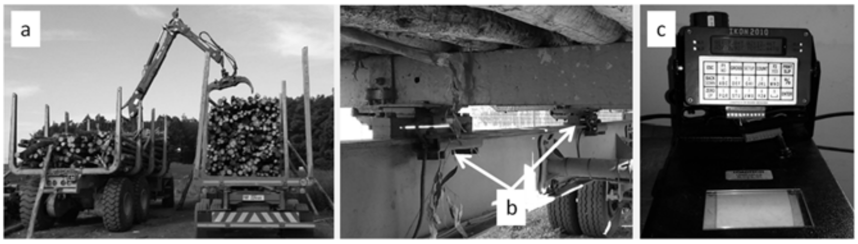

Figure : Loading of logs into a trailer in a, b mechanical load cells and c the data logger

The load cells were installed underneath the uprights of each billet as shown in Fig. 1. Once the trailer was loaded infield, it was taken to Mondi Seele office complex in New Hanover, where the load cells were coupled to a data logger. The data logger records the weight of the load in five minute intervals for a period of 12 weeks.

The main variables of interest in this study were: the as-received volume (m^3), as-received weight (kg) and the climatic variables. The as-received density, BWD and MC were determined using the approach in Tappi (2006). In particular, the as-received density was obtained by dividing the as-received weight by as-received volume; the BWD was obtained by dividing oven-dry weight by swollen/green volume; the MC was obtained as:

$$\mathrm{MC} = \frac{((\text{as received weight}) - (\text{oven dry weight}))}{(\text{as received weight})} \times 100 \cdot$$

At this point, the amount of climatic data available is not adequate to draw reasonable conclusions on the functional relationship between weight loss and climate.

Newton's law of cooling was used to model weight loss over time. $T(t) = T_c + (T_0 - T_c)e^{-kt}$, where: $T(t)$ is temperature at time t ; T_c is temperature of the surrounding; T_0 is the starting temperature and k is the rate at which the temperature changes. Detailed literature on how this equation is derived can be obtained in Gockenbach and Schmidtke (2009). If we apply similar analogy to weight loss, we have the following relationship:

$W(t) = W_c + (W_0 - W_c)e^{-kt}$, where: $W(t)$ is the weight in % on day t; W_c is the estimated air-dry weight in %; W_0 is initial weight in % and k is the rate at which the weight decreases over time.

Results

The BWD and MC of Woolstone F005 are 536kg/m^3 and 51.4%, respectively. There was one Summer load and one Autumn load which resulted in two different weight loss curves. The model is $W(t) = 71.6 + (100 - 71.6)e^{-0.033t}$. It can be observed in Figure 2, that the conversion factor at 2 weeks (14 days) is approximately 1.010m^3/ton.

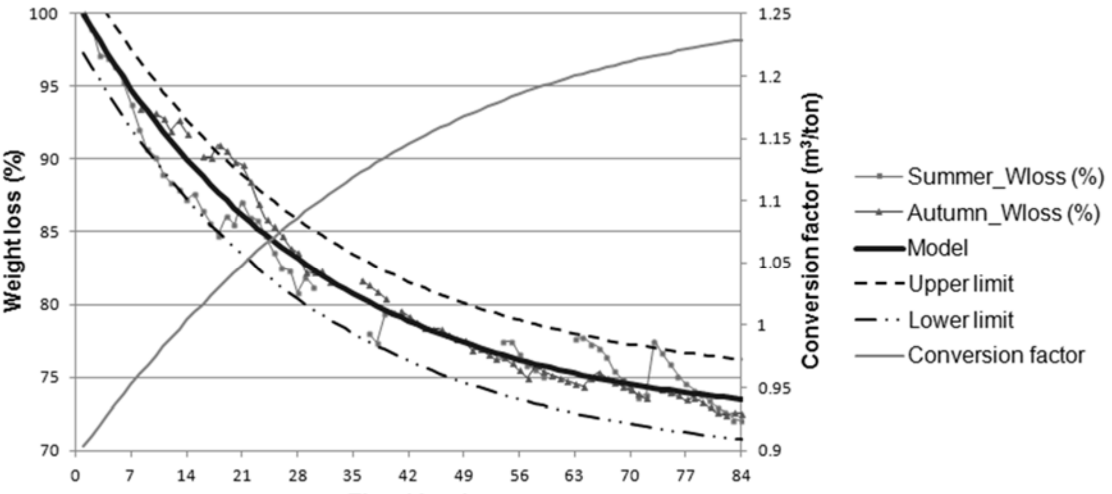

Figure 2: E. dunnii moisture loss curve

Discussion

The wood properties of Eucalypt species were compared in Table 1. It can be observed that the conversion factor of *E.dunnii* is significantly lower compared to *E.nitens* and E.*macarthurii.* Furthermore, the results indicate that the weight loss of *E.dunnii* is also the lowest compared to other species.

Table 1: Wood properties of Eucalypt species

Species	**ARD (kg/m^3)**	**ARMC (%)**	**BWD (kg/m^3)**	**2 weeks**	
				CF (m^3/ton)	**Wt_loss (%)**
E.dunnii	1107	51.4	536	1.010	10.2
E.fastigata	1114	53.5	518	1.065	16.0
E.elata	1043	54.2	478	1.165	17.7
E.nitens	1080	48.2	560	1.076	14.0
E.grandis	988	52.7	439	1.330	19.0
E.macarthurii	1118	49.2	568	1.056	15.3

Conclusions

In this study, the MC and BWD of *E. dunnii* were determined from only one stand. There were two loads which resulted in two weight loss curves as measured with the weight loss trailer. These curves had different initial values and therefore, it was sensible to compare them in percentage form. The wood properties comparison indicated that, BWD of *E. dunnii* was similar to that of *E. nitens* and *E. macarthurii*. However, the conversion factor of *E. dunnii* at two weeks was significantly lower.

The question most readers would ask is: why is the conversion factor of *E. dunnii* at two weeks significantly less than that of species with similar density?

The answer is most probably, slower weight loss. It can be observed that species with similar density lose approximately 15% of initial weight in two weeks. This is significantly higher than the 10% observed for *E. dunnii*. The hypothesis is that, weight loss at early stage is higher for shorter logs. This hypothesis is based on the fact that the study by Shonau (1989) was done on 2.5m logs.

The methodology of a trailer fitted with load cells seems to be precise in monitoring weight loss and thereby providing precise conversion factors from m^3 to tons.

Recommendations

It is recommended to continue with this automated process for major species while maintaining the integrity of climatic data. This will ensure that that the functional relationship between weight loss and climate can be determined with precision and accuracy.

Acknowledgements

We are grateful to Richard Borain from Timber24, John Harrison from LoadTech, Nicola Edwards and John Eggers from Mondi for their contributions.

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Using photogrammetric point cloud data to modernise stockpile measurements

R. Woolley

[1]Senior GIS Specialist, Mondi Forests South African Division, Mondi House, 380 Old Howick Road, Hilton, Kwa Zulu Natal, South Africa.

Robin.Woolley@Mondigroup.co.za

Introduction

Accurately estimating the solid volume of large stockpiles of logs at our sidings is both time consuming and challenging. Manually measuring the stack dimensions and excluding the air spaces of a single accessible stack is difficult - doing so for large contiguous blocks - nearly impossible. Estimating the stockpile average basic-wood density and moisture content, to convert the volume to tonnes, simply adds to the error of the estimate.

Background

Taking stock of stacked logs at roadside, depot or siding is a three-step process.

1. Measure (or estimate) the length, width and height of each stack to calculate the frame (or bulk) volume in m^3.
2. Measure (or estimate) the solid volume factor of each stack (the ratio of solid wood to air). The SVF typically ranges from 0.5 - 0.8 and varies with log form, taper, length, diameter and method of stacking. Multiply the frame volume by the SVF to calculate the stack solid wood content in m^3.
3. Measure (or estimate) the average as-received density (kg/m^3) of the stack and derive the m^3/tonne conversion factor to convert the solid volume to tonnes.

It requires two people, one day and many assumptions to estimate siding stocks with an error of ±20%. Not a satisfactory outcome.

Modernised Approach

Log stocktaking (at our sidings) has now been partially modernised. Formal quarterly inventories are performed using photogrammetric point-cloud and digital image analysis technologies. A small plane, on a single flight, takes heavily overlapping images of the log stocks at all active sidings. Simultaneously, geo-referenced digital images of the exposed stack faces are taken at regular intervals. Our remote sensing partner LRI then analyses the images and very accurately calculates and reports the solid volume per stack and siding.

Methodology

Soon after the start of the project during June 2015 the siding boundaries were confirmed and the terrain surveyed. Following each flight, individual stacks are identified and numbered.

Figure 1: The identification of Sidings confirmed (photo: Mondi GIS)

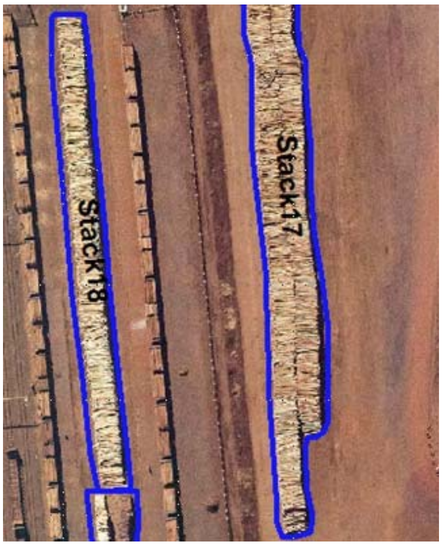
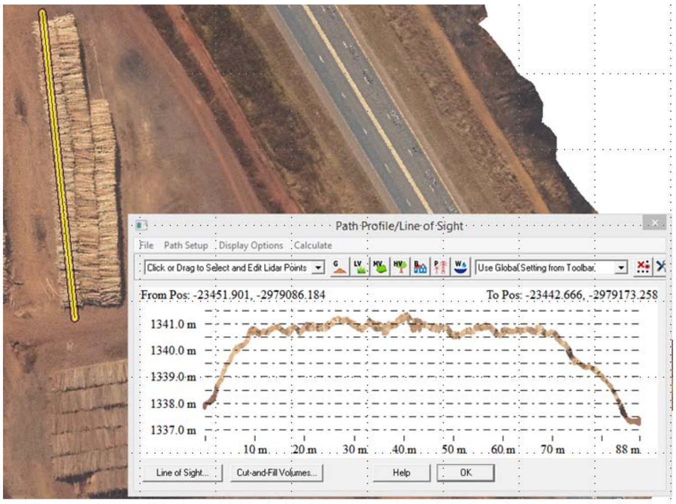


Figure 2: Individual stacks identified (photo: LRI)

The photogrammetric point-cloud of the overlapping images clearly identifies the space occupied by wood, allowing for a very accurate calculation of the frame volume.

Figure 3A/B: Photogrammetric point cloud with corresponding imagery (photo: LRI)

The stack shape and variability of height over the length of a single stack is shown below.



From Pos: -23451.901, -2979086.184

To Pos: -23442.666, -2979173.258

Figure 4: Log stack profile (photo: LRI)

The geo-tagged digital images of the exposed stack faces are then analysed to determine the solid volume factor and solid volume for each stack.

Figure 5: Example of geo-tagged image taken along the log stack face (photo: LRI)

Figure 6. Example of individual log identification process (photo: LRI)

Results

The individual stack solid volumes are aggregated per siding and reported to Mondi within four days of month-end.

Table 1: Breakdown of individual Stack measurements

STACK NO	FRAME VOLUME (m^3)	AIR VOID RATIO (%)	SOLID VOLUME (m^3)
Kemp_1	2063.56	71.66	1478.75
Kemp_2	1900.01	69.28	1316.29
Kemp_3	2956.00	64.16	1896.50
Kemp_4	2238.97	67.13	1503.05
Kemp_5	548.64	70.66	387.66
Kemp_6	259.74	55.43	143.97
Kemp_7	1212.62	65.18	790.37
Kemp_8	662.41	69.58	460.94
		Total	**7977.54**

Area management reconciles the aerial stock figures with those taken manually and calibrates their measurements and solid volume factors. Discrepancies are investigated and accounted for.

Future Research

Converting the solid volume to tonnes is an important next step. A handheld Bruker Raman Spectrometer that can measure basic wood density and moisture content has been trialled. We are awaiting the results.

The Richards Bay pulp mill stocks were included in the June 2016 inventory.

As modernised stocktaking costs decrease, their frequency should increase, to the point where they replace the manual monthly count.

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Assessing the structure of degraded forest using UAV. Case study in Yungas cloud forest, North Argentina

F. Rossi[1]*, A. Fritz*[2]*, G. Becker*[1]*, B. Koch*[2]

[1]Faculty of Environment and Natural Resources, University of Freiburg, Chair of Forest Operations, Werthmannstraße 6, 79085 Freiburg, Germany

fernando.rossi@fobawi.uni-freiburg.de

[2]Faculty of Environment and Natural Resources, University of Freiburg, Chair of Remote Sensing and Landscape Information Systems, Tennenbacherstr. 4, Freiburg 79106, Germany

Introduction

To rehabilitate degraded forest is a global challenge. Those forest, typically show a very diverse structure, which make it difficult to plan and implement appropriate rehabilitation management. The structure of degraded forest has been assessed with different satellite sensors (Souza et al. 2005). Those approaches have their limitations with respect to the possible ground resolution, frequent cloud cover and costs of the imagery (Souza, Roberts 2005). Unmanned Aerial Vehicle (UAV) technology appears to be very promising to overcome these limitations, since it offers a high acquisition flexibility and resolution at relatively low costs. This high resolution UAV imagery, could have the potential to substitute a great number of sample plots based in the field. A priory stratification could further reduce the field inventory plots. Furthermore, up to date detailed and accurate maps for planning of harvesting and silvicultural activities would reduce the cost of implementation.

This research aims to approach to the potential use of UAV combined with sample plot field inventory for the assessment of degraded forest lands in North West Argentina as a tool to be used in planning and implementation of forest rehabilitation activities. The preliminary results based on visual interpretation of the imagery from two representative examples are shown as a first approach to the assessment of the full site.

Materials and methods

The study area is a partially degraded native forest in the temperate Yungas cloud forest, 29 km to the Northwest from the city of Embarcación in the province of Salta, Argentina. The total size of the study site is 14,622ha, from which 11,575ha are under forest management.

The forest has been managed by unplanned selective logging what may have brought a reduction of stock of economically valued species. Furthermore, recurrent fires have affected the area. The last one took place in November 2013 mainly in the middle and south of the area. For this area of 4519ha a first delineation was carried out with an unsupervised classification of a Landsat 8 Scene from 19th December of 2013.

UAV imagery acquisition

The UAV imagery were acquired in December 2015 with a fixed wing UAV (*eBee* from the company *senseFly)* which was equipped with a standard camera (Canon S110). The camera was modified to take pictures in the near infrared (NIR). The UAV has a maximum take-off weight of <1kg and a flight duration of max. 40min. However, the actual duration varies based on age of batteries, air temperature, wind speed and altitude. In our case no flights longer than 25min have been conducted.

The images acquired by the UAV have been attached with coordinates from the autopilot and then further processed with the image matching software Photoscan 1.2.4 (Agisoft). The software calculates in several steps four outputs. 1. interior and exterior orientation for each image, 2. 2.5D-point-cloud 3. digital surface model and 4. ortho-mosaic. The last two are of major interest because they are closely related to forest structure. Initially the ground resolution varied from 19-23cm. In total 19 UAV flight were completed covering 2060 hectares in 5 days of good weather conditions. Counting with 3 batteries and 2 chargers, up to 6 flight per day are feasible, when the weather conditions are favorable.

Plot-based field inventory

As a reference, a plot-based field inventory was carried out. Based on Balducci et al. (2012) circular concentric plots of 300m^2 for trees with diameter at breast high (DBH) up to 30cm, and of 1 000m^2 for trees with diameter over 30cm were set and the coordinates were achieved with GPS receiver. In August 2015, 24 Plots were located in 5 transects every 300m. In a second step, in December 2015, 23 more plots were selected randomly from a grid every 500m. Due to local conditions (terrain, accessibility) plots were located in a maximum distance of 500m from forest roads. From the trees were noted name, species, stem circumference, tree height, stem height, health, damage by fire, silvicultural class (mature, future crop tree, indifferent, competitor) and observations. In total, 3 weeks were necessary to complete the inventory.

Results

Two typical examples are presented to show the preliminary results of visual interpretation. The first example (plot 1) shows the mosaic of an intact forest with a basal area of alive trees of 19.4 m^2/ha, which is similar to the average for the intact forest before the fire (17.15 m^2/ha-Balducci et al. 2012). The average number of trees per hectare was 96 for future crop trees, and 40 for mature trees. Based on Balducci (2009), this stand could be classified as healthy forest (Figure 1). In the figure *1b*, the green color from de NDVI, which indicates high NDVI values (close to 1), may be related to the gaps in the forest shown in the figure *1a*. The 3D visualization from the figure *1c* confirms the findings from the previous images.

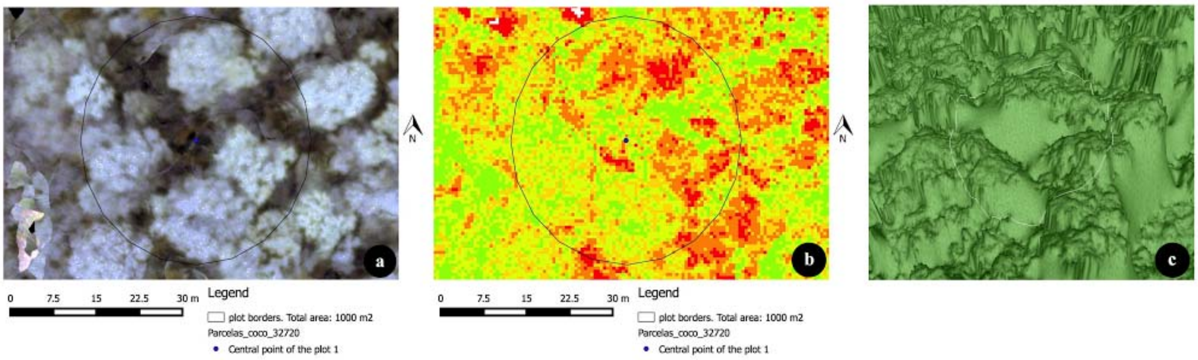

Figure 1: a) 2D visualization with channels NIR, red and green, b) NDVI and c) 3D visualization of the plot 1

The second example (plot 2) shows a burned stand whose basal area of alive trees was only 5.8 m^2/ha, and the number of future crop trees and mature trees is only 10 for each case.

Those differences are also reflected in the UAV-data (Figure 2). The texture of the mosaic of the example 1 shows a predominance of big trees, but a high number of small crowns in the example 2. It could be deduced that the small crowns in the example 2 refer to the regeneration after two years from the fire of November 2013. For this reason, small crows show a higher value of DNVI (greener). Based on the 2D and 3D visualization (figure *1a* and *1c*), the lower NDVI value (red and yellow) can be linked to older trees.

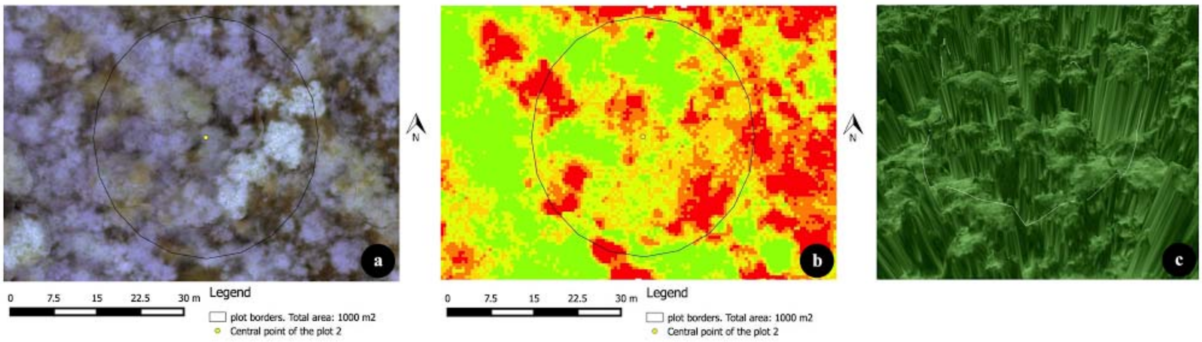

Figure 2. a) 2D visualization with channels NIR, red and green, b) NDVI and c) 3D visualization of the plot 2

Conclusion

Manual delineation of a degraded forest based on visual interpretation of the 2D and 3D visualization seems to be possible with the UAV imagery. Furthermore, NDVI from the drone imagery also allows identifying gasps. Even though, those results must be validated with statistic analysis, which requires a larger sample number.

With regard to the imagery acquisition, drone campaigns require specific site conditions which are not always present, especially in remote and steep areas. A flat field free from obstacles of at least 20m wide and 100m length is necessary for landing with our UAV. Good quality mosaics are achieved when the wind speed is lower than 6m/s. That is indicated especially for forestry, due to the movement of the branches, which reduce the number of matching key-points for the bundle block adjustment. Furthermore, high wind speed (above 6m/s) and also air temperature above 40°C should be also avoided because the autopilot unit and batteries would be negatively affected.

Imagery analysis finds limitations when the illumination conditions are different between the flights, making recommendable to flight the UAV at similar day time. Shadow effect can be reduced if the flight is as close as possible to midday time.

High resolution imagery also requires high precision for the geolocation to make a valid cross-reference between the data acquired in the field and the one acquired from the images. In some cases, this is in practice hard to achieve, because dense vegetation blocks the GPS and possible correction signals. A possible solution could be to establish a local coordinate system.

In our case a DTM with a suitable resolution was not available for the study site, therefore classification procedures (van Leeuwen 2011, Timothy 2016) including vegetation height are difficult to apply. Incorporating a LiDAR-based DTM makes many forest and ecology related indices possible to obtain from the data, e.g. height percentiles and tree height distribution. This lack of vegetation height information is typical for UAV operations, which implies further research to overcome this challenge.

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BesTWay – Optimized logging trail planning under implementation in Swedish forestry

G. Andersson[1], P. Flisberg[1], M. Rönnqvist[2], G. Friberg[1] and E. Willén[1]

[1]Skogforsk, The Forestry Research Institute of Sweden, Uppsala Science Park, SE-751 83 UPPSALA, Sweden.

gert.andersson@skogforsk.se

[2]Université Laval, Département de génie mécanique, Pavillon Adrien-Pouliot, bureau 3345 1065, avenue de la Médecine, Université Laval, Québec (Québec) G1V 0A6

Introduction

Both planner and operator often face dilemmas that require difficult assessments but quick decisions, shall I take the wood via the road to the south or the west? Will the ground support the forwarder? Is it worth building a long log ridge? Is the sideway slope too steep? Anything that can speed up reconnaissance in the field and lead to better decisions is welcome."

BesTWay is a decision support for logging planning. An optimization model is used where the objective is to determine the most efficient logging trail pattern using a digital terrain model, a wet area map and an estimate of stand volume based on laser scanning, see Fig. 1. The model also includes information of landing sites and terrain obstacles as well as environmental or cultural considerations.

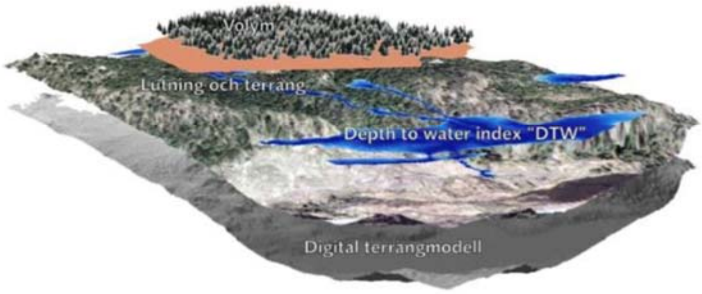

Figure 1: Different layers used in the BesTWay model; digital terrain model, Wet Area Maps and forest volume.

Skogforsk and Université Laval have developed and tested BesTWay together with four Swedish forest companies, SCA, Orsa Besparingsskog, Mellanskog and BillerudKorsnäs. During 2016 six different planners and their supervisors have tested the tool in operational conditions. Their experiences show that BesTWay is an efficient tool for planning of main logging trails and also gives the possibility to conduct scenario analysis where i.e. different landings and alternative passes over water can be tested.

Results

BestWay calculates near-optimal routes based on the detailed input data with a spatial resolution of 2-15m pixels, see Fig. 2. The calculations are based on a cost-weight model with typical higher weights on wet and hillier areas. No-go areas as protected sites and cultural heritages are added. The model does not place base roads in sensitive wet areas, but the planner can indicate one or more suitable crossings. The model can then be used to calculate new routes based on the new conditions. The model can also be used to weigh different proposals against each other, the planner can test alternative locations for landings and crossings by clicking on the map and immediately seeing how the forwarding distance is changed. The planning tool can be used on the office computer or on a tablet with a map tool out in the field. The model also gives a good estimate of the forwarding distance, an objective base for dialogue between clients and contractors to agree on correct payment.

The validation reveals promising and useful results (Fig. 3) in particular to utilize the suggested base roads. The possibility to compare the estimated forwarding distance when using different landing sites opens for new scenario modelling. The practical use of the tool also shows how advanced models can be easily implemented in operational forestry planning.

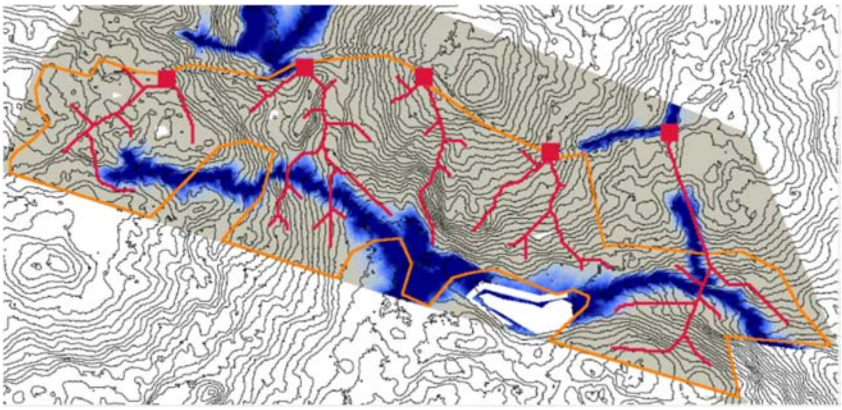

Figure 2: Main trails calculated with BesTWay optimization tool. The system minimises the driving distance under restriction of avoiding the wet areas. Calculation time for an area of 15 ha is approximately 1 – 2 minutes.

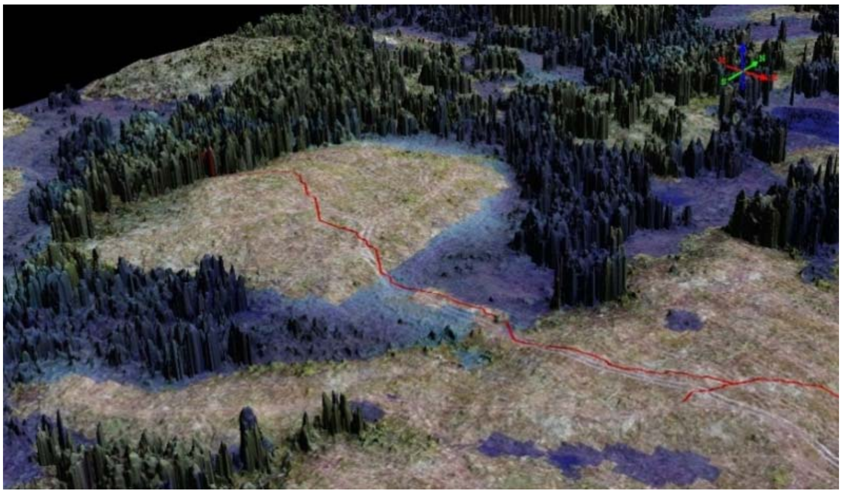

Figure 3: Follow Up study of actual logging trails (shown on this photo taken from a drone) compared with a suggested base road calculated with BesTWay (red). Wet areas are marked in blue. Orsa Besparingsskog, Sweden.

Conclusion

The following conclusions have been drawn from ongoing development and studies of BesTWay:

- BesTWay supports efficient calculation of main logging trails already in the first planning phase in office.
- BesTWay offers efficient planning via scenario analysis of different alternatives for landings and passes over wet areas.
- BestWay cannot be used as an exact planning tool yet, manual adjustments might be necessary due to deviation in real ground surface and ground water levels compared to input data.
- The model has allowed too much side-slope in some routes. This needs to be changed in the model.
- Further development should include a more advanced calculation of secondary logging trails, better estimation of time consumption for forwarding operations and a possibility for the operator to easily change the allowed side-slope for a forwarder route within the BesTWay user interface.

During 2017 more companies will test BesTWay in their operational planning. Adaption of the BesTWay programme to company systems has to be conducted.

Data collection for Precision Forestry: the role of an automatic weather station programme

M. Norris-Rogers[1,2], H. Kotze[2] and P. Sithole[3]

[1]RasterMatics Intl. P.O. Box 628 MSUNDUZI 3231

marknr5@gmail.com

[2]Mondi Ltd P.O. Box 39 PIETERMARITZBURG 3200

[3]South African Sugarcane Research Institute, 170 Flanders Drive, Mount Edgecombe

Introduction

Precision forest management cannot begin until there is, firstly, a base of reliable, relevant information being collected and, secondly, there is an understanding of how this data impacts tree growth, forest planning, and forest operations. The fundamental driver of tree growth and yield is the availability of rain-fed moisture and related temperature regimes. For many years, the recording of rainfall and submitting this data to the national weather service was a daily routine for foresters. While this may still be the case, the changing nature of the forester's role and in many cases, the reduction in the number of foresters in the field, has led to a major decline in the density and quality of this vital information source. This has been exacerbated by difficulties in obtaining verifiable, comprehensive quality weather data from the national weather service, for a variety of reasons. This is evidenced by the fact that the Forest Industry research arm, the Institute for Commercial Forestry Research (ICFR) has to purchase, at great expense, annual data from the national weather service (Germishuizen 2016). This data has considerable data gaps in it which need to be patched before it provides a useful data source. This takes time and effort, which adds to its already high cost.

Background

The current drought being experienced across Southern Africa has highlighted the Forest Industry's exposure to this lack of weather data, as it has been almost impossible to reliably quantify the growth impact and relate this to reliable weather data in order to model the impacts going forward. In stark contrast, the South African Sugar Industry (SASA), through its research arm, The South African Sugarcane Research Institute (SASRI), has for many years had a comprehensive weather monitoring programme using a combination of automatic and manual weather stations across their sugar cultivation areas (Sithole 2013). Not only do they record the weather data, but have developed automatic algorithms to validate and fill in (patch) missing data (such as where an instrument might malfunction). They have also undertaken extensive research to understand the impact of weather data on the physiology of cane growth, characterise areas of similar growth patterns, and utilise this information to inform strategic decision making. An example of this was their decision, in the last season, to not open a Sugar Mill in one area because they could predict that there was insufficient sugarcane available to feed that mill. Subsequent events validated their decision, which was able to be made because they had good data and a fundamental understanding of its impact on sugar growth. This information is freely available to all their stakeholders (especially farmers) via a web-service, which provides relevant information to allow farmers to make good management decisions. The URL to this site is: http://portal.sasa.org.za/weatherweb/.

In view of this lack of reliable weather data, in 2015 Mondi took a decision to partner with SASRI to deploy 29 automatic weather stations across the Mondi landing holdings, such that SASRI would manage the programme on Mondi's behalf, while Mondi gained access to the full SASRI weather database, expertise and equipment management programme. Because there is a large geographic overlap between the forest and sugar industries, particularly in KwaZulu-Natal (KZN), the Sugar Industry benefits from a more comprehensive data collection base.

Materials and methods

Equipment Selection: Mondi has a series of Davis® electronic weather stations across it landholdings. However, these are primarily used for fire protection purposes during the fire season (May to October). In addition, this data does not have a validation/patching system and so does not provide a robust data source that is required for growth and yield study purposes. In order for Mondi to be part of the SASRI data collection system it was necessary to use the identical equipment that SASRI utilises. This system is based on Campbell Scientific® weather station equipment (Campbell Scientific Instruments 2016) and consists of a CR800 data logger (Campbell Scientific) connected to a vane and anemometer wind sentry (RM Young); temperature and relative humidity (Campbell Scientific) probes; self-emptying tipping bucket rain gauge (Texas Electronics) and a pyranometer (Li-cor) to measure solar radiation. In addition, the data is automatically transmitted via a modem (Sierra Wireless) connected to the cell phone network (using a standard SIM card on a data package). The data is sent to SASRI's centralised web-service, using LoggerNet software package (Campbell Scientific) for further validation and processing. The system requires a connection to a power source (Eskom mains) in order to provide power to a battery charger. A solar panel can also supply the necessary power, but is a security risk and so was not considered. The logger, modem and battery charger are housed in a weather-proof box mounted on a tripod stand which is also used to mount the various weather sensors. The rain gauge is mounted on a separate pole 1.0m above the ground, and connected to the logger via a cable.

Site Selection: Site selection is a balance between obtaining the maximum coverage but at an affordable cost, due to the cost of the equipment (~R80 000/site). In addition, each site had to meet the following criteria: Security; Mains Power Source; Cell Phone Data Coverage. Sites that met these basic requirements then had to have open areas sufficiently far away from buildings and trees to prevent shadows (solar radiation), interference with wind flow (speed and direction) or rainfall. The sites also had to have a lawn ground cover to minimise false temperature readings that might occur if a concrete or asphalt base was used. In addition, there had to be a local staff person available (usually the local forester) who could monitor the equipment in case of power failures/tripping, rain gauge being blocked by leaves, bird droppings etc. and other incidental events that might interfere with the continuous operation of the weather station. Site selection was done in consultation with SASRI, such that where Mondi's landholdings coincided with sugar growing areas (e.g. Southern KZN, Melmoth area and Zululand coast) sites were selected that enhanced the existing SASRI network while meeting Mondi's needs. Where there was a SASRI site in the vicinity of a Mondi plantation, no Mondi site was selected. However, where there was a gap in the SASRI network close to a Mondi plantation, a Mondi site was installed. In areas where there was no sugar being cultivated (KZN Midlands; Paulpietersburg/Piet Retief areas), site selection was based on covering the range of weather patterns within those areas.

Site Establishment: Once the sites had been selected, following field visits to confirm the selection criteria were met for each site, a focussed project was put in place to manage the site setup. This involved having each site fenced off, concrete foot pads laid for the weather station tripod mounting, as well as a rain gauge mounting pole and power cables and isolator switches installed. These were done by professional fencing companies in order to have a properly constructed infrastructure to provide sufficient protection for the weather station equipment. Once the sites were erected, the SASRI Meteorological Staff undertook the actual weather station installation, as there are critical parameters required to ensure accurate data collection.

Data Processing: The accuracy and relevance of weather data based predictions, information or decisions are influenced significantly by the quality of the input data (Sithole 2013). Efforts are therefore made to ensure data integrity. This process consists of two complimentary operations i) on-site sensor maintenance and calibrations by trained SASRI technicians and ii) a rigorous computer based automated data quality check and validation system developed to identify missing, erroneous and suspect data. Such data are automatically replaced by data derived from related climatic variables, neighbouring sites or from historical records. This system occurs daily with each data uploading procedure. The main purpose is to flag and replace (patch) erroneous data (e.g. due to sensor malfunction), missing and suspicious values. There are two main levels this data quality check and validation i) acceptable range limits and ii) internal and spatial consistency levels.

Acceptable range limits; Upper and lower limits are set for all variables based on one or a combination of theory, historical records and specifications of the recording instrument. This limits all values to within an acceptable range e.g. relative humidity has to be within the range of zero to 100%. Long term historical records may be applied to further refine the range.

Internal and spatial consistency; Data are checked for consistency at a given site to ensure that there is agreement between related/associated variables, for example minimum temperature has to be always less than maximum temperature. The rate of change of values between successive days is also checked to make sure it’s plausible. Similarly, trends between neighbouring sites are also validated for consistence (may be done for daily, weekly or monthly values depending on the variable in question).

Application to Growth and Yield Data: Once sufficient weather data has been collected it is planned to utilise this in building an understanding of the impact of weather cycles on tree growth. It is also planned to link this data to dendrometer trials that are currently being initiated in conjunction with the University of Stellenbosch.

Conclusion

While this is a long-term project, significant steps have been achieved in a relatively short period of time, such that an extensive infrastructure has been established and linked into a proven data capture/validation/archiving programme in terms of SASRI’s weather data collection facility. This will allow Growth and Yield Researchers to fast-track their investigations into the impacts of weather cycles on forest growth and yield. A modelling approach similar to that proposed by Scolforo et al. (2016) is planned as an initial step in this process.

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Theme Three: Optimised Logistics - from seed to product

Session Chair: Reino Pulkki

Efficiency of high capacity trucks in forestry

V. Saksi[1,2]*, P. Venäläinen*[2] *and B. Dahlin*[1]

[1]Department of Forest Sciences, University of Helsinki, Helsinki, Finland.
bo.dahlin@helsinki.fi

[2]Metsäteho Oy, Vantaa, Finland

Introduction

Forestry is in most parts of the world is relying on truck transportation as a significant part of the supply chain. Hence, effort is put into making this undertaking more cost-efficient. This can be done in several ways, *e.g.* to make roads better to allow higher speed and/or to make trucks bigger to allow higher payloads. Although Finland has one of the highest allowed gross vehicle weights (GVW) globally with a maximum of 76 tonnes on public roads, it still is of interest to improve efficiency. As a means to do that some High Capacity Transport (HCT) trucks has been tested to further study the potential and effects of HCTs. The HCT combinations could be of various types, but all exceeding the general limitations in weight and length. The maximum axle weight still has to be observed, and that is why the number of axles has to increase with higher GVW. In table 1 some (but not all) combinations of HCT vehicles are given. Similar studies have also been made in other countries, *e.g.* Sweden (Löfroth and Svensson 2012)

The objectives of this study are to investigate productivity, fuel consumption and emissions for HCT trucks.

Materials and methods

Three different HCT trucks were studied during several months between 2014 and 2016. Finnish Transport Safety Agency has given permission to exceed the general limitations (in GVW and length) for some designated routes. The study took place in two different areas, one in the north of Finland and one in the south. The conditions of the areas are quite different, as the northern area reaches above the Arctic Circle, while the other is as far south you can get in the east of Finland.

Even if the study is restricted to three HCT trucks, the actual vehicle configurations varied for one of the trucks. One example of an HCT configuration is shown in Fig. 1.

Most of the transport using the HCT trucks was from terminal to terminal; most often the terminal was situated at mill yard. Hence, the loading and unloading were done by a separate loader making a truck mounted loader redundant.

In the northern area the average transport distance was over 250km. In the southern area the transport distances were shorter, but as the terminal stops were located almost on a circle the empty driving could be restricted to less than 10% of the total driving.

Data was collected with the HCT trucks' on-board data loggers and was retrieved using the manufacturers' software during the period March 2014 – September 2016. The number of trips for each truck is shown in Table 2. Unfortunately a large number of observations had to be dismissed due to inconsistency in the data. Those observations are not included in the figures of table 2.

Table 1. Different configurations of truck and trailers in Finland. The "Normal" vehicle configurations are all common truck and drawbar trailer combinations. They are eligible to drive on public roads. The ones with a grey background are the studied HCT configurations (Venäläinen & Korpilahti 2015). They all need special permit to drive and only on designated routes.

		Gross vehicle weight, tonnes		
Vehicle type	**Number of Axles (truck + trailers)**	**Truck**	**Trailer(s)**	**Total**
Normal A	3 + 4	22-26	34-38	60
Normal B	3 + 5	26-28	40-42	68
Normal C	4 + 4	30-35	33-38	68
Normal D	4 + 5	34-35	41-42	76
HCT A	4 + 4 + 5			104
HCT B	3 + 4 + 5			94*
HCT C	5 + 5	42	42	84*

*The technical gross vehicle weight of these combinations is higher than the permitted gross weight due to infrastructure restrictions on the routes.

Figure 1: One of the HCT trucks studied, a Volvo FH16 with 750 hp (559 kW). Truck + semitrailer + drawbar trailer. The length is 30.5 m. It is actually designed for 102 tonnes, but for the designated routes the maximum allowed GVW is 94 tonnes. (Photo: Bo Dahlin)

Table 2: Number of observed trips for each studied vehicle.

Truck	Number of trips
HCT A	448
HCT B	309
HCT C	317

Results

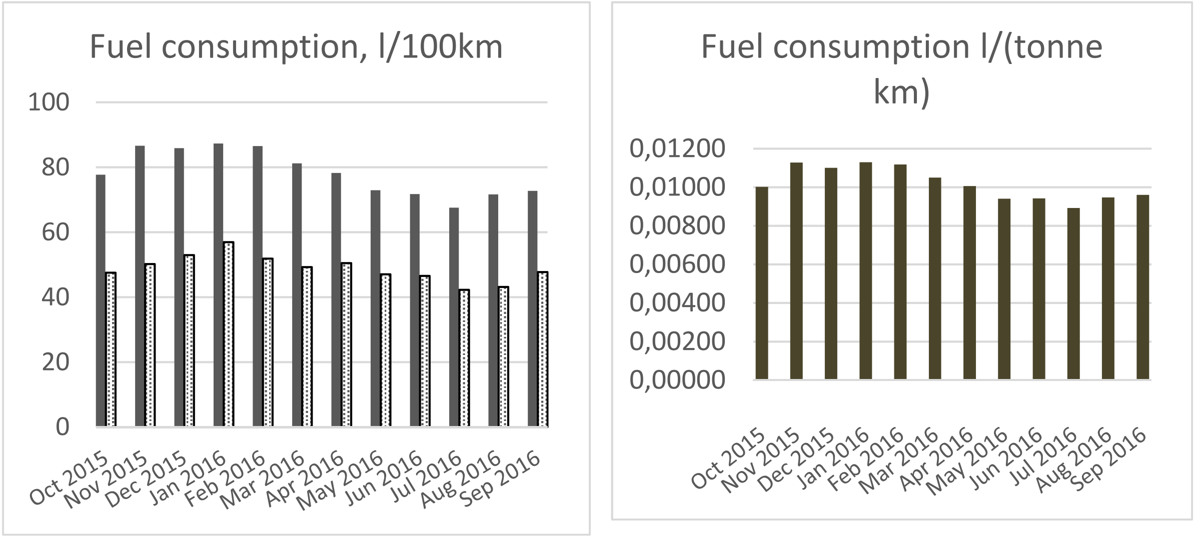
The average speed and distances driven for the three trucks are presented in Table 3. Observe that one cannot calculate the proportion of empty driving directly from those figures. Especially for HCT B it was often so that there was no empty driving between loads.

Table 3: Average speed and driving distances for the three trucks in the study.

Truck	Average driving speed , km/h		Average distance per trip, km	
	Loaded	*Empty*	*Loaded*	*Empty*
HCT A	73	78	272	283
HCT B	53	58	165	93
HCT C	71	71	160	144

The fuel consumption was about 60% higher when driving loaded compared to empty driving (Fig. 2). The consumption also showed some seasonal variation. Even if the data in Fig. 2 is only for one truck, the same pattern is seen also for the other trucks.

The emissions of carbon dioxide (CO_2) showed a big difference between HCT B and the two others (Fig. 3). It is not so much related to a more environmental friendly engine as to the amount of empty driving. While HCT trucks A and C had around 50% of empty driving, HCT B had less than 10%. The efficiency in route planning is shown in amount of CO_2 emissions (as well as in the fuel consumption per tonne km).



a b

Figure 2: Fuel consumption for HCT A configuration during October 2015 – September 2016. a) Fuel consumption loaded (solid) and empty (dotted) per 100 km. b) Fuel consumption in litres per tonne and km.

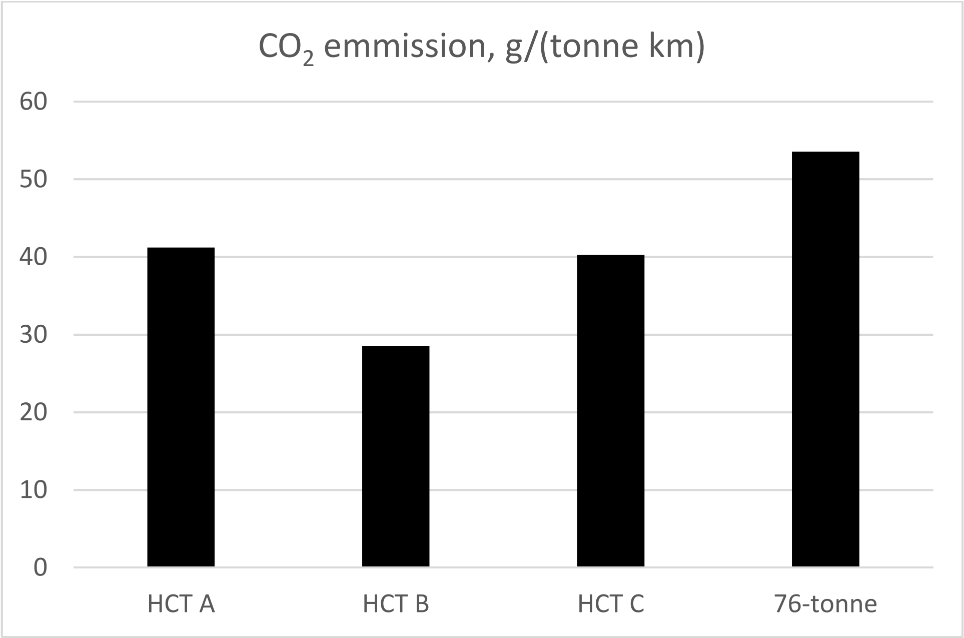


Figure 3: CO_2 emissions for the three HCT trucks and one 76-tonne truck. The empty driving is 10% for HCT B and 50% for the others. 8% of the fuel is bio-based, which has been deducted from the emissions. The trucks were not utilizing the same routes, which is an additional cause of difference.

One of the most significant factors of fuel efficiency found was the driver. The difference in fuel consumption was 16% for empty driving and 18% for loaded between the best and worst driver. The comparison is done per truck.

Conclusions

The interest to use HCT trucks have increased, especially on terminal to terminal routes. Where no railway is available the HCT is of particular interest, but even if the rail would be an option, HCT has the advantage of greater flexibility and versatility than a train. Of course the road network including the bridges has to be able to cope with the extra weight. However, the axle weight of the HCT trucks are the same or even less than for regular trucks. There are studies showing no or very small differences in traffic safety compared to regular trucks (Andersson *et al.* 2011). In Finland an ongoing project is investigating the effects of HCT and road wear.

McKinnon & Piecyk (2011) among others has pointed out that increased payload of trucks reduces the emission of carbon. The environmental impact is lower than from regular trucks as the fuel consumption per tonne and km is significantly lower. One obvious result from this study is that the amount of empty driving has a very strong effect on the emissions per accomplished transport work. Higher back haulage rates could be even more efficient as bigger trucks.

The driver's effect on the fuel efficiency has been studied e.g. McCormack (1990) and has been shown to have a significant influence. One may assume that modern trucks with automatic gear boxes would be less prone to the driver's influence, but this study shows otherwise. Education of drivers how to drive efficient should be considered to further increase fuel efficiency.

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Benefits on supply chain performance of implementing a regional logistic centre

F. Sarrazin, L. LeBel and N. Lehoux

FORAC, Université Laval, Québec (QC), G1V 0A6, Canada
luc.lebel@sbf.ulaval.ca

Introduction

The forest industry's quest for greater efficiency in regards to resource utilization and fuel consumption has justified important efforts towards optimization of its transportation and sorting operations. To this end, the scientific literature has clearly identified sharing of transportation resources to be profitable economically and environmentally (Epstein et al., 2007). Authors have also pointed out, however, that resource sharing and route optimization can be quite complex to implement (Frisk et al. 2010).

In addition to transport optimization, the desire to obtain the highest value of every stem is another driver of wood supply chain innovation. In this regard, the implementation of sort and consolidation yards distinct from harvesting sites offers opportunities for maximizing revenues and minimizing operational costs. Benefits of these yards suppose, however, efficient sorting processes and effective transport coordination. Inserting a sorting yard and coordination centre (hereafter called *logistic centre*), into an existing forest supply chain is made difficult by issues related to the implementation cost, changing demand, multiple sorts decisions, resources sharing, and transport route definitions.

Defining the conditions in which a logistic centre can be profitable and which specific advantages it can provide in terms of cost control and value creation is difficult. Intuitively, the greater the level of raw materials diversity, the more interesting it should be to perform comprehensive sorting. Similarly, low handling costs would also favour a greater use of sorting. Considering tradeoffs between those and other factors is essential to properly analyse whether or not to implement a sorting facility.

Our objective is to identify the parameters having the highest influence on the profitability of a logistic centre comprising both sorting operations and transportation management optimization. To achieve this, we are proposing a profit maximization model of a forest supply chain which can include (or not) a yard specifically dedicated to sorting while making possible to combine different deliveries to diminish empty returns. We have noted that such a modeling of a regional logistic centre remains seldom studied in the scientific literature, even though it may represent a means to increase agility and cost efficiency.

Method

Identify the parameters having the most impact on the profitability of a logistic centre required us built an optimization model which maximizes the profit of a forest supply chain encompassing multiple mills, a dedicated sort yard, and routing operations. The model is solved in a two phases process: First, we run an aggregated version of the model to determine the production the mills and the sort yard have to reach for each period. In addition, it selects the processes and the transportation routes that will be submitted to the second phase. In Phase two the model determines the harvesting levels, the quantities for each raw material and intermediary products going through the different sorting and production processes. Our approach is inspired by Troncoso et al. (2015) who used a somewhat similar method of problem decomposition.

We first assume that wood in the forest is harvested, sorted by broad categories, and stored at the road. The raw materials are then delivered to a set of mills. A more comprehensive sorting can take place at the yard before hauling to the mills, where logs are process and then be sold to different clients. Coproducts such as wood chips are delivered to pulp and paper mills. Within the supply chain, sites can eventually receive the infrastructure of the logistic centre, i.e., a dedicated sort yard distinct from the harvesting sites and mills. It is supposed that wood can be delivered to this yard to be sorted more accurately than in the forests. It is also assumed that sorting costs would be lower at a sort yard than in the forest because of the greater specialization of the equipment and the manpower.

We have chosen to design a fictitious supply chain based on costs and other data related to a specific region in the Province of Quebec, Canada. Our supply chain includes one peeler mill, three sawmills (including one processing hardwood and two others processing softwood) and two pulp and paper mills. The volume available for harvest is based on annual planning over a two-year horizon. The conversion rates of the sorting processes, that is the number of units of products exiting a sorting process for one unit of input, were deduced from data obtained from a government agency and industrial partners. A total of 3,788,268 cubic meters (m^3) of wood is available for harvest over the two-year period. Seventeen different wood species are present, with spruce and fir being dominant. Nine harvesting area (which represent an aggregation of different harvesting sites) are available to supply six mills. Each mill and the implemented logistic centre can be used as a vehicle terminal, which means that trucks start and finish their delivery routes from a mill or from the sort yard. We have defined nine different raw materials (one for each forest site), 1116 intermediary products and a total of 103 finished products. Our hypothesis is that the demand of a given final product corresponds to the capacity of the system to produce this same product. We introduce seasonality in demand for the different products in an attempt to mimic what can be observed in the field. Our model and our database were validated through a thorough analysis of a first series of optimization.

Results

Once the model was validated, we tested four scenarios according to the presence or absence of a sort yard as well as the use of routing (combining multiple deliveries vs one delivery at a time). We have been able to identify the improvement in profit that either one of these options (or both simultaneously) brought. After having obtained results for a base instance, 56 other instances were tested. We have therefore modified transportation costs, distances to forests, the number of trucks delivering oversized loads, and the proportion of sorting costs at a sort yard in relations to sorting costs when sorting is done in the forest. A sensitivity analysis was done to identify the parameters that had the greatest impact on the logistic centre's profitability.

Results from the base instance show that the total profit for the network would be \$ 37,462,353 in the base scenario (no sort yard and no routing). Profit increases to \$ 39,469,581 when a sort yard is introduced, to \$ 42,157,191 when routing is used alone, and to \$ 48,345,325 when both a sort yard and routing are used simultaneously.

If we measure the gains relative to the 3,788,268 m3 available to our network (Table 1), we see that adding a sort yard brings a rise in profit of \$ 0.53 per available m^3. Performing routing increases profits by \$1.24/available m3. Combining both the sort yard and routing yields a gain of \$2.87/available m^3. We can see that there is a dynamic effect since the gain obtained when combining the yard with routing procedure is greater than the sum of each approach.

Table 1: Gains by scenario (in \$/available m^3)

Transportation/sorting	No Sort Yard	Sort Yard
No Routing	-	+ \$0.53
Routing	+ \$1.24	+ \$2.87

Further investigations reveal that higher revenues are the main reason for the gains taking place when the sort yard is used alone (\$0.67/available m^3), followed by lower sorting and production costs (\$0.50/avail. m^3). Lower transportation costs represent most of the gains in the Routing scenario (\$1.20/avail. m^3) with a small increase in revenues (\$0.06/avail. m^3). In the scenario with both a sort yard and routing, transportation costs go down by \$1.77/avail. m^3 while revenues go up by \$1.63/avail. m^3. There is also a decrease in sorting costs (\$0.63/avail. m^3) while the yard itself generates extra costs of about \$0.40/avail. m^3. There is also an important increase in harvesting costs and royalties (\$0.77 per avail. m^3). Inventory costs stay basically the same for all scenarios.

The next steps in our study will focus on studying the impacts of different locations for the logistic centre. We also intend to introduce best practices found in an on-going benchmarking project for operating a logistic centre shared by a wide group of forest companies. Technologies for product and truck tracking, as well as yard management equipment could be more easily implemented once the benefits of a logistic centre have demonstrated.

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Forest biomass supply chain optimisation to produce bioenergy, biomaterials and biochemicals: a systematic literature review

L. Dessbesell[1]*, R. Pulkki*[1]*, C. Xu*[2] *and M. Leitch*[1]

[1]Faculty of Natural Resources Management, Lakehead University, 955 Oliver Road, Thunder Bay, Ontario, Canada.

ldessbes@lakeheadu.ca

[2]Institute for Chemicals and Fuels from Alternative Resources (ICFAR), Department of Chemical and Biochemical Engineering, Western University, Ontario, Canada.

Introduction

Forest biomass is a promising renewable alternative to produce chemicals, materials and energy, including transportation fuels, heat and power, which will ultimately help to ensure long-term industrial and environmental sustainability. A variety of chemicals and materials have been developed as substitutes for petroleum-based products; however, this research has resulted in few biorefineries. Challenges still exist to introducing new bio-based value-added products in the market. A number of published studies address forest biomass supply chain (SC) focusing on economic, environmental and social aspects. Several exhaustive literature reviews regarding biomass supply chains concentrate on different issues, but some questions are not answered in previous publications; for example, the final products are not identified within forest biomass SC optimisation papers. Therefore, this study aims to identify the final products of the forest biomass SC papers, demonstrating where there has been development and where more research is necessary.

Materials and methods

The approach used in this study was a systematic literature review, which identifies key terms/words, locates and searches literature, checks publications applicable to the topic, classifies the literature and composes the literature review.

The keyword "biomass* suppl* chain*" was searched within the ISI Web of Knowledge, resulting in the retrieval of 979 documents. All database years of ISI were taken into consideration until October 6, 2015. The results were saved in EndNote Web for external review and verification. The data were then entered into Microsoft Excel for analysis. The review focused on English language peer-reviewed literature documenting forest SC technical and economic optimisation. Figure 1 presents the number of papers excluded (913) for each criterion and the number of papers included (66).

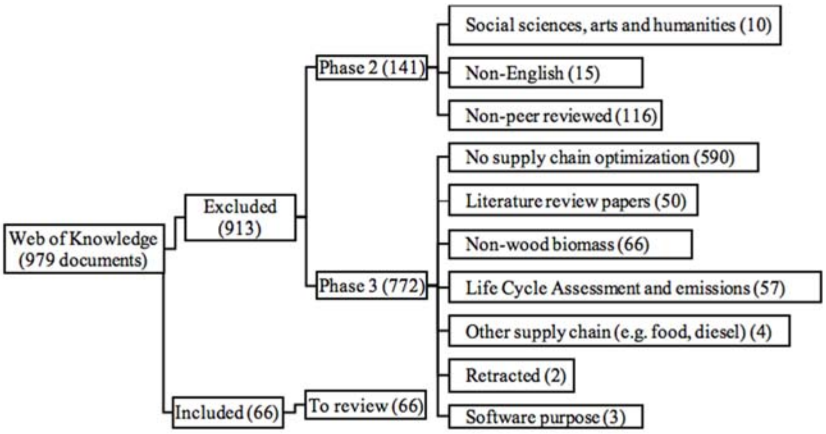

Figure 1: Summary of document screening showing search criteria for excluding and including papers.

Papers can be classified within several exclusion groups; therefore, documents were assigned based on evaluation of the principal motive for exclusion.

Results and Discussion

It is evident that published papers on economic optimisation of forest biomass SCs have increased significantly since 2008 (Fig. 2 A). The United States of America (USA) (35%) and Canada (11%) lead the number of publications (Fig. 2 B).

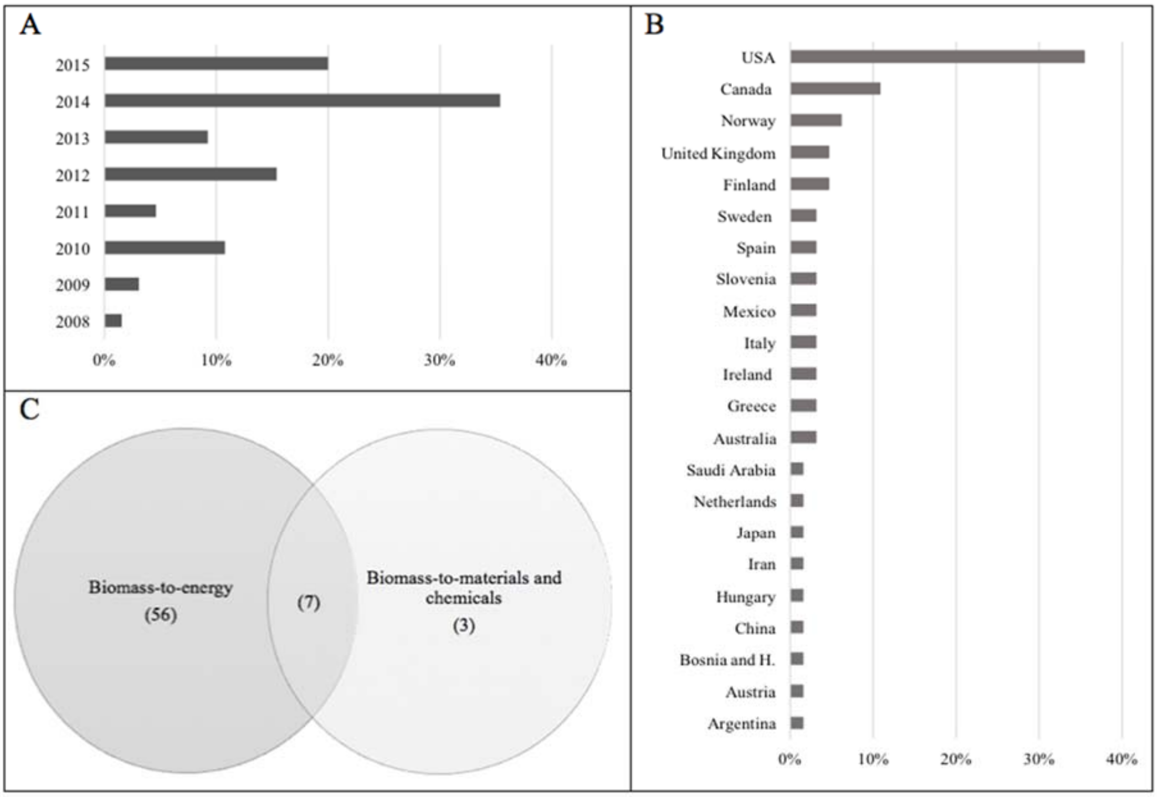

Figure 2: A: Papers reviewed percentage by year, B: Papers reviewed percentage by country, C: Final product of forest biomass SC economic optimisation from the 66 reviewed papers.

The Canadian forest products industry needs to diversify its portfolio to remain competitive. For Shahi and Pulkki (2013), under-utilization of forest resources reduced Canadian competitiveness in the global market. Therefore, SC optimisation studies are essential for the introduction of high-value bio-based products. Once such SC optimisation studies are completed, analysts can determine the most appropriate fibre use strategies to maximize value generation based on current forest market conditions (Shahi and Pulkki 2013).

The increasing number of publications on SC optimisation indicates that the research community is uniting to provide solutions and alternatives for the Canadian forest industry. Additionally, the Canadian government, through Natural Resources Canada (NRCan), has encouraged and supported development and implementation of bioenergy and biorefinery technologies (Paleologou et al. 2011). For instance, FIBRE (Forest Innovation by Research and Education) was founded in 2008 to develop innovative products, applications and processes, as well as policy for the forest industry through seven different networks (FIBRE 2016).

In the USA, the Energy Independence and Security Act of 2007 (Public Law 110-140-dec. 19, 2007) and the USA Environmental Protection Agency (EPA) regulate the supply of renewable transportation fuels consumed through the Renewable Fuel Standard (RFS2) program. According to Zhang and Wright (2014), refiners, renewable fuel producers and other stakeholders are mandated to meet annual biofuel production and environmental requests to obey the RFS2. The increasing number of studies in the USA highlight the efforts for increasing renewable production of petroleum-based products in the USA.

The majority of the papers (84.8% or 56 papers) focused on biomass-to-energy production (Fig. 2 C). For biorefineries, the ideal would be to produce biomass-to-energy and biomass-to-materials and chemicals in the same facility to extract the highest possible value of the fibre feedstock. However, only 10.6% of the papers explored options in this category (Fig. 2 C). The other 4.6% of the reviewed papers focused solely on biomass-to-materials and chemicals; specifically, the main products addressed were ethanol, electricity and heat.

Biorefineries integrate biomass conversion processes to produce fuels, power, heat, and value-added chemicals and products. A biorefinery should produce at least one energy and one non-energy product according to the International Energy Agency (Bell et al. 2014). From the reviewed papers, it can be inferred that there is an incomplete understanding of the biorefinery concept, as some papers use the term biorefinery in reference to facilities that produce bioenergy only.

Conclusions

An increasing number of papers explore forest biomass SC optimisation over the past two years, with the USA and Canada leading the number of publications. The emphasis of previous SC studies has been within the area of energy production, including ethanol, electricity and heat production, with little focus on the production of chemicals and materials. Finally, this literature review identifies the need for further studies that focus on forest biomass supply chain optimisation and consider new high-value bio-based materials and chemicals.

Acknowledgements

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Analytics and Big data in route selection

P. Flisberg[1]*, M. Rönnqvist,*[1,2] *and G. Svensson*[1]

[1]Skogforsk, The forestry Research Institute of Sweden, Uppsala Science Park, SE-751 83 Uppsala, Sweden.

[2]Université Laval, Département de génie mécanique, Québec city, Québec, G1V 0A6, Canada.

mikael.ronnqvist@gmc.ulaval.ca

Introduction

Long-distance road transportations by truck are costly and represent a high proportion of the production cost of low-value raw material. One example is transporting forest raw material, such as logs for sawing or pulp and paper and forest residues for heat and power, from landings in forests to processing mills. In Sweden, 80 million tonnes of logs and forest bioenergy is transported annually in more than two million truckloads, at a cost of more than EUR 0.7 billion. The average truck transport distance is 95km, and logging transport accounts for more than 25% of the forest industry wood procurement cost. This transport involves more than 2000 trucks and 5000 drivers working in different shift forms. The number of transport companies is large, as many of the trucks are run by independent contractors who often work for several forest companies.

Each year there are about 200,000 new harvest areas from which the raw material (in the form of several assortments or products) is transported to more than 800 mills and terminals. On average, about 440,000 new routes from the new landings must be established each year. Swedish forest sector transports are paid according to distance (km) and payload unit (tonne or m^3). It is therefore important to establish a correct and fair routing distance between forest landing and unloading point at pulp or sawmill (Flisberg et al. 2012). Historically, distance has been measured in different ways by forest companies buying transport services. This inconsistency created problems for haulers working for different customers, when the same assignment could be invoiced differently depending on customer.

Materials and methods

To support distance computation, forest companies started to develop IT support systems in the 1990s, and collaborated on building and filling structured databases with relevant road information. This work was done in collaboration with the Swedish Government and led to the development of NVDB, the Swedish National Road Database under the auspices of the Swedish Transport Administration. The need to standardize distance computation and the development of NVDB formed the basis for development and implementation of the Calibrated Route Finder (CRF) system in 2009. CRF uses data from SNVDB, a version of NVDB that also includes additional forestry-related road features.

Route selection is not simply a matter of finding the shortest path in a given road network. Instead it is a trade-off between many road features, including distance, routing time and road quality, but also stressful situations and road safety. For example, low-quality roads considerably increase fuel and time consumption and a longer distance on a better-quality road are often favorable. Driving on narrow forest roads with many curves is a stressful environment, as drivers must be prepared to brake quickly when approaching vehicles suddenly appear.

Heavy trucks can also be very dangerous for children while driving in cities close to primary schools and kindergartens, and such traffic should be avoided, if possible. Some parts of cities where there are, for example, many stop signals and crossings, are sensitive to heavy traffic, and specific by-pass routes should be used. Finding a balanced weighting among such different features is a very difficult task even for the most experienced planner.

Minimum-cost routing is based on a cost (weight) per arc in a network of nodes and arcs. Even finding suitable balanced cost or weights of two attributes, for example distance and time, is a difficult task. In the CRF system, more than 100 weights for attributes must be set before the network is defined, and standard minimum-cost algorithms such as Dijkstra can be used to find the best route and its corresponding distance. One of the main operational research (OR) problem is to find weights of a set of measured attributes (in the road database) so that all objectives of the route selection are considered. One important aspect in developing the process has been to collect 1500 detailed best practice routes evenly distributed over Sweden. The best practice routes are called key-routes and are predefined routes agreed by major forest companies and haulers between landings in the forest and unloading places (mills and terminals). As a comparison, the shortest paths are as much as 9% shorter compared to the agreed distances, showing a huge potential problem when using shortest paths in both invoicing and route and transportation planning (Carlsson and Rönnqvist 2007). The key-routes are subjective, representing a mix of economic, social and environmental factors as well as traffic security and maintenance.

Our approach is to consider the key-routes as the optimal solutions to a minimum-cost route problem, and then solve an inverse optimization problem to establish the weights. A general inverse optimization problem is to find a minimum adjustment of the coefficients of the cost function to ensure that the given solution is optimum. In general, all objective function coefficients can be changed but, in our case, all arc costs (i.e. objective function coefficients) are determined implicitly through the weights of the measured attributes. In the inverse optimization model, the weights are the decision variables, and the objective is for as many as possible of the key-routes to be the optimal solution when a standard minimum-cost route problem is solved (i.e. the route generation in the CRF system).

In our inverse optimization model, we need to identify which route is best between any pair of start and end nodes, and for 1500 key-routes there are a huge number of potential alternative routes as the network is very large including some 4.5 million arcs and 2.2 million nodes. Due to the model´s potentially large size, a constraint and column generation approach is developed. In each iteration, a set of new routes is generated together with the associated constraints in order to identify the best route for each pair of start and end nodes (i.e. key-route). The process is repeated until no more improved routes are found. One consideration in the overall modeling and solution approach is that data may be missing or erroneous, and a number of error detection & correction procedures have been incorporated.

A number of additional analytics developments are critical to the success of the system. Two of the main concerns of the drivers are to avoid ‘curvy’ and ‘hilly’, routes as they increase fuel consumption, route time, and stress levels, and raise road safety concerns. In order to include these features in the CRF system, we have developed a novel approach to measure curvature and hilliness with quantitative measures (Svenson et al. 2016). These are based on detailed descriptions of acceleration, braking and fuel consumption along road segments with a huge number of detailed 3D geographical coordinates available in NVDB. Another development is to model correct turning at road crossings. Essentially, all commercial route generators use heuristics to implement some restrictions on forbidden, impossible, unpractical and potentially dangerous turning options at road crossings. The approach we have developed is different, and involves generating an augmented network where every possible turning option in all road crossings is modeled with individual arcs. This enabled us to eliminate more than 60,000 wrong turnings per year in the routes generated. This network also enabled very detailed description of fuel consumption, CO_2 emissions and route time (Svenson and Fjeld 2015). Such aspects are becoming increasingly important in view of the move towards green logistics, and enables measurement of the environmental impact.

Results

The development of the CRF system has involved many actors in the Swedish forest industry. The development is ongoing at several organizations involving many persons with much varied backgrounds (for example, OR, GIS, road database, planning, software design, programming and various management skills) as more details and considerations are included. The optimization for finding the minimum-cost routes is distributed among three webservers. The NVDB is updated on a daily basis and all visual information is included directly in the graphical interface. Also, there are multiple networks depending on season (summer or winter). About 100 companies, including all major forest companies in Sweden, are currently using the service directly to calculate invoiced distance; in addition, CRF is consulted for planning purposes and visualization). Current market penetration is about 60%, and companies using CRF appreciate accuracy, transparency, uniformity and reduced administration. It is also an important contribution to the international competitiveness of Swedish forestry. Using CRF has both qualitative and quantitative benefits. The proposed routes are efficient and balance safety, economy, fuel and environmental impact. Very important is that all participants in the wood flow chain feel the system is fair, standardized and transparent.

A natural question is what the savings are. The primary purpose of the CRF was to establish fair and efficient route generation, not to save money. However, we can also report on large potential savings of using CRF routes. One is reduced administration cost and another is reduced fuel consumption due to following best practice in the industry. The average cost of a transportation assignment is about EUR 350. The overall administration cost can be up to 7% of the transportation cost; by removing one of the more time consuming parts, i.e. deciding and discussing distance, administration costs can be reduced. Different estimates indicate a saving of between EUR 1-2 per assignment. As there are as many as two million transports every year, the potential savings through decreased administration can be as high as EUR 2-4 million annually. Our studies also show it is easy to save either a few liters of diesel or a few minutes in route time. This represents another EUR 2-3 per transport, or a total of EUR 4-6 million annually. The system also has a direct positive impact on greenhouse gas emissions, with a reduction of 16,000 tonnes of CO_2 per year. The CRF also enables more extensive collaboration between companies in wood bartering, as they need a common and standardized way to represent the collaborative OR models.

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Theme Four: Operations Research - optimisation, heuristics and simulation

Session Chair: Luc LeBel

Solving Problems and making decisions using discrete event simulation

P. Jönsson

Skogforsk, the Forestry Research Institute of Sweden, Uppsala Science Park, 751 83 Uppsala, Sweden

petrus.jonsson@skogforsk.se

Introduction

Our paper presents examples of discrete event simulation (DES) models used by Skogforsk in recent years. Our aim is to present some common problems encountered in Forest Operations Research and to discuss the usefulness of DES as a tool for solving these problems. The different problem types presented are 1) Concept machine evaluation, 2) Wood supply analysis and 3) Decision support models for supply chain management.

An important task for forest operations R&D and practice is continued rationalization and productivity growth. When evaluating new or different methods in forest operations and their effects on productivity there is always a risk that the results have limited validity outside the specific study conditions. The results could differ if variations are included in the evaluation, in forest operations there are several factors that have an effect on productivity. Thus terrain, forest, weather and not least the operator have all big variations and will affect the productivity.

Skogforsk are combining DES and time studies as a tool to broaden the results so that more conditions and variations in the conditions are included in the final results. This way the results are more generally applied to describe the actual result that could be expected. There are also a reductions of risk that the results are only meet for very narrow conditions.

Materials and methods

Concept machine evaluation

The example builds on the pre-production evaluation of “Cintoq” a concept feller-bundler for young, dense forest stands. The machine has three key processes, 1) harvesting and accumulating trees in the felling head and, 2) feeding and delivery crane which autonomously bucks and feed the accumulated trees into 3) the bundling process unit.

Figure 1: CAD-drawing of machine concept, Cintoq

When modelling a concept machine like Cintoq, uncertainty concerning parameters and values derived from time studies of other machines with similar functions must be considered. The model must reflect reality sufficiently well to illustrate this uncertainty. The models most have stochastic elements for the activities that are critical for describing the overall work cycle, or process. In the activities and processes where there is some kind of uncertainty, probability distributions are determined by using historical data or time studies. Data are used to calculate the expected value for activities and/or processes.

Simulation models give results as expected values and with a confidence interval. With the results decision makers can decide if the results are good enough and judge if the risk and uncertainty is below the level that would halt continued development.

Wood supply analysis

Seasonal inventory levels and sufficient transportation capacity is important for commodity flow to the industry, while the storage levels and transportation cost are kept down. Together with the large forest company SCA we examined how variations in the flow of raw materials affect the production of pulp at mill if an expansion of existing pulp mill should be realized. Part of the work was to find stable supply chains for pulp wood. To capture the changing reality that affects the entire flow of raw materials from forest to wood yard DES was used to analyze both the variation in wood requirements and the availability of time. Historical data were used in the simulations to describe the weekly average and standard deviation for storage levels, frequency of trucks, trains and boats departure from their locations and arrivals to pulp mills wood yard. The rate of pulp usage in the production at the paper mill was simulated with higher resolution, one day, than for the other processes in the model. Reason to have different resolutions of time was partly that for the paper mill it wasn't acceptable to run short of pulp wood and to keep down the execution time for the whole model.

Decision support models for supply chain management

Historical flows in a region for the five companies that delivered wood chips to a number of heating plants are shown in Table 1. Where a total of 18,824 truckloads were included in the simulation data set. The objective was to investigate the potential for bartering.

Table 1: Total number of transports and average transport distance for each of the five haulage companies over one year. This data was included in the study. Haulier ID No of loads

Hauler ID	**No of loads**	**Average transport distance, km**
A	7543	54,5
B	3350	54,7
C	7694	56,6
D	872	48,4
E	734	82,8

The model was designed to search for possible location barter options based on the possible destinations for a volume of biofuel from a given landing. In order for a candidate to be nominated, transport distance must be reduced by at least 10 percent by sending it to an alternative destination. Landings within a 10 km radius from the intended customer will not be available for location exchanges. The requirement of 10 percent reduction in transport distance was set up as a base-line level in order to make barter worthwhile in practice.

Results and discussion

In cases like most of the forest operations were a systems state vary depending of outer factors DES can give valuable information in form of how big is the risk in a particular decision. There are many cases were optimization methods could be a more adequate approach. One of these areas are when there is a deterministic system and don't have to many stochastic variables.

The innovators of Cintoq had two issues that were of particular interest, 1) to quantify the impact of the felling heads capacity to accumulate trees 2) and secondly to adjust and balance the felling and the bundling capacities to avoid system delimiting bottle necks in the total process. Asked questions was answered and showed that an increase of only a few trees more in the accumulation of the head has a strong positive impact on the entire machine system. Where bundles are not still going to be a bottleneck, but manages with the specified time to bundle trees before the autonomous loading crane must leave the next bunch of trees. The DES approach constituted a cost-effective means in the innovation process, far faster and cheaper compared to many other alternatives.

As for the wood supply analysis, the simulation pinpointed what kind of supply chains should the transporting company focus on. These supply chains were robust against variance from outer factors, but showed sensitivity to supply chains with low frequency but large volumes delivered to the wood yard. The company could make use of the simulations when planning for the large industry investments at the paper mill at hand. Results pointed out what kind of supply chains should the transporting company focus on. If the scope is to have reasonable low storage levels and a very low risk in causing the paper mill of running short on pulp wood.

Finally, for the supply chain management case, the simulations showed that barter of location is cost-effective with various amount of reduction of transports but without increased risk for participating companies. A major concern is the risk involved in barter because the forest fuel and its quality is poorly defined, and only a general description of the material at the landing is available, it is hard to evaluate whether materials of equal value and quality are being bartered. Furthermore, unlike pulpwood, there is no fixed price for forest chips, which increases the risk involved in the transaction.

Using discrete event simulations for evaluating flows, interactions between activity's and systems helps in describing and understand even complex real world systems. By using animation features in simulation models, the client that know the simulated system is enabled to easily follow decisions made by the model and verify the correctness off the model. The possibility to pause simulations direct after event takes place and discuss how the real world should act on that information and then see if the models behave as expected contribute to the high value of simulations.

Coordinated planning of harvest and roads at SCA

V. Asmoarp[1], M. Bergqvist[1], P. Flisberg[1], M. Frisk[1] and M. Rönnqvist[2],

[1]Skogforsk, The forestry Research Institute of Sweden, Uppsala Science Park, SE-751 83 Uppsala, Sweden.

Victor.asmoarp@skogforsk.se

[2]Université Laval, Département de génie mécanique, Québec city, G1V 0A6, Canada

Introduction

Transportation of round wood represents a significant part of the overall wood supply cost in Swedish forestry with about 28%. Hence, transportation efficiency is important to maintain and increase profitability in the wood supply chain. Efficient transportation requires a well-functioning road network with high accessibility all year around. Lack of roads with sufficient bearing capacity causes increased costs for transport, storage and unevenly use of resources. To deal with low and uncertain accessibility in the forest road network and to decrease the supply chain's dependence of the road network forest companies can use vehicles equipped with Central Tyre Inflation (CTI), terminals for storage or make upgrade investments on the forest roads. How to use these alternatives is however a complicated problem which requires information on forest stands, harvesting plans, road accessibility, costs for upgrade, transport and storage, mill demands and truck capacities.

Traditional medium-term forest planning have forest inventory as input and results in a list of harvest areas with selected stand to harvest per year and season (Nilsson et al. 2012). The time horizon of the list of harvest sites is only a few year but the planning process will still handle a longer plan horizon, often up to 10 years. In the planning process the use of decision support systems (DSS) like Heureka (Wikström et al. 2011) is common. However, this planning take no consideration to the road network, transport fleet or industrial demand. Instead, road network planning is often made with the result from the medium-term planning as an input, which can lead to sub-optimal road investments. In a case study made at the forest company Sveaskog, Frisk et al. (2014) showed that there is a great potential for better medium-term planning when matching harvest areas against industry demand in terms of volume, species distribution, thinning percentage and road network accessibility.

The many approaches means that planning process is very complex. Today, the plans often are based on the decision maker's experience and often carried out manually. The manual handling is time consuming which makes re-planning due to changed conditions difficult and unwelcomed.

In a case study at SCA, one of the largest forest companies in Sweden, the aim was to perform a strategic analysis of cost-effective road investments on three forest holdings, with *particular* focus on coordinated planning of harvest, transport and forest road upgrades using the decision support system RoadOpt.

Materials and methods

In this presentation we describe a decision support system with an optimization model for harvest planning and planning of road upgrade investments at a forest company. The model, RoadOpt (Frisk et al. 2014) is developed by Skogforsk for analyzing the upgrading needs for roads in a forest road network, with the aim of ensuring wood supply over time. The analysis considers industrial demand, available harvesting sites, transport capacity, and costs for improving road accessibility. The model makes decisions on time for harvesting, allocation of harvested volumes, road upgrade investments and use of CTI and terminals while minimizing costs for transport, storage and road upgrades.

The study was performed as a scenario analysis where two scenarios were evaluated against each other. In the first scenario an attempt was made to simulate real practice as far as possible. In this scenario real practice means a first phase of manual medium-term forest planning and a second phase with road investment planning afterwards, the road investment planning was made as an optimization with RoadOpt. In the other scenario, coordinated planning, both medium-term forest planning and road investment planning was made in a common optimization with RoadOpt. It was the same forest stands that was harvested in both scenarios but in the second scenario, RoadOpt had the possibility to re-plan which stands to harvest during each season.

The study was made at three forest holdings on a five year planning period. The supply was 21,088 harvest stands and a demand at 19 industries sums up to 15.2 million cubic meters. All harvest stands needed to be harvested to fill the demand.

Results

We have compared the costs for road upgrading and transportation between the two scenarios. The results show a great potential to decrease costs through more coordinated planning of harvesting, transport and road upgrades. For the three investigated holdings, a potential was found to be 24.1 million Euro for a five year long period. Savings could be done at both road upgrading and transportation. Transportation cost could be reduced by 0.3 EUR/m^3 through coordinated planning. The largest savings were found for road upgrading with 1.3 EUR/m^3.

Table 1: Costs for road upgrading and transportation for the two scenarios manual and coordinated planning

Scenario	Road upgrading	Transportation	Total
Manual planning (million EUR)	33.0	166.4	199.4
Coordinated planning (million EUR)	13.3	162.0	175.3
Savings (million EUR)	-19.7	-4.4	-24.1
Diff cost (%)	-60%	-3%	-12%

The case study also showed that in the manual scenario there was a sub-optimization between the three holding in term of harvest volume per holding and season. One of the holdings had much worse ground conditions than the other two, which means more expensive road upgradings. By moving harvest machines from this holding during spring thaw, big savings could be done by reducing the number of road upgrading at this holding. Still, the largest potential saving was due to better coordinated planning within each holding.

Conclusions

The study showed that there is a large potential to reduce costs when coordinating planning of harvest and roads in medium-term planning. This kind of complex problem is too hard to solve manually due to long time horizons and large areas. In order to handle this kind of problems there is a need of advanced DSS like RoadOpt. However, in order to have reliable results there is a need of accurate and credible input data of high quality. There is probably an even greater potential if the model can integrate the decision of harvest volume levels but this will be the scoop for further research.

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Prediction model for variations in harvester production

V. Asmoarp, A. Davidsson and P. Jönsson

Skogforsk, The Forestry Research Institute of Sweden, Uppsala Science Park, SE-751 83 UPPSALA, Sweden.

aron.davidsson@skogforsk.se

Introduction

Wood consumption at the mills are often quite stable with some temporary disruption, on the other hand there is a big seasonal irregularities in wood harvest during the year. This make a significant challenges for wood supply management in Sweden. The irregularity consists of both timed events such as holidays, hunting season and non- timed as the spring thaw and heavy rains. This challenges is well known in the Swedish forest industry and wood procurement organizations around the country have different strategies to compensate for these variations, for example, additional transport capacity and safety stock.

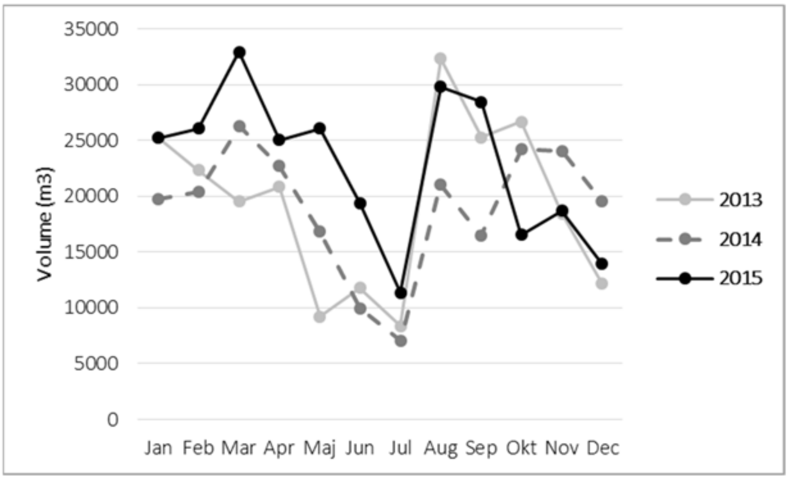

Figure 1: Total harvest production per month in three years. Showing spring thaw in April to May, holidays in July and hunting season in September to October.

Norra Skogsägarna (Norra), a Swedish forest-owner association, with more than 16 600 forest owners as its members and with a total forest holdings of over one million hectares of forest land in northern Sweden. Norra is divided in eight wood supply areas, each responsible for wood supply within the area. The total wood harvest amounts to approximately 1.9 million cubic meters per year.

Norra are now introducing a new approach for better planning volume per assortment and customer, with the purpose to synchronize production- and transport capacity. At Norra the wood supply area manager makes a three-month production plan every month, where the first month is sharp and the remaining months are rolling. This new approach is made with a resolution of a wood supply area per month, harvesting teams and assortment. Norra identified the need to better predict the produced volume per machine, assortment and month.

The purpose of this study is to build models that support Norra wood supply managers in their work with the three-month rolling production plan. The aim is to validate the model on a small area on a limited time period. The hypothesis of this study was that it is possible to build a model that uses historical production data to predict the future production of a harvester. By matching data to produced volume per machine and month with for example size of machine, rainfall and average stem.

Material and methods

The approach was to build a regression-model on historical data, to test how different parameters affecting the respondents, outcome of volume and assortments. The prediction model was split in two parts, the first estimate produced volume per machine and month, and the second estimate the percentage of an assortment in a specific month for a specific machine. This two models combined together will estimate the volume per machine, assortment and month.

Historical data used to build the (from 2013-2015) consisted of harvester data from 27 machines and over 734 000m^3 produced

- Working days per month, *Statistics Sweden*
- Wheater data, *Swedish Meteorological and Hydrological Institute*
- Information about harvested objects, *Norra Skogsägarna*
- Harvesting data, *Skogens Data Central*

For this small dataset the production did not respond to parameters such as working days or weather conditions as temperature, snow depth or rainfall. The strongest relationship was found between production and average stem, norm production and percentage final felling of total objects.

Following model for estimates production, volume (V_{mt}) per machine in machine-class m and month t, hade a R^2 of 77%;

$$V_{mt} = \beta_0 + \beta_1 * A + \beta_t * N + \beta_m * M_t$$

Variables:

(A)	Percentage final fellings of total harvesting objects
(N)	Norm production (m^3/month), contracted volume per year divided with the number of productive month
(M)	Average stem (m^3/stem), calculated as an average over planed harvesting objects a specific month.

Index:

(m)	Machine-class (Small, Medium, Large)
(t)	Time period (Jan, …, Dec)

Parameters:

(β_0)	5.4
(β_1)	728.2

Machine-class (m)	Small	Medium	Large
(βm)	3247.3	1872.6	3755.9

Month (t)	Jan	Feb	Mar	April	Maj	June	July	Aug	Sep	Oct	Nov	Dec
(βt)	0.834	0.890	0.954	0.782	0.535	0.305	0.159	1.022	0.835	0.735	0.615	0.502

The model to estimate the assortment per machine and month in percentage was calculated from the historical data. For each month, machine-class and assortment the volume was summarized, then the percentage of total volume was calculated as an average.

$\bar{P}_{amt}$ Percantage of assortment a for machine-class m in time period t

The combined prediction model that estimate volume (V_{amt}) per assortment (a), machine-class (m) and month (t) can then be formulated as:

$$V_{amt} = \bar{P}_{amt} * \mathrm{V}_{mt}$$

Results

The models was validated at the wood supply area of Södra Ångermanland during a period of January to April 2016 with 12 harvesters operating. The model for production estimated a total volume of ~118 000m^3 and the actual produced volume was ~100 000m^3 during this four months. This means that the model overestimated the produced volume with 18%. Large and small machines fitted the model better than the medium machines.

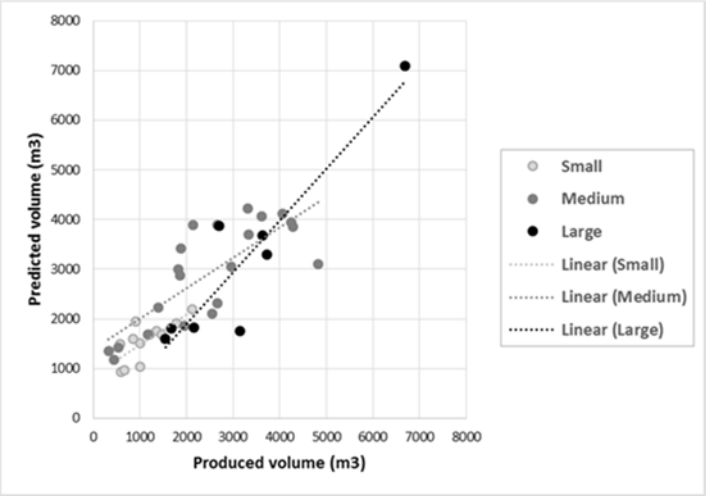

Figure 2: Predicted volume (m3) each month plotted against produced volume per machine size.

The model for proportion of assortment per machine and month estimated the assortments fairly good. The model underestimated softwood pulp and fire wood and overestimated spruce timber, pine timber and poles.

Table 1: Comparison between predicted percentage per assortment and produced

	Assortments **Softwood pulp**	**Fire wood**	**Spruce timber**	**Hardwood pulp**	**Poles**	**Pine timber**
Predicted	31%	5%	31%	19%	2%	12%
Produced	36%	7%	27%	19%	0%	11%

Conclusion

This study has shown that it's possible to use historical harvester data to predict the produced volume per assortment and month for a wood supply area. The small overestimation is most probably due to bad input data about mean steam volume from field inventory. With bigger data set to calibrate this model with there will probably be better predictions.

Harvesting cost calculations on large rasters

N. Egil Søvde, R. Astrup and A. Granhus

The Norwegian Institute of Bioeconomy Research, Ås, Norway

nils.egil.sovde@nibio.no

Introduction

The Norwegian National Forest Inventories (NFI) at The Norwegian Institute of Bioeconomy Research (NIBIO) is estimating available forest resources. Traditionally, the Norwegian NFI has based estimates on plots placed in a grid throughout the country. Each plot is assessed manually at regular intervals. Forest planning is carried out by forest owners. Today, there is a trend that some of the manual surveys are replaced by remote sensing techniques and wall-to-wall inventory estimates. NFIs in Sweden and Finland are surveying all forests using Airborne Laser Scanning (ALS), and the Finnish NFI is even making public, light-weight forest plans.

The transition to full cover inventory is challenging as manual assessment has to be replaced by computer assessment. The focus has been on estimating volumes, whereas other aspects has received less attention. The cost of harvesting has been estimated manually for each plot, but designing computational methods to replace the manual assessment is not straightforward. A forest parcel can be harvested using different harvesting systems (with different costs), and even if each system was modeled, estimates of the harvesting cost have to include some decisions of the most likely harvesting system.

In Norway, systems of harvester and forwarder (HFS) are harvesting more than 90% of the industrially utilized timber (Vennesland et al., 2006). However, in the 1950s and onwards, spruce was planted on large decidious areas in the coastal areas of Norway, and those forests are rapidly maturing. The terrain is typically steep or difficult, and not suitable for HFS. There are largely two alternative harvesting systems used in Norway that can operate in such terrain: cable yarding systems (CYS) and excavator assisted HFS (EHFS).

Aim of the study

The aim of this work is to develop a fast heuristic that can estimate the harvesting cost for large areas.

Research background

Models for HFS

HFS is a wheel based system, and the terrain transportation of such systems has been modeled using network approaches (e.g. Tan, 1992; Contreras and Chung 2011). The terrain is represented by a network of vertices, having a cost of going between neighbouring vertices. Costs of traveling through the network can be found by shortest path algorithms (SPA) (e.g. Dijkstra, 1959), and solved for large problem instances. The computational complexity of SPA is $O\big(nlog(n)\big)$ (Fredman and Tarjan 1987).

Models for EHFS

An EHFS harvesting operation includes an excavator to construct simple machine roads throughout the harvesting unit. It can thus be regarded as a road location problem. Such problems have received some attention in the forest literature, and are usually modeled as a facility location problems (e.g. Dykstra 1976, Chung 2002, Stückelberger 2008), and are in general difficult to solve to optimality.

However, the use of excavators during a forest operations have not been modeled in the optimization literature, and EHFS operations are seldom part of a broader planning of areas outside the current harvesting unit. A productivity study of the system was published by Lileng (2009), but the productivity was related to the harvesting unit. The study was used by Granhus et al. (2011), who added a cost per area for the excavator.

Models for CYS

Cable yarding operations are also often modeled as facility location (e.g. Dykstra 1976, Chung 2002, Bont, 2012).

Whereas large cable yarders require constructed landings, smaller truck based yarders operate from existing roads (Bont et al., 2012). This increased flexibility may lead to larger problem instances, but can also allow simplifications that will reduce the computational complexity. If yarding costs can be estimated without finding the specific locations of each landing and cableway, a polynomial cost model can be formulated. One such approach is Granhus et al. (2011), who used a productivity study by Omnes (1984), yarding distance and forest characteristics to estimate the yarding cost.

Methodology

The cost of harvesting operations is an important aspect for the NFI. Usually, the cost is calculated from parameters of the NFI plots, such as distance (e.g. forwarding or cable yarding), tree size, terrain classification etc. Here, cost functions are basically the same as in Granhus et al. (2011), but parameters have to be estimated for the wall-to-wall map.

The variable forwarding cost was calculated by SPA from road vertices to terrain vertices. For such calculations, c_{ij}, the cost of transport between neighbors i and j, are the only input. Here, this cost was

$$c_{ij} = \begin{cases} max\big((0.06 + 0.12r + 0.18p + 1.2rp), 0\big)d_{ij}, & if r \leq 0.45 \wedge p \leq 0.45 \\ \infty, & otherwise, \end{cases} \quad (1)$$

where r (non-negative) is the roll, p (non-negative) is the pitch, and d_{ij} is the distance between the vertices i and j.

Equation (1) was also used for EHFS. This system require diggable soil, and a cost per area was added. When excavators are assisting the HFS, the excavated trails were assumed to have zero roll, indirectly reducing the variable forwarding cost.

NFI plots in cable yarding terrain include several parameters that are difficult to assess on a wall-to-wall map, e.g. terrain operating yarders and short haulage to roadside. Here, the cable yarders are assumed to be road operated, and the cost is based on the shortest distance to road.

In the forest literature, the cost is usually calculated based on a classification of the terrain. This has also been the approach for the NFI plots (Granhus et al. 2011), where the plots are classified manually at the site. Here, we use an initial cost calculation to select the harvesting system for each vertex. Next, the harvesting cost is calculated accordingly, and timber volume and average harvesting cost reported for three cost classes (0 NOK/m^3 – 100 NOK/m^3, 100 NOK/m^3 – 200 NOK/m^3 and 200 NOK/m^3 – 300 NOK/m^3).

On top of the directly calculated harvesting cost an extra "landing place preparation cost" (10 – 30 NOK/m^3) was calculated based on the density of proper forest roads.

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Poster session

Evaluation of partial least squares and random forest hybrid algorithm for estimation of forest structural characteristics from airborne AISA Eagle Hyperspectral imaging data

A.A. Mohamed[1], D. Drew[1], K.Y. Peerbhay[2], R. Ismail[3]

[1] Department of Forest and Wood Science, Faculty of AgriSciences, Stellenbosch University, Private Bag X1, 7602 Matieland,South Africa

aahmed@sun.ac.za

[2] ICFR, University of KwaZulu-Natal, Pietermaritzburg, South Africa

[3] SAPPI, Paper & Forest Products, Pietermaritzburg, South Africa

Introduction

In South Africa, commercial forests cover approximately 1.0% (1,257,341ha) of the country's land surface (DAFF, 2008). These forests are primarily located in the eastern parts of the country and within the provinces of Mpumalanga and KwaZulu–Natal (DAFF 2008, Tewari, 2001). A rational management of forest resources requires reliable inventory information in space and time. Recent decades have witnessed an explosion in the construction; distribution and use of forest attribute maps and related spatial products. This phenomenon may be attributed to four factors: (1) development of remote sensors of the Earth's surface; (2) availability of data from these sensors in usable formats and at operationally feasible costs; (3) access to fast personal computers; and (4) widespread availability of efficient data-processing algorithms and supporting computer software. Hyperspectral remote sensing techniques are well established in assessing the spatial distribution, structure and composition of commercial forests. However, issues related to data dimensionality and multicollinearity limit the successful application of the technology for forest management inventories.

Methods and materials

Study area

The study site is located at the Hodgsons Sappi plantation in KwaZulu –Natal, South Africa (latitude 29° 13'18"S, longitude 30° 23'13"E). The plantation occupies an area of 6391ha and is situated in the mist belt grassland bioregion of the KwaZulu–Natal midlands. *Eucalyptus grandis, E. nitens, E. smithii, Pinus patula, P. elliotii, P. taeda* and *Acacia mearnsii* are the dominant commercial species occurring in the study area. The study site consists of evenly aged evergreen species compartments with an annual summer rainfall ranging from 730 to 1280mm/year. Misty conditions dominate the area during the winter seasons and provide significant amounts of additional moisture (Dye et al. 2011). The terrain is generally undulating with dolerite intrusions covered by short bunched grasslands. The altitude of the study area ranges from 1030 m to 1590 m above sea level (Mucina and Rutherford 2006).

Image acquisition and pre-processing

Airborne Imaging Spectrometer for Applications (AISA) Eagle hyperspectral imagery was obtained under cloudless conditions during the summer of February 2009. The imagery was acquired at 11:10 and consisted of four flight lines. The AISA Eagle system comprises 272 wavebands operating over the wavelength range 393.23–994.09nm with a spatial resolution of 2.4m and a bandwidth of 2–4nm. A light aircraft was used to collect the hyperspectral imagery at a mean GPS altitude of 2728.42m and a swath width of 3058m. The image was atmospherically calibrated using the empirical line method (Roberts et al. 1986). Contours with an interval of 5 m were used to orthorectify the image and projected to Universal Transverse Mercator (UTM) using the WGS-84 Geodetic System.

Training data

The samples (n = 219) used in the study consisted of the following stands: *E. grandis* (n = 26), *E. nitens* (n = 21), *E. smithii* (n = 47), *A. mearnsii* (n = 52), *P. patula* (n = 36), *P. taeda* (n = 16) and *P. elliotii* (n = 21). To ensure that the sample sizes for the various species were balanced and statistically representative, each stand was sub-sampled using a 30mx30m window to extract the AISA Eagle spectra.

Statistical analysis: Partial least squares regression (PLS)

Partial least squares regression (PLS) is a method for constructing predictive models (Wold et al. 2001). The goal of PLS regression is to provide dimension reduction in an application where the response variable (Y) is related to the predictor variables (X). PLS principally creates a few eigenvectors of spectral matrices, which will produce scores that explain both the variance of the spectral reflectance data as well as the high correlation with the response variables (Li et al. 2007, 2008).

Statistical analysis: Random Forest Algorithm (RF)

The RF algorithm is a robust, nonparametric ensemble classifier, which uses multiple classification trees to classify unknown samples. RF was designed to produce more accurate predictions and does not over fit the data, as the large number of trees are grown using a randomized subset of explanatory variables, thereby actually reducing the generalization error. The algorithm begins by selecting many bootstrap samples with replacement from the original dataset. In a typical bootstrapped sample, ~63% of the original data is present. Those observations which do not appear in the bootstrap sample are referred to as out-of-bag (OOB) samples. Once the bootstrap sample is selected, a classification tree is fitted to the sample. It should be noted that for each tree fitted to the bootstrapped sample, only a small number of randomly selected variables are selected for the node splits, thereby reducing the computational time and the complexity of the classifier. Thereafter, the trees are fully grown (unpruned), and each tree is then used to predict on the OOB samples. An observation is placed into a particular class based on majority vote of the OOB predictions, with ties split randomly.

Statistical analysis: Hybrid algorithm (PLS-RF)

For highly correlated predictors data sets, there may be some benefit to using PLS to generate new features from the original data (the PLS scores) then use those as an input into a random forest model. Both the PLS and random forest models are jointly tuned instead of an initial modelling process that finalizes the PLS model, then builds the random forest model separately. We optimize both algorithms at once. Another important point is that the resampling results reflect the variability in the random forest and PLS models. If we did PLS up-front then resampled the random forest model, we would under-estimate the noise in the modelling process. The PLS–RF model saves the PLS loadings along with the random forest model fit so that the loadings can be used on future samples for prediction

Results and Discussion

Results indicated that the PLS-RF model produced an overall average of $R^2 = 0.95$ (range; 0.91-0.98) of all attributes compared to R^2 values of 0.92 (range; 0.84-0.98) and 0.86 (range; 0.72-0.996) for RF and PLS respectively. Overall, the research has demonstrated the potential of using PLS-RF for reducing the dimensionality and multicollinearity of hyperspectral datasets s to produce the better performance.

Conclusions

Overall, the research has demonstrated the potential of using PLS-RF for reducing the dimensionality and multicollinearity of hyperspectral datasets to produce the better performance. the proposed approach deserves attention in future studies aimed at estimating stand attribute variables by using remote sensing data, especially for more complicated stand structures, such as mixed and uneven aged forests,

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An assessment of variation within valuation methodologies used in South Africa to estimate the value of pulpwood plantations

C. Baptista[1], C. Ham[2] and M. Howard[3]

[1]Mondi, P.O. Box 39, Pietermaritzburg, 3200, South Africa

Carl.Baptista@mondigroup.co.za

[2]Department of Forest and Wood Science, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa

[3]Fractal Forest Africa CC, P O Box 759, Umhlali 4390, South Africa,

Introduction

Forest valuations are required for a range of purposes including property and timber sales, financial reporting, insurance or compensation, and forest planning and management. There is however no strict set of rules or guidelines that prescribe valuation methods allowing some degree of freedom to adjust the outcomes of valuations based on method used and assumptions made. This study sought to assess the possible variations within International Accounting Standard (IAS) 41 compliant valuation methodologies used within South Africa to estimate the value of pulpwood plantations.

Methodology

IAS 41 compliant valuation methods were collected from valuation consultants and companies active within the South African forestry sector. These methods included Standing Value, Cost Value and a combination of Standing and Cost value approaches (MaxSV/CV) as well as three Discounted Cash Flow approaches. Input parameters and methods for the determination of input parameters were also obtained. Methods were amended to accept default standardised inputs from an unnamed South African case study plantation. Valuations were calculated for this case study plantation using the various methods, and used to assess the possible variances between method valuation outputs. In this way the variances derived from the different methods could be compared to each other. A sensitivity analysis was performed to understand the effect of each parameter upon the valuation output of each method.

Results and Conclusion

This study indicated that there are significant differences between valuation outputs as calculated from a range of IAS 41 compliant valuation methods. The collected parameters and parameter classification data also highlighted that parameters such as age class and growth rate were being calculated or determined in different ways by users, resulting in further sources of potential variance in the calculated values produced by the methods.

The study concluded with an evaluation of each of the six unique valuation methods. Two main aspects that should be addressed to ensure comparable valuations are: (i) The standardisation of a method to be used for all valuation purposes; (ii) The provision of rigid guidelines regarding the standardisation of method input parameters.

Modeling the effect of fleet management routines on mill delivery precision and truck utilization

D. Fjeld

Norwegian institute for bioeconomy research, 1430 Aas, Norway

dag.fjeld@nibio.no

Introduction

In the Nordic countries trucks are the dominating method of transport and the small firm size for hauling contractors require transport servicer buyers to work with a large number of contractors. Many chose, therefore, to outsource transport management to transport service provider organizations. Mill service levels for wood supply vary considerably but a common service definition delivery precision, defined as the delivered volume per assortment and month in relation to the ordered volume per assortment and month.

The monthly mill order is commonly broken down to contractor-specific quotas to be filled from the portfolio of harvesting sites which the contractor has responsibility for. Quota follow-up is the interim control of how the contractors are fulfilling their monthly quotas. The follow-up is then the basis for managers' adjustment of goals for the following period (monthly, weekly or even daily). Responses to deviations between planned and actual deliveries can vary from prioritization of resources (to accelerate the flow of certain assortments) to a stop of other flows (if earlier deliveries have already filled mill storage capacities).

At present there is a trend towards increasing mill service demands. A typical goal for monthly delivery precision has been ±10% with many now aiming at ±5%. Even though deliveries are monitored daily, a typical interval for quota follow-up is weekly. The effects of these commonplace routines on mill delivery service and truck utilization have not been quantified. The aim of this study was therefore to model the effects of varying fleet management routines (goals for delivery precision and quota follow-up interval) on mill delivery precision and truck utilization.

Methods

This study focuses on the two aspects of fleet management via quota control: 1) maximum allowable limits for deviations between planned and actual deliveries which initiate corrective measures (allowed delivery deviation in %), 2) interval of delivery follow-up (expressed in days or weeks).

The model type chosen for this study is object-oriented discrete-event simulation. A simple model created loads in three districts, each with a contractor resource pool. At creation each load is assigned a mill destination and waits at a mill-specific road-side stock for available transport capacity from the contracted hauling contractor. Each contractor has three trucks in its resource pool which may be allocated to transport. When the sum of deliveries from all three districts to a mill exceeds the upper allowable limit for deliveries (expressed as a percent of planned deliveries), a full stop of all deliveries to that mill is imposed in all three districts, and the contractor resources are re-routed to the other road-side stocks. When the sum of deliveries to a mill does not reach the lower allowable limit of delivery demand, a priority is attached to all entities destined for that mill, and these are given first right to all transport resources within the respective contractor's resource pool. Both weekly and daily follow-up intervals are modelled within 10 and 5 % limits for allowable delivery deviation. These are nested within three different supply situations; 10% oversupply, supply balance and 10% undersupply. 15 runs were made for each combination.

Results

The resulting mill deliveries (as a proportion of monthly demand) for each combination of supply situation, allowable delivery deviations and quota-follow-up interval are shown below (top). For balanced in supply and demand, daily quota follow-up enabled fulfillment of mill orders for both levels of allowable deviations (5 and 10 %). The greatest variation in deliveries was for 10 % oversupply and the least variation was for 10 % undersupply. Deliveries (as a percent of monthly demand) were always higher for daily follow-up than weekly and the difference between daily and weekly follow-up were greatest for oversupply and least for undersupply. In cases where there was an oversupply or balance in wood supply, and given the same follow-up frequency, deliveries were higher for an allowable delivery deviation of 10 % than for 5%.

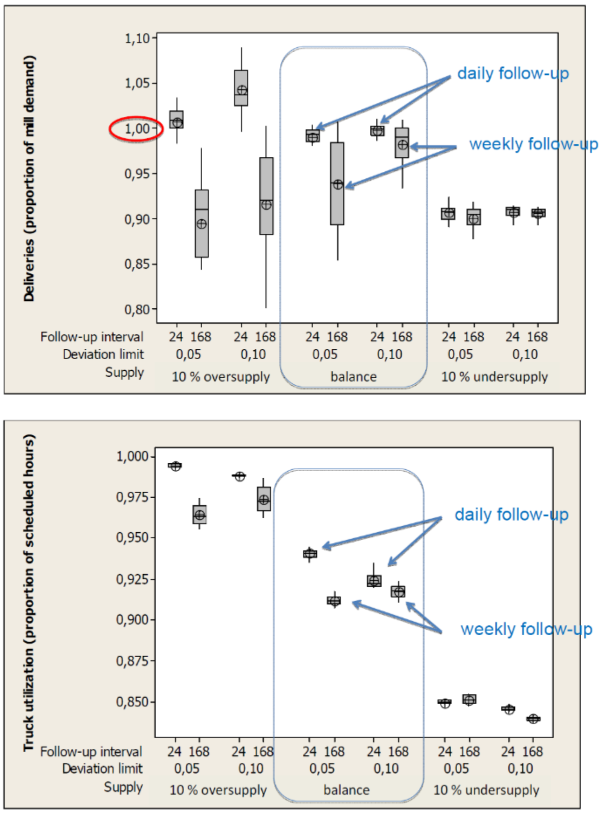

Figure 1: Deliveries (top) and truck utilization (bottom) for varying fleet management routines. Quota follow-up interval is show in hours (24=daily, 168=weekly).

The truck utilization for the three contractors for each combination of supply situation, delivery deviation limits and quota-follow-up interval are above (bottom). The average utilization varies from 96-99% for oversupply to 91-94% for balance and 84-85% for undersupply. In almost all cases (5 of 6) utilization was higher for daily than weekly follow-ups. Given an oversupply or balance in supply and demand the two following results can be noted: 1) Given daily follow-ups, narrower limits for allowable delivery deviations increased truck utilization, 2) Given weekly follow-ups, narrower limits for allowable delivery deviations reduced truck utilization. The effect of increasing delivery precision on utilization depends therefore on follow-up frequency.

Discussion

According to the simple simulation model used in this study, the effect of precision goals and management routines on mill deliveries and truck utilization are dependent on the supply situation. The corrective measures simulated in this study clearly limit truck utilization. In supply situations where there is enough wood at roadside, narrowing the limits for allowable delivery deviations from 10 to 5 % caused a reduction in utilization when implemented through weekly quotas. However, the same step increased utilization when implemented through daily quota follow-up. Regardless of the effects on average utilization, almost every case of narrowing allowable deviations resulted in a slightly greater variation in truck utilization.

The effect of weekly quota follow-up on hauling contractor profitability has been shown earlier in Lindström and Fjeld (2011) where contractors subject to weekly quota control had lower net operating margins than others. The reason for the lower profitability with quota control can be partially explained by the added restrictions and reduced freedom to find efficient routing solutions. Auselius (2009) also cited frequent changes in wood flows as hinders to efficient routing. General theory of system dynamics (Fowler 1999) also points out the dangers of high gain responses in a feedback system with long lead times. The type of simulation approach used in the present study provides a basis for further examining such effects of fleet management routines on mill service and transport resource utilization.

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FOREST MOBILE APP: Development of an offline GIS Incident Capture System and Pest and Disease Reference Library

J. Meyer[1], R. Woolley[2] and C. Baptista[3]

[1]*Crop Protection Specialist, Re-Engineering Dept., Mondi Ltd, Mondi House, 380 Old Howick Road, Hilton, jacqui.meyer@mondigroup.co.za*

[2]*Senior GIS Specialist, Planning Dept. Mondi Ltd. Mondi House, 380 Old Howick Road, Hilton, robin.woolley@mondigroup.co.za*

[3]*Senior Planning Analyst, Planning Dept., Mondi Ltd, Mondi House, 380 Old Howick Road, Hilton, carl.baptista@mondigroup.co.za*

Introduction

With the increasing number of pests and diseases infesting our plantations, it is necessary to understand the impact they are having on our yields.

The incident capture system is the current mechanism for recording these incidences (and others) and the consequent losses. This information is recorded in MicroForest and enables us to make volume changes, if necessary.

One of the most important needs to improve management of pests and diseases is through more effective monitoring. At present this monitoring is conducted in a haphazard and unbalanced fashion. Internationally researchers and authorities are increasingly using cellular phone apps to involve in-field specialists (foresters and contractors) to assist with this task. The goal of the app is to make identification and reporting easy and as efficient as possible. Species identification guides include images and information on the most important pests and pathogens affecting forestry species.

The Foresters App will ensure the elimination of the weaknesses of the existing manual incident reporting system. The design of the App is envisaged to ensure that the interface is always relevant to the Foresters requirements in order to manage change in an efficient manner.

Scope

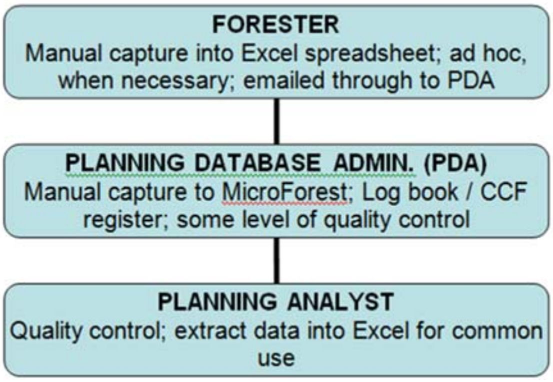
Development of an easy to use, spatially-driven App (GIS off-line Incident Capture System), which can be run on most devices (PC, laptop, tablet, phone). The App enables users (foresters) to (1) view maps; (2) view reference database of pests and diseases (3) record incidences observed in the field and (4) sync data when back in office.

Expected business outcomes:

- More accurate incident reporting w.r.t (1) quantifying losses; (2) better capture of actual cause of loss and (3) improvement in reporting of losses which currently is poorly and inconsistently done.
- Reference to assist with identifying pests and pathogens causing losses (Fig. 1).
- Maps generated to show losses.
- Easier capturing of losses; can be done in field.
- Eliminates double handling of incident capturing (and therefore reduced potential for error) (Fig. 2 and 3).

These greyish-black to greyish brown caterpillars with a smooth skin are the larval stage of several species of indigenousnocturnal moths. They are often associated with high rainfall and dense weed coverage.

Figure 1: Pest and disease reference library will be logic driven and easy to use.

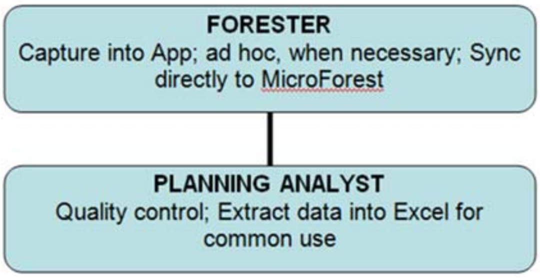


FORESTER
Manual capture into Excel spreadsheet; ad hoc, when necessary; emailed through to PDA

PLANNING DATABASE ADMIN. (PDA)
Manual capture to MicroForest; Log book / CCF register; some level of quality control

PLANNING ANALYST
Quality control; extract data into Excel for common use

Figure 2: Current incident capturing process.



FORESTER
Capture into App; ad hoc, when necessary; Sync directly to MicroForest

PLANNING ANALYST
Quality control; Extract data into Excel for common use

Figure 3: App allows for direct capturing of incidents to MicroForest by Foresters.

Advantages:

- No additional software required.
- Hardware independent
- Mondi owns the code.
- Three months support incorporated into budget.
- Modular system – can add on e.g. Change control module.

Way forward and timeline:

The project started at the beginning of June 2016. Development will take 5 months which will include testing. Thereafter the app will be rolled out with training and a further 3 months system support.

Measuring the spatial volatility of the cryptic pathogen, *Uromycladium acacia*, across black wattle timber plantations in KwaZulu-Natal

K. Peerbhay[1], I. Germishuizen[1] and M. Omar[2]

[1]Institute for Commercial Forestry Research (ICFR), P O Box 100281, Pietermaritzburg 3209, South Africa

Kabir.peerbhay@icfr.ukzn.ac.za

[2]University of KwaZulu-Natal, Private Bag X54001, Pietermaritzburg 3209, South Africa

Introduction

Acacia tree species are cultivated as a valuable economic resource by the plantation forest industry covering an area estimated to be over 100 000 hectares (MacTaggart et al. 2015). In particular, *Acacia mearnsii* (black wattle) produces wood material which is usually sourced for chip export, pulp or mining timber while the bark is known for having the richest content of the naturally occurring compound, tannins (Roux et al. 1995). These tannins are versatile and have a high demand in leather processing, manufacturing of adhesives, pharmaceuticals products and recently in the production of steel corrosion inhibitors (Peres et al. 2014). In this regard, black wattle has captured the status as being one of the most valued forest planation species within the forestry sector. However, as an exotic cultivated species, *Acacia mearnsii* has been prone to various tactical damaging enemies that threaten forest productiveness.

Among the natural damaging agents, black wattle has predominantly experienced risk to pathogens (Roux et al. 1995). During 2013, an outbreak of a new disease has been observed in the Natal Midlands area, caused by a rust fungus. The pathogen appeared to be spreading fast and posing an enormous threat to the production of wattle growers in the region. A concerted effort has therefore been undertaken by the Tree Protection Co-operative Programme (TPCP) together with the Institute for Commercial Forestry Research (ICFR) and NCT Forestry to help understand and respond against the impact of the rust. Recent DNA sequencing and other methods have been used to identify the rust as, *Uromycladium acaciae* (MacTaggart et al. 2015). Some of the symptoms of the affected trees include leaf spots, leaf curl, defoliation, gummosis, stunting and dieback of seedlings. Currently, the spraying of fungicides is being tested and used in the preliminary control of the spread of the rust (Little and Payn, 2016), however, to date the overall effort has proven challenging. Therefore, more research is required to understand the trends of occurrence and the seasonal life cycle of the fungus to develop effective solutions and to prevent infection. A necessary response to combatting this outbreak is to determine the current spatial extent of the infected area before assessing damage severity to forest production. This study, therefore seeks to develop a detection methodology that can be used for the routine mapping of the rust presence using cost effective remote sensing technologies.

Methods and Materials

The study plantation is located near the town of Richmond (29.8667° S, 30.2667° E) in the KwaZulu-Natal province. The study area is situated at an altitude range between 900m and 1400m above sea level receiving an annual rainfall ranging from 800m to 1280mm. Average annual temperatures of 17°C are prominent in this region. Two LandSat 8 satellite images (spectral range: 300nm – 900nm, resolution: 30m x 30m, swath:185km x 185km) were acquired from the United States Geological Survey website (www.earthexplorer.ugs.gov) and atmospheric calibrated to surface reflectance using the FLAASH processing module (Adler-Golden et al. 1998). Following the industry protocol developed, eighty-one rectangular 30m x 30x field plots were inspected and surveyed for the presence and level of infestation of the rust. Moreover, wattle compartments between 7 and 9 years were sampled covering an area greater than 7ha (approximately 9 pixels) to avoid spectral noise from adjacent land cover and background effects of smaller stands. Each 30m x 30m plot (100 trees planted at a spacing of 3 x 15m) was established in a uniform area of the compartment and used to extract spectra for statistical analysis. Approximately 70% of the dataset was used for the training dataset while the remaining 30% was used for the validation dataset. Final overall classification accuracies were derived using the confusion matrix.

Results

Classification results revealed successful detection accuracies of the rust fungus in infected wattle compartments. Using partial least squares discriminant analysis (PLS-DA) as a classifier, wattle rust was mapped with an overall accuracy of 83% from uninfected wattle compartments (Fig. 1). The PLS-DA model used an optimal number of 7 latent components.

Using the variable importance in the Projection (VIP) scores to determine the most relevant variables in the model, showed that the blue bands, near infrared and normalized difference vegetation index (NDVI) were important. Therefore, providing motivation to investigate other vegetation indices including climatic factors for addressing the detection of the wattle pathogen, especially when mapping the severity of infestation in the future.

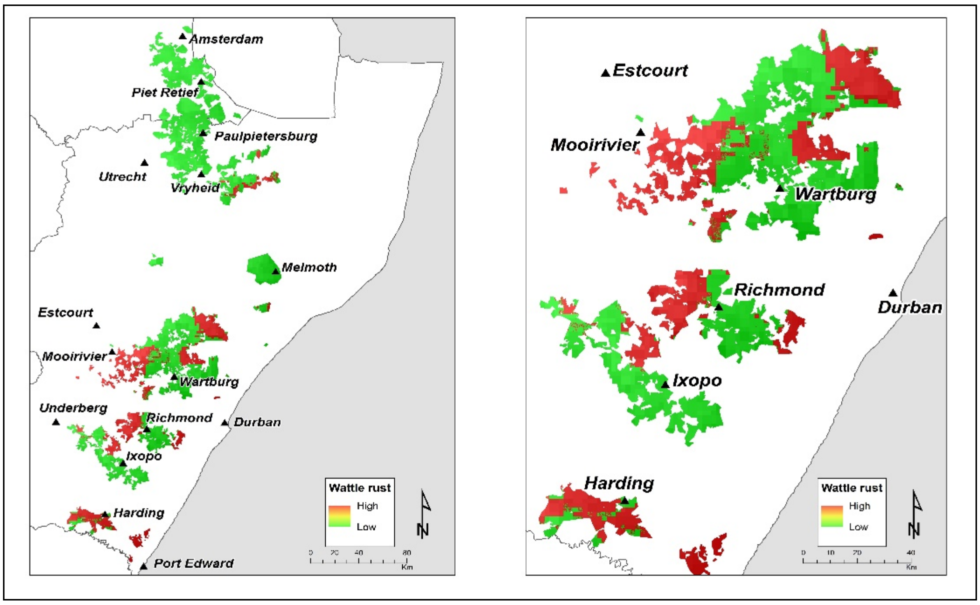


Figure 1: Potential distribution of Uromycladium acaciae in black wattle compartments in KwaZulu-Natal.

Conclusion

The study has shown the capability of the new generation Landsat 8 operation land imager (OLI) to spatially detect and map the cryptic pathogen, *Uromycladium acaciae*, at a plantation scale. This study provides the evidence of upscaling the framework to develop a national level monitoring tool for routine mapping of this new pathogen across all black wattle plantations. Additionally, this would contribute towards an essential part of an effective forest protection management strategy, for early detection and inoculation control as well as to ensure the sustainability of our valuable black wattle forest resources.

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Modelling stem diameter variability in a multi-species stand: a new approach

P.O. Adesoye

Department of Forestry, University of Venda, Private Bag X5050, Thohoyandou, South Africa.

Peter.Adesoye@univen.ac.za

Introduction

Diameter variability is a well-known and widely developed concept useful for effective forest management planning. Several studies (e.g. Bailey and Dell 1973, Hafley and Schreuder 1977, Borders et al. 1987, Mehtatalo et al. 2008, Kayes et al. 2012, Poudel and Cao 2013, Sipilehto and Mehtatalo 2013) have put considerable effort to modeling diameter distribution using different theoretical distribution functions. Although, varying degrees of success have been achieved in modeling diameter distribution, there is however, room for improvement. To date, little has been done to explore the modeling potentials of two chief characteristics of stem diameter variability, that is standard deviation of diameter (SDD) and coefficient of variation of diameter (CVD). Zeide and Zhang (2000) proposed a model for estimating SDD using stand attributes such as average diameter, number of stems and age. Their model explained 91% of the variation in SDD. However, standard deviation is often criticized to be unstable in magnitude and tricky to interpret (e.g. McDonald 2014). A lower standard deviation does not necessarily imply lesser variability. In this study, with particular focus on multi-species stand, the CVD is proposed as a suitable alternative to SDD because its value is stable across different groups of sizes and conditions which is a recurring experience in natural stands. This study therefore investigates whether SDD and CVD are indeed independent from stand attributes.

Materials and Methods

The data used for model fitting in this study were collected from Ekuri Community Forest, located in the buffer zone of Cross River National Park of Nigeria (Fig. 1). A total of 32 temporary sample plots of size 25m x 25m were randomly laid. Tree size variables measured within each plot each plot include diameter at breast height(cm), total and merchantable heights(m), number of stems and percentile positions of stem diameter at 24th (P_{24}), 63rd (P_{63}), 76th (P_{76}) and 90th (P_{90}) (merchantable limit was taken as the minimum top diameter of 10cm). Correlation and multiple linear regression analyses were used to analyze the data. The SDD and CVD were used as response variables; while three categories of explanatory variables were investigated (i.e. measures of tree size only – mean diameter, basal area/ha, number of trees/ha, etc.; measures of distributions – percentile positions P_{24}, P_{63}, P_{76} and P_{90}; and combinations of the these measures). The set of explanatory variables used were also checked for multicolinearity by observing their variance inflation factor (VIF). Model evaluation and comparison were achieved using standard error of estimate (SEE), relative standard error (RSE), coefficient of determination (R^2), prediction residual sum of squares (PRESS) and Akaike's information criterion (AIC). Model with smaller values of PRESS, AIC, SEE, RSE; and higher value of R^2 was considered to have better fit. Furthermore, explanatory variable with VIF greater than 5 was not included in any category of models investigated.

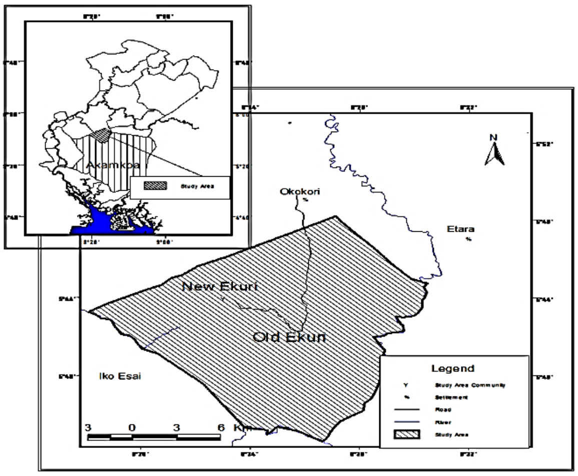

Figure 1: Inset Map of Cross River State Nigeria Showing the Study Area

Results

The rectangular correlation matrix of SDD and CVD against stand variables is presented in Table 1. All the stand variables are correlated with SDD and positively so with the exception of number of trees/ha. Highest correlation with SDD was found to be P_{90}. On the other hand, CVD was only correlated with mean dominant height (H_d), basal area per hectare (BA/ha) and P_{90} and positively so. Consistent positive correlation between stand variables and the two measures of variability suggests that diameter variability increases with increase in stand attributes. The selected candidate models, fitted to the data with their corresponding parameter estimates, fit and prediction statistics are presented in Table 2.

Table 1: Rectangular Matrix Correlation Coefficients of SDD and CVD against Stand Attributes

	D_{am}	H_d	N/ha	BA/ha	P_{24}	P_{63}	P_{76}	P_{90}
SDD	0.72*	0.38*	- 0.03	0.85*	0.39*	0.50*	0.38*	0.90*
CVD	0.35	0.47*	0.09	0.59*	0.01	0.08	- 0.01	0.75*

** = Significant correlation at α level of 0.05*

Table 2: Candidate Models with Parameter Estimates, Fit and Prediction Statistics

Model No.	Model	R^2	AIC	SEE	RSE (%)	PRESS
	SDD Candidate Model					
1	$SDD = -24.9 + 0.743D_{am} + H_d$	0.61		4.342	21.01	702.868
2	$SDD = -10.5 + 0.412P_{90}$	0.81		3.011	14.57	329.193
3	$SDD = -6.62 + 0.102BA + 0.276P_{90}$	0.86		2.644	12.79	325.908
	CVD Candidate Model					
4	$CVD = 0.348 + 0.003BA$	0.35		0.099	18.62	0.4105
5	$CVD = 0.428 - 0.024P_{24} + 0.009P_{90}$	0.78		0.058	10.91	0.125
6	$CVD = 0.222 - 0.012D_{am} + 0.01P_{90}$	0.70		0.069	12.88	0.171

Among the SDD models, the model with combination of stand size variable and measures of tree size distribution (i.e. Model 3) gave a better fit judging from the fitting and prediction criteria (i.e. higher R^2 of 0.86, lower values of SEE of 2.644, PRESS of 325.91 and RSE of 12.79%). Among the CVD models, the model with mainly, measures of tree size distribution (Model 5) gave a better fit judging from the fitting and prediction criteria (i.e. higher R^2 of 0.78, lower values of SEE of 0.058, PRESS of 0.125 and RSE of 10.91%). Generally, it is not appropriate to compare two models with different response variables using R^2 and SEE. However, such comparison is made possible using relativized standard error (defined as the percentage ratio of SEE to average estimate produced by the fitted model). Hence, comparison of the best SDD and CVD models, on the basis of RSE indicates that CVD model (Model 5) is superior to the SDD model (i.e. Model 3).

Conclusion

The modelling potentials of two chief characteristics of stem diameter variability, standard deviation of diameter (SDD) and coefficient of variation of diameter (CVD) were investigated in a multi-species stand. The study shows that models with measures of stem diameter distribution (i.e. percentile positions) as explanatory variables ranked overall best. The stability of CVD in measuring variability across different groups of stand sizes also support preference for CVD over SDD. The CVD increase with P_{90} and it decrease with increase in P_{24}. This trend raise a question: why does CVD decrease with increase in P_{24}, but increases with increase in P_{90}? It is expected that stand level growth models based stem diameter variability can be improved by using the CVD model 5.

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