PRECISION FORESTRY SYMPOSIUM
3 – 7 FEBRUARY 2025

FEBRUARY 3 - 7, 2025

PRECISION FORESTRY:
AT THE DAWN OF ARTIFICIAL INTELLIGENCE (AI)

Proceedings of the 5th International Precision Forestry Symposium

Stellenbosch, South Africa

ORGANIZED BY

Stellenbosch University Iyunivesithi Universiteit

IUFRO Interconnecting Forests, Science and People

The Southern African Institute of Forestry

SPONSORED BY

remsoft

OPTRON

Softree Engineering an Easier Way

JUNIPER SYSTEMS

micro forest

TIMBETER

Alternative Structures

Proceedings of the 5th Precision Forestry Symposium: "At the Dawn of Artificial Intelligence". Edited by Justin Erasmus, Bruce Talbot, Phozisa Dlokweni, and Gunta Grube, 3rd to 7th February 2025, Stellenbosch University, Stellenbosch, South Africa.

ISBN: 978-0-7972-1923-6

Organising Committee:
Justin Erasmus
Bruce Talbot
Phozisa Dlokweni
Anton Kunneke
Gretchen Dube
Gunta Grube

Scientific Review Committee:
Bruce Talbot—Uni Stell, ZA, Leader IUFRO 3:04 Forest Operations Management
Justin Erasmus—Uni Stell, ZA, Organizer
Stefano Grigolato—Uni Padua, IT, Leader IUFRO 3:10:00 Robotics
Charlie Blinn—Uni Minn, US, Editor: Int J For Eng
David Everard—Editor: Southern Forests
Rob Keefe—Uni Idaho, US
Philippe Giguère—Uni Laval, CA
Thomas Purfurst—Uni Freiburg, DE

Published by:
Department of Forest and Wood Science
Faculty of AgriSciences
Stellenbosch University
Private Bag XI
7602 Matieland
South Africa

Editors:
Justin Erasmus
Bruce Talbot
Phozisa Dlokweni
Gunta Grube

Cover Design:
Gunta Grube

Printed by:
Department of Forest and Wood Science, Stellenbosch University

This booklet was created using a customized version of the open LaTeX template `AMCOS_booklet`, available at GitHub.

Contents

Preface **8**

Partner Institutions and Sponsors **9**

About **10**

Keynote Speakers **11**

List of Abstracts – Talks **12**

Wednesday, 5th February 12

AI and Robots – Drivers and Trends in Forest Operations 12
Ola Lindroos

Measuring Tree Diameter Using AI-Assisted Smartphone Application: A Case of Karacabey, Türkiye. 12
A. E. Akay

Development of a Forest Technology Testbed for Remote Controlled and Autonomous Operations – Results and Examples from Ongoing Studies in Sweden. . . . 19
G. Andersson, T. Semberg, A. Nilsson, P. Jönsson, L. Hansson, M. Rossander, M. Englund

Comparative Analysis of Remote Sensing and Ground-Based Surveys in Determining Merchantable Volume of a Boreal Forest Stand. . . . 21
D. Guindon, D.Y. Amishev

Precision Forestry in a Messy Forest 22
Mark J. Ducey

Assessing GNSS-Based ICT Systems for Sustainable Small-Scale Forestry Operations. 23
R. Picchio, R. Venanzi, A. Bonaudo, L. Travisani, F. Latterini

Assessment of the Implementation of a GIS-Planned Strip Road Network in Pine Forest Thinning in Central Italy. 24
R. Venanzi, R. Picchio, A. Bonaudo, F. Latterini

Actual Tree Size Distribution vs an Assumption of Normal Tree Distributions Towards Precise CTL Harvesting Productivity Modeling of Two Different Size Harvesting Machines. 25
S. Ackerman, J. Bekker, R. Astrup, B. Talbot

Using UAV Multispectral and Non-Imaging Hyperspectral Remote Sensing to Develop Detection Techniques for Eucalyptus Leaf Diseases. 28
M. Mohobo, M.L. Schröder, A. Hammerbacher, A. Ramoelo, W.H. Maes, B. Slippers

The Potential of a Low-Cost Wireless Dendrometer and Environmental Sensing System: What Information Can Be Inferred? . . . 30
C. Erasmus, D. Drew, T. Booysen

Continuous Improvement through the Integration of Optimization, BI and AI within an Intelligent Forestry Planning Platform. . . . 32
P. Asiron

A Data Integration Framework for Annotated Forestry Datasets: Combining RGB Imagery and Harvester Data. . . . 33
C. Höök, O.M. Trejo, C. Häggström, O. Lindroos

Advancing Crown Architecture Characterization in Eucalyptus Using Terrestrial Laser Scanning. . . . 34
O.F. Gakenou, A. Kunneke, A.A. Myburg, D.M. Drew

Capturing a Digital Model of the Supply Chain for Precision Forestry Planning and Decision Support. . . . 35
P. Asiron

Predicting Growth and Yield Using Empirical Models and Climatic Modifiers for Short-Rotation Eucalyptus Pulpwood in South Africa. . . . 36
M. Chauke, H. Kotze

Thinning Effects on Light Capture, Light Use Efficiency, Risk Management, and Stand Productivity in a Radiata Pine Plantation. . . . 41
L.O. Pienaar, B. du Toit

Availability and Transformations of P and N Across Climatic Zones, Soil Type, and Fertilization in Early Response in South African Commercial Forestry. . . . 43
T.Z. Tekleab, I. Germishuizen, B. du Toit

Understanding the Impact of Under Canopy Mulching as a Fuel Load Management Tool. . . . 44
L. Mahadeo

Discriminating Commercial Forest Plantation Species at the Species Level Using Multi-Temporal Unmanned Aerial Vehicle Imagery. . . . 45
W. Khumalo, M. Mngadi, I. Germishuizen

The Effect of Training Set Size on the Performance of Machine Learning Models in Detecting Young Pine Trees. . . . 46
J. Kok, S. Ackerman, B. Talbot, J. Erasmus

Thursday, 6th February . . . 47

Pixels, People, and Precision: Aligning Technological Innovation with Human Adaptation in Forestry. . . . 47
M. Wilson

Examining the Utility of a Hybrid Approach for Predicting Forest Structural Attributes Using Hyperspectral Data. . . . 48
M. Parag, R. Lottering

Detection of Phytophthora Root Rot in Eucalyptus Using Hyperspectral Leaf Reflectance and Machine Learning. . . . 49
E.H. Esterhuizen, T. Bose, A.S. Bosman, J. Roux, W. Jones, B. Slippers, A. Hammerbacher

Automated Terrain Roughness Assessment Using TLS as a Proxy for Machine-Mounted LiDAR Applications. 50
G. Grube, B. Talbot, S. Grigolato

The Digital Forester: Leveraging Remote Sensing Technology at Scale. 52
N. Agjee, K. Tasker, K. Peerbhay, J. Crous

A Severity Index for Forestry Machine Impact in Mountains Using Machine Learning. 53
A. Udali, D. Imperiali, N. di Marzio, S. Grigolato

Assessing Stand Heterogeneity in Plantations Using UAV-Derived Data and Deep Learning for Crown Segmentation. 55
M. Jordaan, K. Y. Peerbhay, B. Talbot

Assessing Gonipterus sp. n. 2 Defoliation Levels Using Multispectral Unmanned Aerial Vehicle (UAV) Data in Eucalyptus Plantations. . . . 56
P. Nzuza, M.L. Schröder, R.J. Heim, L. Daniels, B. Slippers, B.P. Hurley, I. Germishuizen, B. Sivparsad, J. Roux, W.H. Maes

Friday, 7th February 59

Big Data in the Agriculture Sector 59
Kanshukan Rajaratnam

Detecting and Measuring Tree Stumps in UAV-derived Imagery. 59
A. Hubbard, B. Talbot

Precision Weed Detection with Machine Learning. 61
J. Park, L. Steyn, B. Talbot

Adapting Computer Vision Technologies for Measuring Plant Quality and Vitality at Sappi's Largest Commercial Nursery. . . . 62
K. Peerbhay, M. Maresch

Harnessing Near Infrared Spectroscopy for Advancing Smart Forest Management: Innovations and Applications. 63
I. Germishuizen

Stump to Mill: Leveraging UAV-Based Technologies for Precision Forestry Operations. 64
K. Tasker

Evaluation of Integrated Multi-satellite Retrievals for GPM (IMERG) in South African Forest Plantations. . . . 65
N. Kheswa, S. Upadhyaya, M. Wilson

Log Identification Using Computer Vision Techniques. 66
J. Kok, J.P. Van Der Merwe

Useful Information **68**
Conference Venue 68
Conference Venue and Location 68
Internet Access 68
How to Get to the Conference Venue 68
From Cape Town International Airport (CPT) 68
From Cape Town City Center 69
From Somerset West 69
From Stellenbosch Central 70

Catering and Social Events 70
Local Transportation and Parking 70

Preface

Precision Forestry in the Dawn of Artificial Intelligence (AI)

The field of Precision Forestry has witnessed an extraordinary evolution over the past decade, fuelled by advances in remote and proximal sensing technologies, as well as the transformative potential of artificial intelligence (AI). This symposium is a unique opportunity for researchers, practitioners, and industry leaders to engage, collaborate, and envision the future of Precision Forestry—where technology, humans, and nature converge to foster smarter, more sustainable forest management.

Since the last Precision Forestry Symposium of 2017, the COVID pandemic and the subsequent release of publicly accessible AI platforms, has impacted the way that research is done in many ways. These innovations have redefined how we monitor, manage, and optimize forest resources, offering unprecedented accuracy, efficiency, and insight into the complexities of forest ecosystems.

At the heart of these developments is the integration of cutting-edge sensors—ranging from LiDAR, UAVs, and satellites to ground-based systems—that enable us to gather vast amounts of high-resolution data on forest structure, biodiversity, health, and growth. These technologies have not only improved the precision with which we assess forest conditions but also expanded the spatial and temporal scales at which we can operate, making it possible to track forest dynamics in real-time.

Simultaneously, the rise of AI and machine learning has unlocked new opportunities for data analysis, pattern recognition, and decision-making. By harnessing the power of algorithms to interpret complex datasets, we are able to extract actionable insights that were once beyond our reach. Whether it's predicting forest growth, identifying pest outbreaks, or optimizing harvest strategies, AI-driven solutions are enabling forest managers to make smarter, more sustainable decisions.

As we gather for this symposium, we celebrate the progress made and look forward to exploring the latest breakthroughs and applications in these fields. The range of abstracts in these proceedings already provides a good indication of the transition of research focus towards AI-based methods, and the next wave of Precision Forestry promises even greater potential.

A short word of thanks goes first and foremost to the delegates and especially the presenters, to the scientific and organising committees, and not least to the sponsors of the event. On behalf of the Southern African Institute of Forestry, The International Union of Forest Research Organisations, and the Department of Forest and Wood Products Science at Stellenbosch University, we wish you a constructive and enjoyable Symposium.

Bruce Talbot and ChatGPT!

The South African Institute of Forestry (SAIF)
The International Union of Forest Research Organisations (IUFRO) – Div 3
The Department of Forest and Wood Product Science, Stellenbosch University

Partner Institutions and Sponsors

We extend our sincere gratitude to our sponsors and partners for their generous support in making this event possible.

PARTNERS

IUFRO
Interconnecting Forests, Science and People

The Southern African Institute of Forestry

PLATINUM SPONSORS

remsoft

GOLD SPONSORS

microforest

Softree
Engineering an Easier Way

OPTRON

TIMBETER

JUNIPER SYSTEMS

SILVER SPONSORS

Alternative Structures

About

Precision Forestry Symposium 2025

The 5th Precision Forestry Symposium will be held in Stellenbosch, South Africa, from 3–7 February 2025. This symposium serves as a global platform for researchers, industry professionals, and policymakers to discuss advancements in precision forestry, sustainable wood science, and digital innovations shaping the future of forestry operations.

Conference Themes

The symposium will cover a range of cutting-edge topics, including:

- **Optimization & Simulation** in forest operations
- **Machine Learning & AI** in precision forestry
- **Remote and Proximal Sensing** applications
- **Forest Machine Data Handling & Interpretation**
- **Robotics and Unmanned Platforms**
- **Geographic Information Technologies & Geomatics**
- **Forest Management, Planning & Scheduling Systems**
- **Precision Infrastructure Planning, Construction & Monitoring**
- **Energy Expenditure and Emissions** in wood supply
- **The Man-Machine Interface, Operator Performance & Wellbeing**

Keynote Speakers

The organising and scientific committees are pleased to announce the following invited speakers who will give keynote presentations dealing with the themes of the symposium:

Prof. Ola Lindroos (Sweden)

Ola Lindroos, born in **Sundsvall** in 1976, graduated as a forester from **SLU** in 2000 and later earned a **PhD on family forestry efficiency and safety** in 2007. He continued research and teaching at **SLU**, with a postdoc at **IIASA in Vienna** (2010–2011). Appointed **Associate Professor** in 2011, his work focuses on **forestry technology and forest machines**. He was **editor-in-chief** of the *International Journal of Forest Engineering* (2012–2015) and received **SLU's pedagogical prize** in 2014.

Miranda Wilson, a **geospatial professional** with a background in **Geography and Computer Science**, has worked in **Utilities, Mining, Sustainability, and Forestry.** Before joining **Mondi South Africa** in 2019, she received **ESRI Inc.'s Special Achievement in GIS Award** for developing a geospatial **decision support platform**. Her work has driven the adoption of geospatial technologies in Mondi's precision forestry agenda.

Ms Miranda Wilson (RSA)

Prof. Kanshukan Rajaratnam (RSA)

Professor Kanshukan Rajaratnam joined **Stellenbosch University** in 2020 as the inaugural director of the **School for Data Science and Computational Thinking.** Previously, he was an **associate professor of finance at UCT**, holding leadership roles. His research focuses on **data science in finance and banking** and is recognized by the NRF as an internationally acclaimed researcher. With industry experience at **Accenture, Nedbank, and Capital One**, he leads the School in advancing data science in Africa, gaining global recognition since its 2019 launch.

List of Abstracts – Talks

Wednesday, 5th February

AI and Robots – Drivers and Trends in Forest Operations

Ola Lindroos[1],
1 – Swedish University of Agricultural Sciences (SLU), Sweden

Keynote Speaker

Measuring Tree Diameter Using AI-Assisted Smartphone Application: A Case of Karacabey, Türkiye

Abdullah E. Akay[1],
1 – Bursa Technical University, Faculty of Forestry, Forest Engineering Department, Bursa, Türkiye

The first phase of harvesting in the forest stand consists of marking the trees that are decided to be cut according to the plan. This marking process is done with a special forestry stamp and is carried out within the principles specified in the Stamp Regulation (Anonymous, 2004). A marking team is required for stamping work. The stamp team consists of forest engineer, forest conservation officer, diameter-measurer, and tree forest workers performing bark removal with an axe, recording measurements and stamping trees.

Diameter (DBH) measurement is made with a caliper from the uphill side of the selected tree at a breast height (1.30 meters) and according to the slope of the tree. Breast height level can be determined by measuring with a tape, but this takes a significant amount of time. On the other hand, determining the 1.30-meter chest level of the diameter-measurer with a tape measure before starting the stamping work offers a practical measurement opportunity (Menemencioğlu et al., 2013). However, this measurement method may not provide accurate results as expected. In addition, difficult terrain conditions and dense vegetation make the diameter measurement phase difficult in stamp works.

The precision forestry approach using high technologies allows providing detailed information about a single tree, and by using such technologies, it is possible to increase data sensitivity in forestry measurements. In addition, precision forestry tools help to implement forestry activities more economically and meet the demands of society and the environmental requirements (Eker and Özer, 2015). Precision forestry methods using LiDAR (light detection and ranging) technology and structure-in-motion photogrammetry have been used to measure single tree stem diameter (Balenović et al., 2020; Gao and Kan, 2022). In recent years, precision forestry related studies have been conducted to evaluate the performance of LiDAR-equipped smartphones and tablets in real-time DBH measurements (Uçar et al., 2022; Gülci et al., 2023). In those studies, third-party software such SLAM app and ForestScanner app was used for DBH measurements.

SLAM (Simultaneous Localization and Mapping) app provides positioning information without GNSS signals in areas covered by vegetation such as forests. In SLAM app, tree heights can be estimated in real-time using the dense point cloud data provided by a smartphone with RGB-D SLAM (Fan et al., 2018). ForestScanner app provides real-time DBH measurement and the location of an individual tree based on 3D point clouds generated using LiDAR-equipped smartphones. ForestScanner can estimate the stem diameters and coordinates based on real-time instance segmentation and circle fitting. During the process, the users can visualize and control the scanning results (Tatsumi et al., 2022).

In this study, the DBH measurements were performed by using iPhone 12 ProMax smartphone with a free-of-charge app of iForester. iForester is an integrated AI-assisted smartphone app that automatically calculates DBH on individual tree given minimal user input such as tapping the photo image of tree base on the screen (PERSEUS, 2024) (Figure 1). iForester can provide accurate tree locations, DBH calculation, and diameter at any location tapped along the trunk calculation.

Field Measurements

In the field, the smartphone with iForester app was used to measure DBH for three tree species including Stone pine, Black pine and Mediterranean cypress in the stands located in Karacabey province of Bursa in Türkiye (Figure 2). In the application, 30 sample trees were measured for each species. The performance of the smartphone-based measurements was evaluated by comparing results with the traditional caliper measurements (Figure 3).

Statistical Analysis and Accuracy Analysis

Figure 1: DBH measurement using iForester app

The relationships between tree diameters determined by caliper and smartphone in sample areas were examined with statistical analysis. SPSS 20 and MsExcel programs were used for statistical analysis. In the analyses, R2 value was calculated to analyze the accuracy of linear relationships. To investigate the effects of tree diameter on the accuracy of the smartphone-based method, dimeter of the sample trees was divided into three classes including small (<30 cm), medium (30-40 cm), and large (>40 cm) classes. The ratio of the diameter difference to the diameter value measured with a caliper was used to compare diameter classes.

To examine the measurement error, root mean squared error (RMSE) were calculated for each species using following equation where N refers to the number of sample trees, yi refers to field measurements, and ŷi refers to the values determined by iforester data.

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2} \tag{0.1}$$

Results and Discussion

The results indicated that iForester app slightly overestimated tree DBH for three species compared to caliper measurements (Table 1). In the field study, it took about 135 minutes to measure DBH of total 90 trees using caliper, while it took only 21 minutes using a smartphone. It was determined that there was a linear relationship (R2) between the tree diameters determined with a caliper and with a LiDAR-equipped smartphone (Figure 1-3).

The effects of tree diameter class on the accuracy of the smartphone-based method was evaluated for all sample trees (90). It was found that there was a significant DBH differences between diameter classes.

Figure 2: Study area

Figure 3: DBH measurements using smartphone (left) and clipper (right)

Table 1: *Statistical summary of DBH measurements*

Tree Species	**DBH Measurement**	**Average DBH (cm)**	**Difference (cm)**
Stone pine	iForester app	40.00	1.16
	Caliper Method	38.84	
Black pine	iForester app	39.21	1.11
	Caliper Method	38.10	
Mediterranean cypress	iForester app	28.04	0.91
	Caliper Method	27.01	
Total	iForester app	35.58	1.06
	Caliper Method	34.52	

The ratio of DBH error increased from small diameter class to large diameter class (Table 2-3).

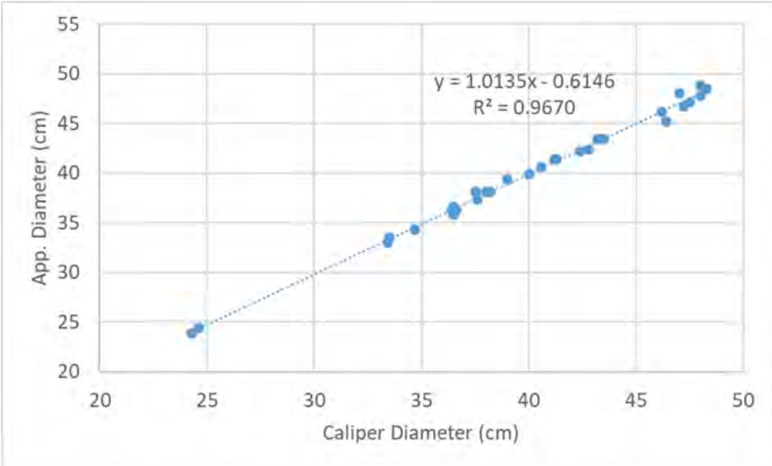


Figure 4: Linear relationship between DBH measured by caliper and smartphone for Stone pine

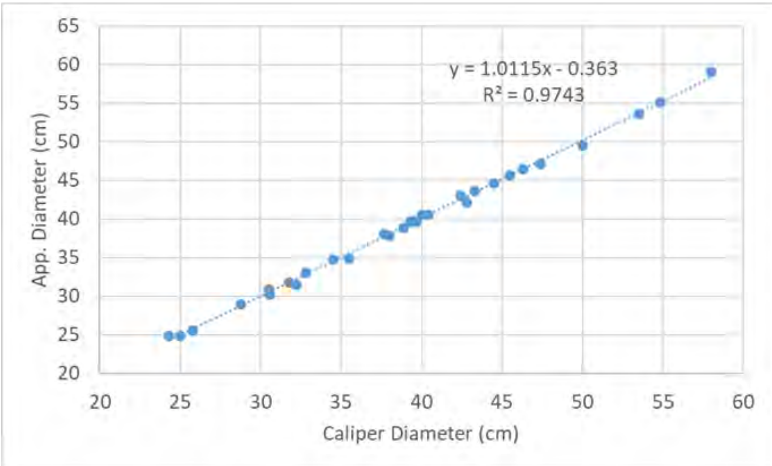


Figure 5: Linear relationship between DBH measured by caliper and smartphone for Black pine

Table 2: *ANOVA analysis result*

Source of Variation	**df**	**Sum of Squares**	**Mean Square**	**F**	**Sig.**
Between Groups	2	11.034	5.517	7.753	0.001
Within Groups	87	61.908	0.712	-	-
Total	89	72.942	-	-	-

The RMSE values were 1.54, 1.42, and 1.11 for Stone pine, Black pine and Mediterranean cypress, respectively. When tree species were compared, it was seen that the error was lower in cypress trees. The main reason for this is that the trunk structure of cypress trees has a more cylindrical and smooth form compared to the pine trees.

Conclusions

In this study, the success of a LiDAR-equipped smartphone in measuring tree diameters was tested. Measurements made with LiDAR-equipped smartphone showed a high level of linear relationship with

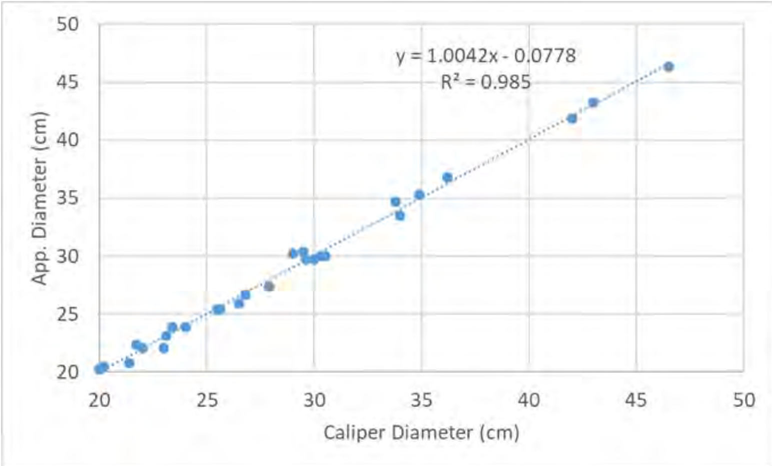


Figure 6: Linear relationship between DBH measured by caliper and smartphone for M. cypress

Table 3: *DBH differences of the diameter classes*

Diameter Classes	N	Mean	Std. Deviation
Small	32	0.7493	0.65357
Medium	32	0.9916	0.64745
Large	26	1.6094	1.19451
Total	90	1.0840	0.90530

measurements made with the traditional caliper method. It was found that the ratio of DBH error increased from small diameter class to large diameter class. The results suggested that smartphone-based method can reduce labor intensity and save time required for tree marking activities in the field. The accuracy of DBH estimated by using a LiDAR-equipped smartphone was reliable. Thus, the LiDAR-equipped smartphone method would be an effective alternative in diameter measurement during tree marking activities. LiDAR technology and iForest application available on smartphones have a user-friendly interface and can be easily used in the field. This application would contribute to the widespread use of technology integration in forestry activities.

References

Anonimous (2004). Damga Yönetmeliği. Orman ve Su İşleri Bakanlığı, 10.04.2004 tarih ve 25429 sayılı Resmi Gazete, Ankara.

Fan, Y., Feng, Z., Mannan, A., Khan, T.U., Shen, C., Saeed, S. (2018). Estimating Tree Position, Diameter at Breast Height, and Tree Height in Real-Time Using a Mobile Phone with RGB-D SLAM. Remote Sens., 10(11), 1845.

Gülci, S., Yurtseven, H., Akay, A.O., & Akgul, M. (2023). Measuring tree diameter using a LiDAR-equipped smartphone: a comparison of smartphone and caliper-based DBH, Environ Monit Assess, 2023, 195:678.

Menemencioğlu, K., Kılıç, A., Buğday, E. (2013). Ormancilikta dikili ağaç damga işlerinde zaman etüdü. Balıkesir Üniversitesi Endüstri Mühendisliği Bölümü & Türk Ergonomi Derneği, 399-407.

PERSEUS (2024). Promoting Economic Resilience and Sustainability Of The Eastern U.S. Forests. Year 1 Annual Report & Year 2 Work Plan. 13 p.

Tatsumi, S., Yamaguchi, K., & Furuya, N. (2022). ForestScanner: A mobile application for measuring and mapping trees with LiDAR-equipped iPhone and iPad, Methods in Ecology and Evolution, 14(7), 1603-1609.

Ucar, Z., Değermenci, A.S., Zengin, H., & Bettinger, P. (2022). Evaluating the accuracy of remote dendrometers in tree diameter measurements at breast height. Croatian Journal of Forest Engineering, 43(1), 185–197.

Development of a Forest Technology Testbed for Remote Controlled and Autonomous Operations – Results and Examples from Ongoing Studies in Sweden

Gert Andersson[1], Tobias Semberg[1], Anders Nilsson[1], Petrus Jönsson[1], Linnéa Hansson[1], Morgan Rossander[1], Martin Englund[1],
1 – Skogforsk, The Forestry Research Institute of Sweden, Uppsala, Sweden

Skogforsk, the Forestry Research institute of Sweden, has during the last six years developed a Forest technology testbed for development of remote controlled- and autonoumus operations. The presentation will summarize and describe the quite rapid development taking place at the testbed and also discuss needs and demands for further development. Background Productivity in Swedish forest operations has declined, Automation/partly automated operations in combination with digital transformation/AI are considered to be the path ahead. The relation: 1 operator to 1 machine has to be changed in favour to: 1 operator: >1 machine. Silviculture operations, scarification, planting and pre-commercial cleaning are labour demanding (often with workforce from abroad), attempts to fully mechanize and automate the silviculture operations are also high on the strategic agenda.

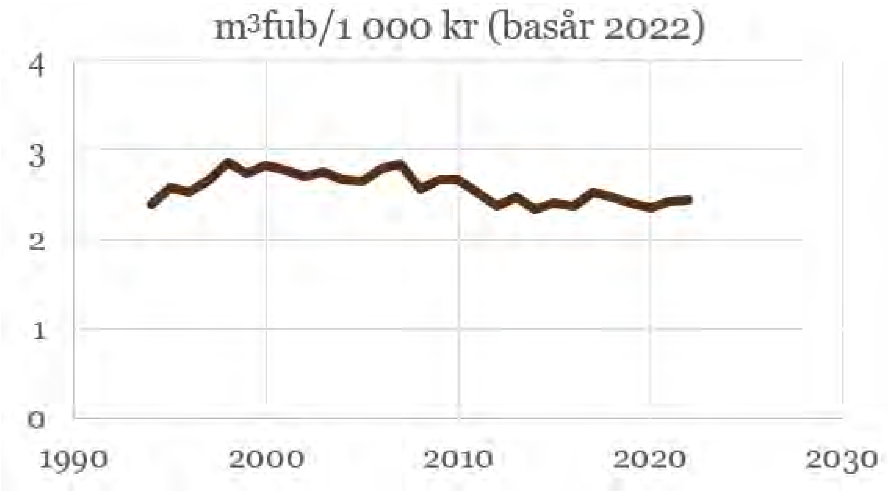


Figure 1: Productivity expressed as m3 sub per 1000 kr cost of operations from stump to mill (100 Euro or US dollars)

Results

During the last six years a number of projects, studies, tests and cooperations with universities cooperations have taken place at the testbed or in connection to the testbed, i.e:

- Remote controlled and autonomous driving with a 14-ton forwarder, the Auto project
- Development of autonomous loading of a forwarder with novelle technique
- Tests with different communication modes, i.e., WiFi, private- and commercial 5G
- Project Autoplant, development of a prototype for autonomous scarification and planting
- Remote controlled scarification, development and demo of remote controlled scarification with a 4-row Bracke mounder based on a large forwarder chassis
- Project with a robot for precommercial cleaning (just starting)

An overview of the results and findings from the different projects will be given richly illustrated with pictures and videos.

Figure 2: Left, tests with remote controlled operated mounder, Bracke 4-row mounder on a large Komatsu forwarder. Right, tests with remote controlled forwarding operation, communication via commercial 5G and a drone for amplifying the 5G signal at the rural logging site. Distance between operator and forwarder approx. 150 km.

Discussion

Forestry is in a fast transition where digital transformation and automation are in focus. Findings from studies in Skogforsks technical testbed are crucial for navigating in this new terrain. Cooperation and implementation of technique from other business sectors and cooperation within the forest sector, with universities and cooperations are essential.

References

Rossander, M, Semberg, T., Englund, M., Eliasson, L., (2024). Teleoperated forwarder with VR:impact of latency on operator log handling performance. Article, International Journal of Forest Engineering

Wiberg, V., Wallin, E., Fälldin, A. Semberg, T., Rossander, M., Wadbro, E., Servin, M., (2024). Sim-to-real transfer of active suspension control using deep reinforcement learning. Article, Robotics and Autonomous Systems.

Comparative Analysis of Remote Sensing and Ground-Based Surveys in Determining Merchantable Volume of a Boreal Forest Stand

Dan Guindon[1], Dzhamal Y. Amishev[2],
1 – Interfor, Ontario, Canada
2 – Lakehead University, Department of Natural Resources Management, Ontario, Canada
***Corresponding Author:** Dzhamal.amishev@lakeheadu.ca

Accurate volume estimations are pivotal for effective forest resource management, influencing stakeholders throughout the forestry industry. Traditionally, estimations relied on stem diameter measurements and geometric assumptions. However, advancements in remote sensing have revolutionized volume calculations, offering new possibilities for precision and efficiency.

This project delves into volume estimations within the Romeo Mallette Forest of Northeastern Ontario's Boreal Forest, employing a multifaceted approach that includes ground surveys, Ontario Forest Resource Inventory (FRI) data, and drone-based remote sensing. The objectives encompass evaluating the accuracy of FRI data, assessing ground surveys' precision, investigating drone-based remote sensing techniques, leveraging FPInnovations' Single Tree Metrics and Stand Assessment (STEMS) algorithm, and scrutinizing the variance between estimations and final mill volumes.

The study evaluates the efficacy of the STEMS algorithm against ground surveys and FRI merchantable volume estimates, utilizing the final Bill of Lading (BOL) as the control measurement. Remarkably, the initial Remotely Piloted Aircraft System (RPAS) flight path, harnessing STEMS technology, emerged as the most precise in estimating merchantable volume, yielding 129 m3/ha compared to the final BOL measurement of 122 m3/ha. In contrast, ground surveys anticipated 134 m3/ha, while the FRI data was the only underestimation at 106 m3/ha. This singular study underscores the potential of STEMS in accurately estimating merchantable volumes in forestry, signaling a significant advancement in volume estimation methodologies.

Precision Forestry in a Messy Forest

Mark J. Ducey[1],
1 – Department of Natural Resources and the Environment, University of New Hampshire, United States

The forests of the northeastern United States present a challenging case for the implementation of precision forestry. Land ownership is predominantly private, and harvesting regulations are sparse. Plantation forests are quite rare, so managed forests are species-diverse. Both natural stand dynamics and management interventions tend to promote stand structures that are horizontally and vertically complex. Many forests across the region have seen management of dubious silvicultural intent, leading to a reduction in volume – and especially value – of growing stock. However, the potential for future financial value is substantial, and both public and private landowners place a premium on the non-market benefits these forests can provide.

In this context, the use case for precision forestry techniques is different from what it might be in other locations. Prediction of regeneration and of future growth and yield in these complex forests is an ideal application for artificial intelligence and machine learning. There is a particular need to improve inventory and mapping of the resource: a serious case can be made that unreliable inventory depresses prices for forest land, and disincentivizes silvicultural investment. To be credible, inventory must be transparent and accountable. The complexity of forest composition and structure in this region tends to defeat large-area mapping that relies on moderate-resolution optical data.

Area-based LiDAR is an improvement but not a complete solution. UAS and mobile LiDAR offer the possibility of rapid advances, but there are technical challenges with tree detection in vertically-complex, deep canopy structures that require further work. At the end of the day, there is a question of cost: are better information and better management worth the investment? We hope the answer will be yes.

Assessing GNSS-Based ICT Systems for Sustainable Small-Scale Forestry Operations

Rodolfo Picchio[1], Rachele Venanzi[1], Aurora Bonaudo[1], Lorenzo Travisani[1], Francesco Latterini[2],
1 – Department of Agriculture and Forest Sciences (DAFNE), University of Tuscia, Viterbo, Italy.
2 – Institute of Dendrology, Polish Academy of Sciences, Kórnik, Poland.

Precision forest harvesting leverages advanced technologies to enhance the sustainability of forestry operations (Ziesak 2006). Despite its potential to significantly improve management practices, precision forest harvesting often relies on modern, high-cost machinery that is generally unaffordable for small-scale forestry businesses, particularly those prevalent in the Mediterranean region (Venanzi et al. 2023). Consequently, the adoption of precision forestry methods among these operators remains limited (Corona et al. 2017).

In this study, we aimed to assess the accuracy of a GNSS receiver integral to an innovative Information and Communication Technology (ICT) system, developed specifically for monitoring small-scale forest operations. We tested this GNSS receiver's precision by comparing extraction routes recorded during coppicing operations in two forest sites in Central Italy against routes documented by a more advanced GNSS receiver. To further understand factors influencing positioning accuracy, we employed linear mixed-effects models (LMMs) to examine the role of topographic variables, including slope, elevation, aspect, and the Topographic Position Index (TPI), in GNSS error.

Our findings revealed an average positioning error of approximately 2 meters, with a maximum recorded error of about 5 meters. The LMMs indicated that topographic features did not significantly impact the GNSS positioning error, while GNSS accuracy varied substantially based on the specific forest site, used as a random effect in our model (marginal R^2 0.13; conditional R^2 0.59). Due to the minimal canopy cover following coppicing, the tested GNSS receiver demonstrated reliable performance, suggesting its suitability for visually guiding operators along a pre-planned extraction route displayed on the receiver's screen (Picchio et al. 2020).

Although promising, these findings are preliminary. Further testing across additional sites and varying operational conditions is needed to validate the GNSS receiver's efficacy fully.

References

Corona, P., Chianucci, F., Quatrini, V., Civitarese, V., Clementel, F., Costa, C., Floris, A., Menesatti, P., Puletti, N., Sperandio, G., Verani, S., Turco, R., Bernardini, V., Plutino, M., Scrinzi, G. (2017). Precision forestry: concepts, tools and perspectives in Italy. Forest@ - Rivista di Selvicoltura ed Ecologia Forestale, 14, 1–12.

Picchio, R., Latterini, F., Mederski, P.S., Tocci, D., Venanzi, R., Stefanoni, W., Pari, L. (2020). Applications of GIS-Based Software to Improve the Sustainability of a Forwarding Operation in Central Italy. Sustainabilit, 12, 5716.

Venanzi, R., Latterini, F., Civitarese, V., Picchio, R. (2023). Recent Applications of Smart Technologies for Monitoring the Sustainability of Forest Operations. Forests, 14, 1503.

Ziesak, M. (2006). Precision Forestry-An overview on the current status of Precision Forestry. A literature review. In: Precision Forestry in plantations, semi-natural and natural forests". IUFRO Precision Forestry Conference Technical University, Munich, Germany. pp 5–10

Assessment of the Implementation of a GIS-Planned Strip Road Network in Pine Forest Thinning in Central Italy

Rachele Venanzi[1], Rodolfo Picchio[1], Aurora Bonaudo[1], Francesco Latterini[2],
1 – Department of Agriculture and Forest Sciences (DAFNE), University of Tuscia, Viterbo, Italy
2 – Institute of Dendrology, Polish Academy of Sciences, Kórnik, Poland

In this study, we explore the potential of precision forestry to minimize soil disturbance, specifically focusing on the surface area affected by forestry machinery during thinning operations. The trial was conducted in a black pine (Pinus nigra) forest located on Mount Amiata, Central Italy, where we developed a detailed, GIS-based strip road network to guide thinning activities with the goal of reducing soil compaction and surface disruption. Using accessible open-source software and GIS plugins, we designed a spatially optimized network that could provide machinery operators with clearly defined paths, potentially limiting unnecessary ground impact (Picchio et al. 2020).

Following the completion of thinning operations, we assessed the accuracy of the implemented strip road network by comparing it to the original GIS-planned design. To capture the actual network, we used a high-precision Global Navigation Satellite System (GNSS) receiver to record the established strip roads, ensuring submeter-level accuracy in the field (Picchio et al. 2024). In addition, a drone survey equipped with an RGB sensor was carried out to provide a comprehensive aerial perspective, enabling us to capture detailed imagery of the impacted areas.

The collected GNSS data and drone imagery were then used to reconstruct the actual strip road layout, which we compared to the initial plan. This comparison allowed us to evaluate the precision of the GIS-guided network against the field implementation, identifying discrepancies and areas of additional soil disturbance that might have occurred due to deviations from the planned routes. This analysis provides insights into the effectiveness of GIS-based precision forestry planning in controlling soil impacts during forest management activities (Picchio et al. 2019).

Our findings, which are currently being analyzed, will be presented in detail at the conference. They will include the degree of alignment between planned and actual strip road networks, factors influencing any observed deviations, and an assessment of the soil disturbance relative to the initial forecasts. By quantifying the precision of the implemented strip roads, we aim to draw conclusions on the feasibility and benefits of using GIS-planned networks as a precision forestry tool to minimize soil disruption in managed forest ecosystems. This research contributes to the growing field of precision forestry, emphasizing the value of integrating high-resolution spatial planning with modern GNSS and drone technologies to improve the sustainability of forestry operations.

References

Picchio, R., Latterini, F., Mederski, P.S., Tocci, D., Venanzi, R., Stefanoni, W., Pari, L. (2020). Applications of GIS-Based Software to Improve the Sustainability of a Forwarding Operation in Central Italy. Sustainability, 12, 5716. Picchio, R., Proto, A.R., Civitarese, V., Di Marzio, N., Latterini, F. (2019). Recent Contributions of Some Fields of the Electronics in Development of Forest Operations Technologies. Electronics, 8, 1465.

Picchio, R., Venanzi, R., Bonaudo, A., Travisani, L., Civitarese, V., Latterini, F. (2024). Evaluating an Innovative ICT System for Monitoring Small-Scale Forest Operations: Preliminary Tests in Mediterranean Oak Coppices. Sustainability, 16, 4629.

Actual Tree Size Distribution vs an Assumption of Normal Tree Distributions Towards Precise CTL Harvesting Productivity Modeling of Two Different Size Harvesting Machines

Simon Ackerman[1,2], James Bekker[1], Rasmus Astrup[3], Bruce Talbot[2],
1 – Mondi South Africa, Hilton, South Africa
2 – Department of Forest and Wood Science, Stellenbosch University, Stellenbosch, South Africa
3 – Norwegian Institute for Bioeconomy Research, Høgskoleveien, Ås, Norway

Tree size is one of the predominant factors determining harvester productivity and is heavily influenced by plantation management activities. Stand, silvicultural management can affect tree size, distribution of tree size, and tree height amongst others. Understanding the effect of tree size distribution on harvesting productivity is central for optimizing management of operations.

Traditionally most harvesting machine productivities are predicted from a stand enumerated, sample based, mean tree volume. These tree volumes generally assume a normal distribution of tree sizes around the mean tree. Often, this is not the case, trees in stands often develop in skewed distributions of tree sizes, even in managed industrial plantations. These distributions can be characterised as Weibull distributions where the extent to which trees in the smaller sizes or larger sizes spread across the diameter distribution, affect the mean tree volume. The harvesting machine also handles and processes trees differently, according to the capacity of the machine, where larger machines are more versatile than smaller machines. Smaller machines may be limited in the ability to handle larger trees.

To investigate the effects of tree size distribution on harvester productivity, productivity functions for a medium and larger-sized harvester were applied to harvester derived tree size distributions from 35 clearfelled industrial plantation pine stands. These were generally not normally distributed. Subsequently, these functions were applied to a normal distribution of trees covering the same tree size ranges. Productivity differences were analysed on a stand-by-stand basis.

Results showed that for the larger harvester, productivity rates remained constant (67.1 vs 67.6 m3·PMH-1) indicating relatively little sensitivity to variations in tree size distributions. Although the standard deviation (SD) halved from 11.6 to 5.6 in the case of the uniform tree distribution. The smaller harvester productivity decreased by 15% from 47.3 to 40.1 m3·PMH-1 and the coefficient of variation (CV) by 6% in the same transition to a uniform distribution.

Further investigation was done on more skewed tree size distributions. A family of nine Weibull distributions was generated, representing combinations of three mean DBH classes (25cm, 30 cm, and 35cm) and three levels of CV (15%, 20%, 25%), for each DBH class. Results clearly indicate that different distribution shapes have different effects on different machine sizes, and that a low CV correlates to a higher productivity in larger tree sizes. A more uniform tree size distribution also provides more predictable results (lower CV). These results which would promote machine scheduling and result in fewer discrepancies on production rates and focussing the correct capacity machine on the target tree size. The results also show the effects of mean tree size productivity predictions vs tree size distribution effects.

Interesting results:

In the case of the Beaver (Figure 1), the weighted mean productivity curves peak at roughly the same point for the smaller DBH group. As the trees mean DBH increases greater than 25 cm there is greater variation in the weighted mean productivity peak. The comparison of weighted mean productivity indicate the smaller sized Beaver is much more sensitive to larger tree sizes.

In the case of the larger Bear machine (Figure 2), there is almost no variation in the maximum weighted mean productivity for all the DBH and CV groups, although there is a little in the larger DBH group for this machine. There is an interesting trend for each of these curves, there are differences between the

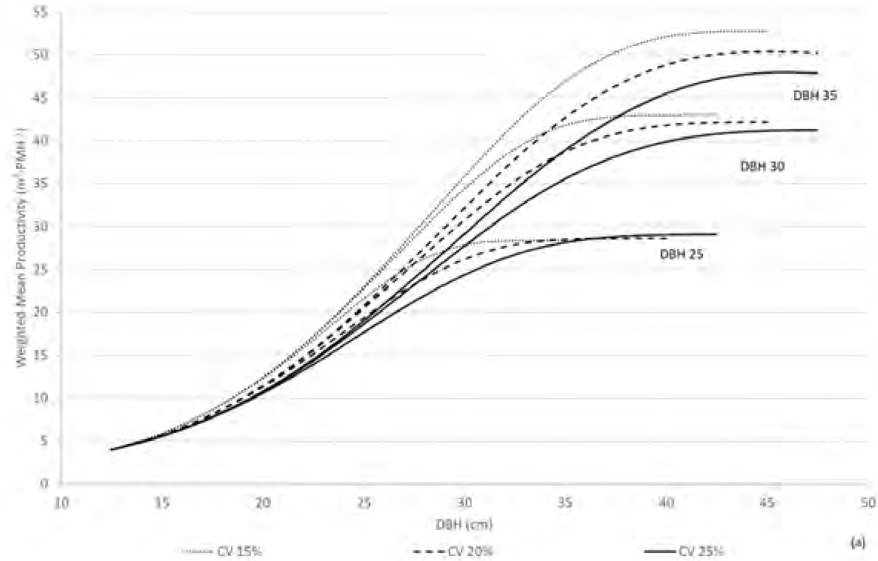


Figure 1: Weighted mean productivity curves for the smaller capacity Beaver, for each of the mean DBH's and CV of the mean DBH

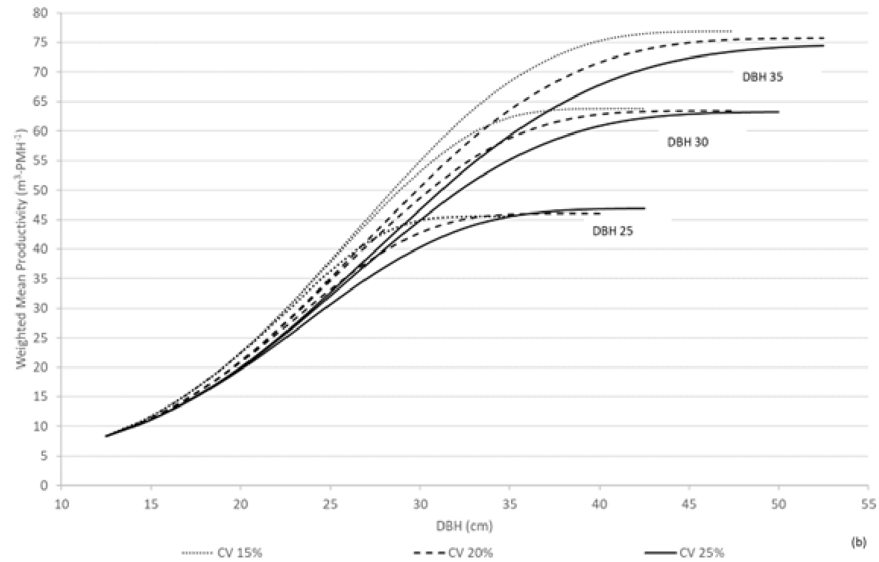


Figure 2: Weighted mean productivity curves for the larger capacity Bear, for each of the mean DBH's and CV % of the mean DBH.

machine productivity at the mean DBH vs the weighted mean productivity across the full tree diameter distribution. For example, the curves show a machine productivity for a mean DBH of 35 cm (the largest DBH grouping) of 68.4 m3·PMH-1, 63.63 m3·PMH-1, and 59.23 m3·PMH-1 for the 15%, 20% and 25% CV respectively for the Bear. This indicates a discrepancy when modelling machine productivity on the mean tree vs across the distribution of trees. The same trend is true for the Beaver.

This abstract is based on the following publication:

Ackerman, S., Bekker, J., Astrup, R. and Talbot, B., 2024. Understanding the influence of tree size distribution on the CTL harvesting productivity of two different size harvesting machines. European Journal of Forest Research, pp.1-13.

Using Unmanned Aerial Vehicle (UAV) Multispectral and Non-Imaging Hyperspectral Remote Sensing to Develop Detection Techniques for Eucalyptus Leaf Diseases

Maphutseng Mohobo[1], Michelle L. Schröder[2], Almuth Hammerbacher[2], Abel Ramoelo[5], Wouter H. Maes[3], Bernard Slippers[4],

1 – Department of Geography, Geoinformatics and Meteorology, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, South Africa

2 – Department of Zoology and Entomology, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, South Africa

3 – UAV Research Centre (URC), Department of Plants and Crops, Ghent University, Belgium

4 – Department of Biochemistry, Genetics and Microbiology, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, South Africa

5 – Department of Geography, Geoinformatics and Meteorology, Centre for Environmental Studies, University of Pretoria, South Africa

Foliar pathogens like Teratosphaeria destructans which cause Teratosphaeria leaf blight (TLB) of Eucalyptus are a considerable threat to the forestry industry. Damage caused by TLB leads to a reduction in yield, heavily defoliation and in severe cases, dead shoots. The presence of TLB is seen through the discolouration of leaves, large circular brown leaf spots with diffuse borders and blight on young leaves and shoots. Early detection of T. destructans is important to prevent outbreaks and facilitating targeted management strategies to minimize the risk of large-scale outbreaks. Traditional health monitoring for plant diseases is physically demanding, time consuming, subjective, has limited coverage and does not allow for continuous measurements as information is captured at discrete time intervals. The aim of this study was to assess the potential of multispectral imagery obtained with Unmanned Aerial Vehicles(UAVs) and non-imaging hyperspectral data to detect damage caused by T. destructans. For this study, 12 data sets of multispectral UAV imagery and hyperspectral non-imaging data were collected from four hybrid genotypes of Eucalyptus grandis X urophylla. The data was collected from a potted trial, which included two treatments (inoculated and control) in a randomized block design. Reference damage levels were obtained through visual assessment and chlorophyll readings on a sample of trees (n = 100). Additionally, three data sets of multispectral UAV imagery and hyperspectral non-imaging were collected in compartments of E. grandis X urophylla with varying levels of TLB infection. Reference damage levels were acquired through visual assessment and chlorophyll readings on a sample of trees (n = 144) at each site. Across both experiments, an increase in canopy reflectance in the visible and a decrease in the near-infrared region was consistently observed with increasing infestation levels. The Normalized Vegetation Index, Enhanced Vegetation Index, Leaf Chlorophyll Index and Red-Edge Position index were consistent with damage levels. Random Forest(RF) and XGBoost were used to model infestation/damage levels. As input, three different scenarios were tested using spectral reflectance bands and chlorophyll, vegetation indices and a combination of spectral reflectance bands, vegetation indices and chlorophyll. The different scenarios were assessed with the conventional train/test split based on all the variables with an accuracy of 68% for RF and 60% for XGBoost. Chlorophyll was identified as an essential variable in classifying infestation levels. This study demonstrates the potential of assessing infestation levels of TLB with UAV-based multispectral imagery and hyperspectral non-imaging data.

References

Abbas, A. et al., 2023. Drones in Plant Disease Assessment, Efficient Monitoring, and Detection: A Way Forward to Smart Agriculture. Agronomy, 13(1524).

Andjic, V. et al., 2019. 23 years of research on Teratosphaeria leaf blight of Eucalyptus. Forest Ecology and Management, Volume 443, pp. 19-27.

Bao, W. et al., 2023. UAV remote sensing detection of tea leaf blight based on DDMA-YOLO. Computer and Electronics in Agriculture, Volume 205.

Naidoo, S. et al., 2014. Uncovering the defence responses of Eucalyptus to pests and pathogens in the genomics age. Tree Physiology, Volume 34, pp. 931-943.

Solis, M., Wingfield, M. J., Hammerbacher, A. & Naidoo, S., 2022. Comparison of the Infection Biology of Teratosphaeria destructans and Teratosphaeria epicoccoides on Eucalyptus. Plant Disease, Volume 106, pp. 1944-1951.

Wingfield, M. J., Hurley, B., Wingfield, B. & Slippers, B., 2020. Tree health in South Africa: Retrospect and prospect. South African Journal of Science, Volume 116.

Zhang, D. et al., 2018. Detection of rice sheath blight using an unmanned aerial system with high-resolution color and multispectral imaging. PLOS One.

Zhang, Y. & Wang, X., 2021. Geographical spatial distribution and productivity dynamic change of eucalyptus plantations in China. Scientific Reports, 11(19745).

Ackerman, S., Bekker, J., Astrup, R. and Talbot, B., 2024. Understanding the influence of tree size distribution on the CTL harvesting productivity of two different size harvesting machines. European Journal of Forest Research, pp.1-13.

The Potential of a Low-Cost Wireless Dendrometer and Environmental Sensing System: What Information Can Be Inferred?

Christopher Erasmus[3], David Drew[2], Thinus Booysen[1,3],
1 – Department of Electrical and Electronic Engineering, Stellenbosch University, South Africa
2 – Department of Forestry and Wood Science, Stellenbosch University, South Africa
3 – Department of Industrial Engineering, Stellenbosch University, South Africa

Dendrometry refers to the field in forestry that focuses on the measurement of tree growth dynamics. A dendrometer is a device that measures long term and short-term variations in tree stems (Drew and Downes, 2009). Traditional dendrometers are analogue devices, requiring expensive data loggers to allow for a high resolution (Gleason et al., 2024). The prices of commercial dendrometers and data loggers are a significant constraint for researchers (Anemaet and Middleton, 2013; Cranston et al., 2020; Gleason et al., 2024). In this study, ten wireless dendrometer and environmental sensing systems were developed to bridge the gap of expensive measurement instruments, to allow accessible solutions to foresters and researchers alike. A novel digitised dendrometer was developed, with an externalised analogue to digital converter (ADC) which can be used with any microcontroller that has I2C communication. Using LoRaWAN, a low-power communication protocol (Davcev et al., 2018), the ten systems collected 102,916 datapoints, at a frequency of 6 min (Erasmus et al., 2024). Alongside dendrometer measurements, temperature, humidity and soil moisture were measured. Using temperature and humidity data, the Vapour Pressure Deficit (VPD) was determined for each instance in the dataset to validate the dendrometers on data trend accuracy. VPD is a driving factor of plant transpiration, and therefore fluctuations in radial stem size can almost directly be attributed to VPD fluctuations (Sanginés de Cárcer et al., 2018; Tumajer et al., 2022). The ten dendrometers deployed in a field test showed moderate to strong correlations between maximum daily stem shrinkage and maximum daily VPD, indicating that the dendrometers detect diurnal tree dynamics.

Mean RMSE (µm)	**Mean R^2**	**Resolution (µm)**	**Mean temperature drift coefficient (µm/°C)**
23.58	0.9999	0.0763	-1.34

Table 4: *Digitised dendrometer characteristics, over the full-scale range (FSR) after calibration. Values are gathered empirically from three experiments across four digitised dendrometers. Mean RMSE gives the mean RMSE between the measured dendrometer values and the ideal values across the four dendrometers. The calibration curves of the calibration of the dendrometers showed a mean R^2 value of 0.9999. The dendrometers have a fixed resolution of 0.0763 µm due to an externalised ADC. The Dendrometers showed temperature drift, which can be corrected using temperature measurements.*

The objective of this study is to develop a sustainable, scalable, low-cost, digitised dendrometer and environmental sensing system (Fig. 1) with reliable wireless data acquisition, validated both analytically and experimentally (Table 1). This system offers researchers valuable insights into diurnal stem fluctuations and long-term growth trends, with potential applications for early drought detection and irrigation scheduling.

References

Anemaet, E., Middleton, B., 2013. Dendrometer Bands Made Easy: Using Modified Cable Ties to Measure Incremental Growth of Trees. Applications in plant sciences 1.

Cranston, B.M., Powers, B.F., Macinnis-Ng, C., 2020. Inexpensive throughfall exclusion experiment for single large trees. Applications in Plant Sciences 8, e11325.

Davcev, D., Mitreski, K., Trajkovic, S., Nikolovski, V., Koteli, N., 2018. IoT agriculture system based on LoRaWAN, in: 2018 14th IEEE International Workshop on Factory Communication Systems (WFCS). Presented at the 2018 14 th IEEE International Workshop on Factory Communication Systems (WFCS), IEEE, Imperia, pp. 1–4.

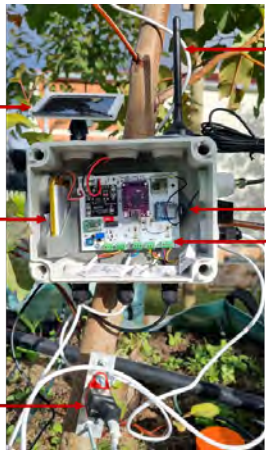


Figure 1: Internal electronics of the generic data logger. The entire system runs on a 5000 mAh battery and a 0.5 W solar panel. Sensors connect to the device via screw terminals. An ESP32 S2-Mini microcontroller is used to integrate components. The generic data logger facilitates various sensor communication technologies (SDI-12, I2C, 1-Wire, UART, ADC). Data is transmitted wirelessly via LoRaWAN to a gateway where it is relayed to a ThingSpeak ("IoT Analytics - ThingSpeak Internet of Things," n.d.) via The Things Network (Network, n.d.) where data is visualised and stored in the cloud. Local SD storage is added for data redundancy.

Drew, D.M., Downes, G.M., 2009. The use of precision dendrometers in research on daily stem size and wood property variation: A review. Dendrochronologia 27, 159–172.

Erasmus, C.S., Booysen, M.J., Drew, D., 2024. Dataset of dendrometer and environmental parameter measurements of two different species of the group of genera known as eucalypts in South Africa and Portugal. Data in Brief 57, 111035.

Gleason, S.M., Stewart, J.J., Allen, B., Polutchko, S.K., McMahon, J., Spitzer, D., Barnard, D.M., 2024. Development and application of an inexpensive open-source dendrometer for detecting xylem water potential and radial stem growth at high spatial and temporal resolution. AoB PLANTS 16, plae009.

IoT Analytics - ThingSpeak Internet of Things [WWW Document], n.d. URL https://thingspeak.mathworks.com/ (accessed 11.5.24).

Network, T.T., n.d. The Things Network [WWW Document]. The Things Network. URL https://www.thethingsnetwork.org/ (accessed 11.5.24).

Sanginés de Cárcer, P., Vitasse, Y., Peñuelas, J., Jassey, V.E.J., Buttler, A., Signarbieux, C., 2018. Vapor–pressure deficit and extreme climatic variables limit tree growth. Global Change Biology 24, 1108–1122.

Tumajer, J., Scharnweber, T., Smiljanic, M., Wilmking, M., 2022. Limitation by vapour pressure deficit shapes different intra-annual growth patterns of diffuse- and ring-porous temperate broadleaves. New Phytologist 233, 2429–2441.

Continuous Improvement through the Integration of Optimization, BI and AI within an Intelligent Forestry Planning Platform

Pablo Asiron[1],
1 – Remsoft Inc., Moncton, New Brunswick, Canada

The forest industry is increasingly embracing advancements in data acquisition, optimization, artificial intelligence (AI) and digital technologies to drive continuous improvement across the entire supply chain. The integration of prescriptive mathematical optimization techniques, such as Linear Programming (LP) and Mixed Integer Programming (MIP), with cloud-based operational planning technology has enabled a cyclical model of Modeling, Implementing and Refining within a connected platform that considers planned values, actuals from the field, and forecasted values.

During the Modeling phase, optimization methods generate strategic, tactical, and operational plans that account for the complexities of forest management, including capital investment and sustainability constraints. These models are continuously refined with real-time data from forest operations, captured through cloud-connected platforms that track actuals from the field. The Implementing phase focuses on the execution of these optimized plans in the field, creating a digital twin of both the planning and operational activities, ensuring precision in decision-making.

The next step in this continuous cycle, the Refining phase, leverages AI to analyze historical and real-time data, providing actionable insights that enhance future planning models. This continuous learning loop enables forest managers to increase efficiency, optimize wood supply chains, and reduce energy expenditure while ensuring sustainability. By harnessing the power of optimization, AI, and operational planning platforms, forest managers can achieve better economic and environmental outcomes. This approach offers a pathway toward smarter, more sustainable forestry operations, significantly contributing to the evolution of precision forestry.

A Data Integration Framework for Annotated Forestry Datasets: Combining RGB Imagery and Harvester Data

Christian Höök[1], Omar Mendoza Trejo[1], Carola Häggström[1], Ola Lindroos[1],
1 – Department of Forest Biomaterials and Technology, Swedish University of Agricultural Sciences, Sweden

The integration of diverse data streams is essential for advancing automation and machine learning applications in forestry. This paper proposes a general semi-automated methodology for synchronizing and integrating heterogeneous data sources, with a focus on combining visual data and machine-generated records. The methodology is designed to generate annotated datasets efficiently by aligning timestamps and integrating metadata across different data modalities. While broadly applicable, the approach is demonstrated in this paper through a case study that synchronizes RGB video footage with operational data from a forestry harvester using the StanForD data standard. This case study highlights the method's capacity for rapid annotation of image datasets, significantly reducing manual labor and ensuring high-quality labeled data for machine learning models.

In the case study, continuous video footage was collected from a harvester during a clear-cut operation in Jämtland, Sweden, and synchronized with StanForD data to extract 840 relevant image frames. 71% of these frames represented relevant data for manual annotation with bounding boxes for trees and logs. The process reduced the overall data volume by 88%, demonstrating the scalability of the method. While this study focuses on forestry operations and manual annotation, the proposed methodology can be extended to other domains and to include fully automated annotation workflows. The framework offers a scalable solution to the challenge of data scarcity, providing a foundation for further automation and decision support systems in precision forestry.

Advancing Crown Architecture Characterization in Eucalyptus Using Terrestrial Laser Scanning

Oluwaseun F. Gakenou[1], Anton Kunneke[1], Alexander A. Myburg[2], David M. Drew[1],
1 – Department of Forest and Wood Science, Stellenbosch University, Stellenbosch, South Africa.
2 – Department of Genetics, Stellenbosch University, Stellenbosch, South Africa.

The integration of Terrestrial Laser Scanning (TLS) into forestry practices offers groundbreaking potential for high-precision characterization of tree crown architecture, advancing sustainable forest management. Traditional methods for assessing crown architecture often lack the resolution and efficiency to capture detailed morphological data. TLS, in contrast, provide non-destructive, high-resolution, and repeatable measurements that enable robust quantification of crown attributes, including crown height, width, volume, and branching structure (Raumonen et al., 2013).

This research utilizes TLS technology to explore the crown architecture of young Eucalyptus grandis trees, leveraging detailed point cloud data to understand structural variations in response to environmental and genetic factors. Conducted in a common garden trial in South Africa, our study examines seed stocks collected from 33 provenances representing the species' natural range, enabling comparisons of crown architecture across a broad genetic spectrum. This presentation will discuss TLS point cloud workflows (Figure 1), encompassing data acquisition, processing, and 3D tree reconstruction, offering a robust framework for assessing phenotypic variations both within and between provenance.

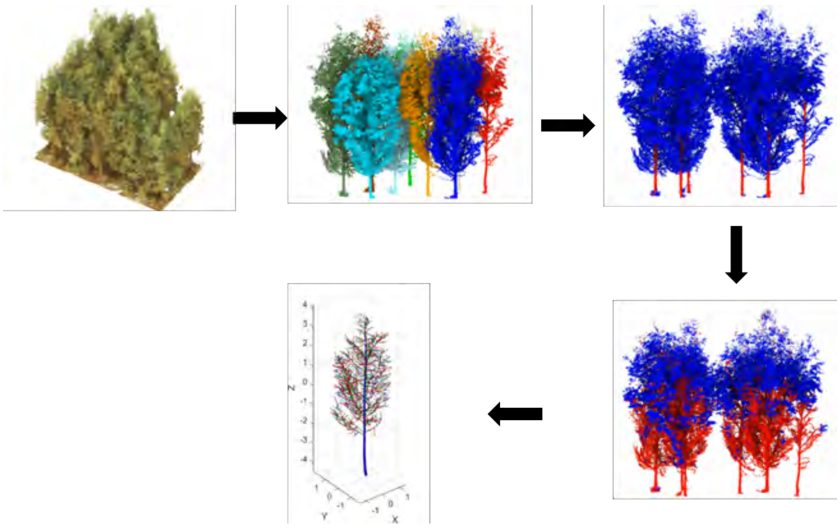


Figure 1: TLS point cloud workflow

Preliminary findings indicate that TLS-derived crown architecture metrics varies between families and provenances. This study contributes to precision forestry practices by advancing methods for detailed phenotypic assessment, ultimately promoting sustainable forestry through improved genotype selection and forest management strategies.

References

Raumonen, P., Kaasalainen, M., Markku, Å., Kaasalainen, S., Kaartinen, H., Vastaranta, M., Holopainen, M., Disney, M., & Lewis, P. (2013). Fast automatic precision tree models from terrestrial laser scanner data. Remote Sensing, 5(2), 491–520. https://doi.org/10.3390/RS5020491

Capturing a Digital Model of the Supply Chain for Precision Forestry Planning and Decision Support

Pablo Asiron[1],
1 – Remsoft Inc., Moncton, New Brunswick, Canada

The forest industry is increasingly embracing advancements in data acquisition, optimization, artificial intelligence (AI) and digital technologies to drive continuous improvement across the entire supply chain. The integration of prescriptive mathematical optimization techniques, such as Linear Programming (LP) and Mixed Integer Programming (MIP), with cloud-based operational planning technology has enabled a cyclical model of Modeling, Implementing and Refining within a connected platform that considers planned values, actuals from the field, and forecasted values.

During the Modeling phase, optimization methods generate strategic, tactical, and operational plans that account for the complexities of forest management, including capital investment and sustainability constraints. These models are continuously refined with real-time data from forest operations, captured through cloud-connected platforms that track actuals from the field. The Implementing phase focuses on the execution of these optimized plans in the field, creating a digital twin of both the planning and operational activities, ensuring precision in decision-making.

The next step in this continuous cycle, the Refining phase, leverages AI to analyze historical and real-time data, providing actionable insights that enhance future planning models. This continuous learning loop enables forest managers to increase efficiency, optimize wood supply chains, and reduce energy expenditure while ensuring sustainability. By harnessing the power of optimization, AI, and operational planning platforms, forest managers can achieve better economic and environmental outcomes. This approach offers a pathway toward smarter, more sustainable forestry operations, significantly contributing to the evolution of precision forestry.

Predicting Growth and Yield Using Empirical Models and Climatic Modifiers for Short-Rotation Eucalyptus Pulpwood in South Africa

Morries Chauke[1], Heyns Kotze[1],
1 – Mondi South Africa, Hilton, KwaZulu-Natal, South Africa

Over recent decades, forestry growth modeling has evolved significantly, with a greater emphasis on dynamic models that respond to environmental variables. This work presents the transition from static to dynamic modeling approaches for key growth components such as dominant height (Hd), trees per hectare (TPH), and basal area (BA). Each of these variables contributes to our understanding of forest growth. Dominant height, a proxy for site index, serves as indicator for site productivity, while TPH and BA provide insight into mortality trends and stand carrying capacity over time. This study also explores how climatic variables, specifically rainfall and soil water deficit (SWD), affect these growth metrics additional to age (A), subsequently affecting utilisable volume (UVOL). The basis for empirical stand level growth modeling in the country was documented by Kotze et al. (2012). These efforts, however, do not explore the effect of climatic variables, which are emergent.

South African forest companies, such as Mondi, have recognised the need for climate-sensitive growth modeling by investing considerably in a network of automatic weather stations (AWS) across its landholdings as well as comprehensive soil mapping. The AWS network allows for real time monitoring of weather, while soil mapping facilitates exploration of SWD effects on growth metrics. These initiatives offer invaluable data, providing flexibility for models to reflect the short-term effects of rainfall and SWD fluctuations more accurately. Recent studies, such as Chauke et al. (2022), underscores the value of these efforts. Global efforts, notably in Brazil (Scolforo et al., 2020; Scolforo et al., 2016; Scolforo et al., 2017), similarly employ extensive weather station networks to address climate impacts on growth components, aligning with the broader pursuit of climate-integrated forestry models.

The objective of this study is to develop and validate a climate-integrated growth model that enhances predictive accuracy for key growth components.

Key Growth components

Dominant Height (Hd): Dominant height, often represented as a function of age, serves as a proxy for site quality or site index (SI). Dominant height is traditionally (in Mondi) modeled using the difference approach, derived from a Hossfeld function (Palahì et al., 2004) as follows:

$$Hd_2 = \frac{A^2}{\beta_1 + A_2\left[\left(\frac{A_1}{Hd_1}\right) - \beta_3 A_1 - \frac{\beta_1}{A_1} + \beta_3 A_2\right]}$$

We extend this function to incorporate the rainfall effect as shown in Figure 1, where QF_PDB044_EGXU002 is the observed plot name:

Trees per Hectare (TPH): TPH represents stand density and is a determinant of inter-tree competition, influencing overall forest structure and productivity. Clutter and Jones (1980) provided an early model for TPH as a function of age, incorporating density reductions over time due to mortality.

$$TPH_2 = \left[TPH_1^{\beta_1} + \beta_2\left[\left(\frac{A_2}{100}\right)^{\beta_3} - \left(\frac{A_1}{100}\right)^{\beta_3}\right]\right]^{\frac{1}{\beta_1}}$$

We extend this function to incorporate SWD.

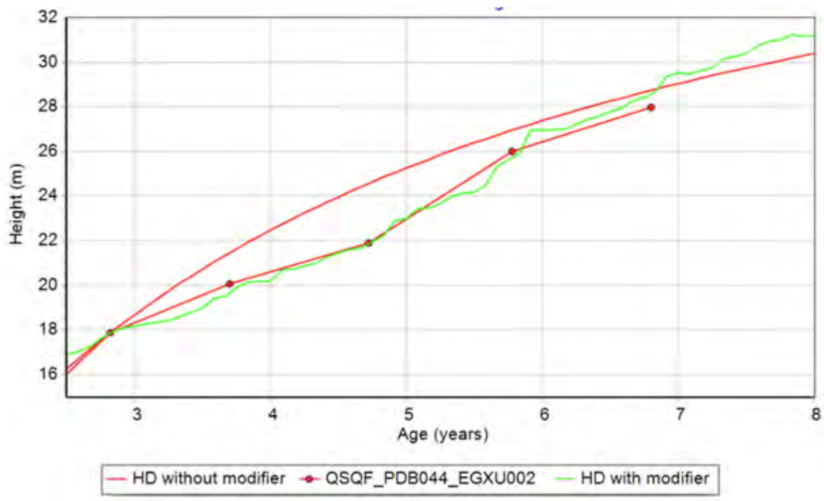


Figure 1: Comparative behavior of Hd model with and without rainfall modifier

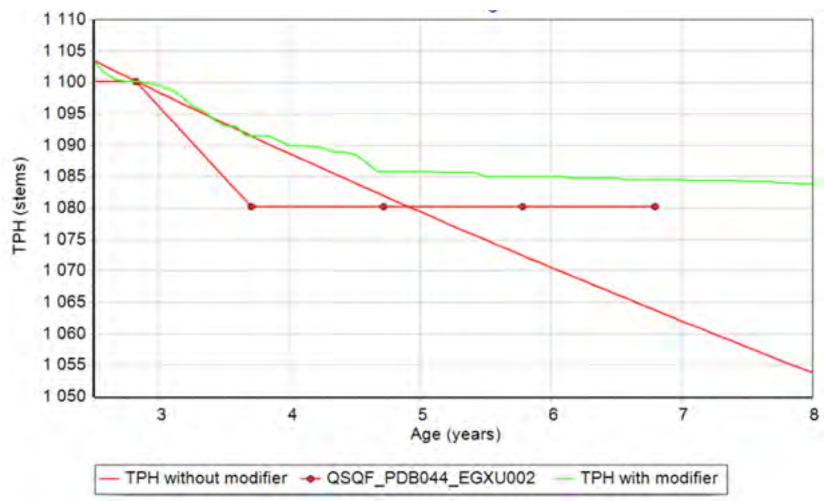


Figure 2: Comparative behavior of TPH model with and without SWD modifier

Basal Area (BA): Basal area represents the cross-sectional area of trees at breast height within a stand, and it is a good indicator of carrying capacity. Pienaar and Harrison (1989) proposed a model that relates BA to age, Hd, and TPH:

$$BA_2 = \exp\left[\ln(BA_1) + \beta_1 * \left(\frac{1}{Age_2} - \frac{1}{Age_1}\right) + \beta_2 \cdot [\ln(TPH_2) - \ln(TPH_1)] + \beta_3 \cdot [\ln(HD_2) - \ln(HD_1)]\right.$$

$$\left. + \beta_4 \cdot \left\{\frac{\ln(TPH_2)}{Age_2} - \frac{\ln(TPH_1)}{Age_1}\right\} + \beta_5 \cdot \left\{\frac{\ln(HD_2)}{Age_2} - \frac{\ln(HD_1)}{Age_1}\right\}\right]$$

We extend this function to incorporate the rainfall effect:

Stand volume (UVOL): Stand volume in this study is estimated through multiple linear regression of

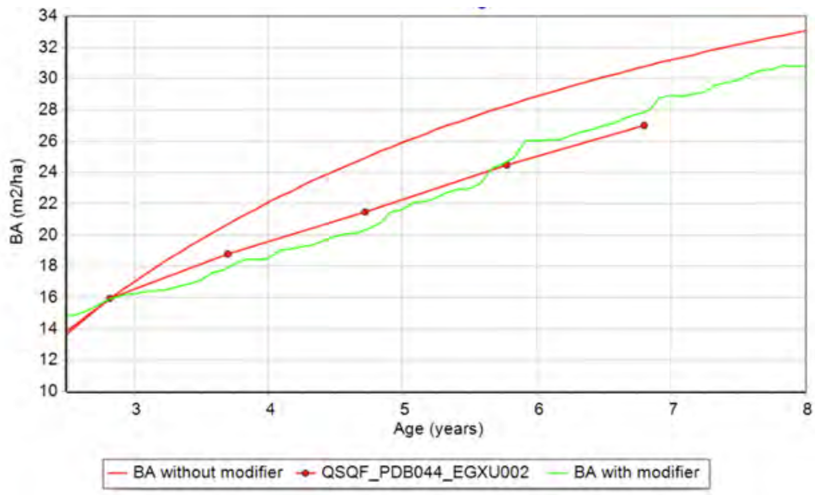


Figure 3: Comparative behavior of BA model with and without rainfall modifier

these key metrics (A, Hd, TPH, and BA) and integrates modified components to reflect rainfall and SWD influences:

$$UVOL = c_1 + c_2A + c_3BA + c_4Hd + c_5TPH$$

This model incorporates the influence of short-term climatic fluctuations on growth, mortality, and density.

Development of climate modified dynamic modeling approaches

Climate modified dynamic models transition growth modeling away from static, age-driven frameworks by incorporating environmental variables such as rainfall and soil moisture. This development reflects a growing recognition that short-term climatic fluctuations significantly affect growth, mortality, and stand density. Mondi's AWS network across plantations in South Africa is a testament to the company's commitment to integrating climate data into growth models. These stations capture real-time weather data, facilitating the analysis of their effects on key growth components. Furthermore, Mondi's soil mapping initiatives provide valuable information on total available moisture, allowing for dynamic adjustments in growth models based on SWD. These insights are crucial for enhancing growth predictions under changing environmental conditions.

Process-Based Models

Process-based models attempt to simulate the physiological processes governing tree growth, including photosynthesis, water uptake, and nutrient cycling. However, their practical application is limited due to the extensive data requirements on soil properties, meteorological inputs, and tree physiology. While promising, process-based models often remain complex and less practical for operational forestry at the compartment level.

Result

The comparative statistics presented in Table 1 indicate that the climate modified dynamic model responds to fluctuations in rainfall and SWD when compared to the model without the climatic effects. The comparative behavior is displayed in Figure 4.

Table 5: Comparative statistics for growth metrics predictions modified for rainfall effect

Model	**MB%**	**SDD (m^3/ha)**	**TSE**
Default model	12.8	33.9	2089
Intro *Hd*, TPH & BA modifiers	10.1	31.8	1593

O_i is the observed value, P_i is the predicted value, n is the number of observations, and Bias is the **mean** *of differences (O_i - P_i).*

Table 6: Details for the comparative statistics

Statistic	**Calculated as**	**Reference**
Mean bias percentage (MB%)	$MB\% = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{P_i-O_i}{O_i}\right) \times 100$	(Hyndman and Koehler, 2006)
Standard deviation of differences (SDD)	$SDD = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i - \text{Bias})^2}$	(Chatfield, 2000)
Total squared error (TSE)	$TSE = \sum_{i=1}^{n}(P_i - O_i)^2$	(Hyndman and Koehler, 2006)

Comparative behavior of UVOL model with and without climatic modifier.

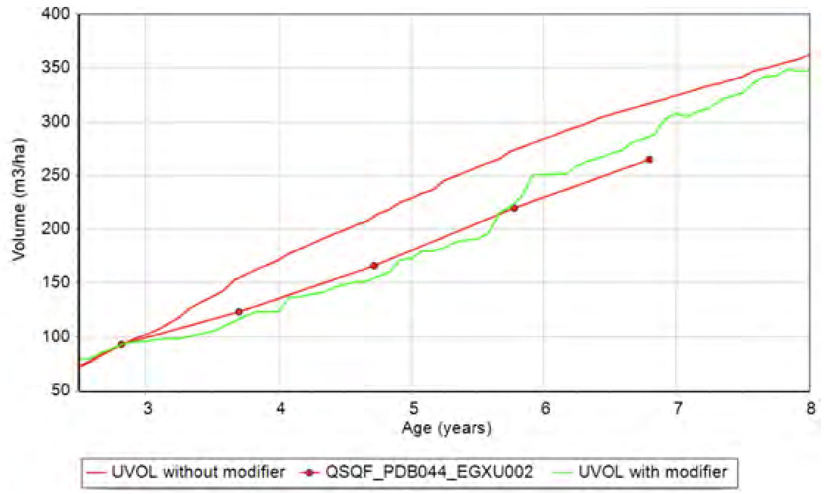


Figure 4: Comparative behavior of UVOL model with and without climatic modifier

Conclusion

The integration of climatic variables into traditional forestry models marks a significant enhancement in growth modeling and shows improved model performance. Modified empirical models serve as sensible and practical solutions to account for climate variability.

References

Chatfield, C., 2000. Time-series forecasting. Chapman and Hall/CRC.

Chauke, M., Mwambi, H. and Kotze, H., 2022. Modelling dominant height growth including a rainfall effect using the algebraic difference approach. Cerne, v.28, e-103112

Hyndman, R.J. and Koehler, A.B., 2006. Another look at measures of forecast accuracy. International journal of forecasting, 22(4): 679-688.

Kotze, H., Kassier, H.W., Fletcher, Y. and Morley, T., 2012. Growth Modelling and Yield Tables, in Bredenkamp, V. and Upfold, S. J. South African Forestry Handbook (5th ed). Southern African Institute of Forestry, pp.175-209.

Palahì, M., Tomé, M., Pukkala, T., Trasobares, A. and Montero, G., 2004. Site index model for Pinus sylvestris in north-east Spain. Forest Ecology and Management, 187(1): 35-47.

Scolforo, H.F. et al., 2020. Site index estimation for clonal eucalypt plantations in Brazil: A modeling approach refined by environmental variables. Forest Ecology and Management, 466: 118079.

Scolforo, H.F. et al., 2016. Modeling dominant height growth of eucalyptus plantations with parameters conditioned to climatic variations. Forest Ecology and Management, 380: 182-195.

Scolforo, H.F. et al., 2017. Incorporating rainfall data to better plan eucalyptus clones deployment in eastern Brazil. Forest Ecology and Management, 391: 145-153.

Thinning effects on light capture, light use efficiency, risk management and stand productivity in a Radiata pine plantation

Otto L. Pienaar[1, 2], Ben du Toit[1],
1 – Department of Forest and Wood Science, Stellenbosch University, South Africa
2 - New Zealand Forest Service, Ministry for Primary Industries, New Zealand

Rationale: Pine plantations constitute an important timber resource in South Africa and its management requires accurate information. Traditional thinning practices in most pine plantation forests aim to produce trees with a moderately large diameter and a substantial fraction of mature wood for adequate strength and stiffness in the structural wood market. Thinning operations therefore include the removal of mostly the suppressed and intermediate crown classes (thinning from below), as this leads to greater product uniformity with associated efficiency gains. In contrast, many managed forest systems in the Northern Hemisphere are managed according to the "plenterwald" (or similar) system whereby a range of size classes are removed in thinning operations to yield multiple products whilst rendering a more heterogenous size class distribution in the remaining stand. This system may include so-called "thinning from above" (removal of co-dominants) and is feasible where appropriate markets exist. We need to add that most of the "plenterwald" systems are light-limited, and that responses may therefore hinge on changes in canopy configuration and light interception.

In South Africa, most of the plantation systems are water-limited, rather than light- limited. Furthermore, many smaller-scale farm forests, situated in locations remote from sawmills, regularly sell to various pole, crate, pallet and biomass markets that can accommodate more variable diameter and wood quality specifications. These factors call for an investigation into the response mechanisms and the viability of alternative thinning regimes. We therefore set the following study objective: to quantify the growth response, light use efficiency (LUE) and vulnerability of mid-rotation Pinus radiata stands subjected to various thinning types. Thinning types included thinning from above (Ta), thinning from below (Tb) or no thinning as a control treatment.

Early results: The growth response indicated that there were no significant differences in quadratic mean diameter (Dq) and volume increment between the two thinning treatments, but that significant differences existed between the thinned treatments and control with the control treatment having significantly higher volume increment, especially during the second year of the study (a very wet period). There were also seasonal differences in Dq and volume increment between the treatments. Similar trends to the volume increment could be seen for the above ground net primary production.

Densification or regrowth of the canopy has not taken place for two years since thinning implementation and the Leaf Area Index (LAI) has remained relatively stable over the duration of the study period. Significant differences were observed in LAI between the thinned treatments and the control. The Light Use Efficiency (LUE) of the treatments were not significantly different from each other when averaged over the full two-year period since treatment. This result is somewhat surprising because heterogenous forests can sometimes change their carbohydrate allocation patterns and hence their LUE. Furthermore, increases in LUE could be seen for treatments from the dry to the wet seasons with significant differences observed for the control versus the two thinning treatments during the second (very wet) year.

The slenderness ratio of the unthinned control treatment measured at the end of the study period indicated that the stands are becoming increasingly unstable, while the relative density has shown that the unthinned controls are approaching a stage where tree mortality is imminent. Notably, the control treatment has shown superior levels of light interception and volume growth in comparison to the thinning treatments.

Conclusions from early results: Leaving the control stands unthinned for longer might be tempting, but this treatment is becoming increasingly unstable and vulnerable to drought and pest or disease outbreaks, and therefore is not recommended. Considering that there were no significant differences in growth response between the Ta and Tb treatments, the decision as to which treatment to implement will be an economical, rather than a biological decision, driven by market demand.

Availability and Transformations of P and N Across Climatic Zones, Soil Type, and Fertilization in Early Response in South African Commercial Forestry

Teklit Z. Tekleab[1,2], Ilaria Germishuizen[2], Ben du Toit[1],
1 – Department of Forestry and Wood Science, Stellenbosch University, Stellenbosch, 7602, South Africa
2 – Institute for Commercial Forestry Research, Scottsville, 3209, P.O. Box 100281, Pietermaritzburg, South Africa.

Commercial forestry in South Africa makes a significant economic contribution and is vital in mitigating climate change. Precision forestry, which aims to maximize productivity while minimizing environmental impacts, requires an in-depth understanding of nutrient dynamics and site-specific fertilization responses. Soil characteristics and nutrient dynamics under eucalyptus plantations are considerably affected by continuous rotations, residue management practices, climate, and soil parent material. However, comprehensive research on N and P dynamics, as well as plantation responses to fertilization across sites with varying climatic zones and edaphic conditions in South Africa's commercial forestry sector, remains limited.

Therefore, this project focuses on investigating the potential N mineralization and P adsorption capacity of sites having different climatic zones and geological backgrounds; analyzing the extent of P bound to Al and Fe; investigating the influence of soil properties and organic matter on P and N availability from planting to the canopy closure period; and assessing plantation growth responses to fertilization across diverse climatic zones and lithologies. Six sites, managed by Mondi and Sappi, located in diverse climatic and edaphic conditions, have been selected for this study. The results of this project will provide insightful information for a comprehensive study on eucalyptus-soil nutrient dynamics and optimized soil management and fertilization strategies aimed at enhancing productivity and environmental protection.

Keywords: N mineralization, P availability and adsorption, fertilization, forestry research, South Africa

Understanding the Impact of Under Canopy Mulching as a Fuel Load Management Tool

Leeshan Mahadeo[1],
1 – Research Division, Sappi, Tweedie, KwaZulu Natal, South Africa.
***Corresponding author:** Leeshan.Mahadeo@sappi.com

There is an increased interest in fuel load reduction practices on commercial forestry in South Africa. Under canopy fuel load reduction refers to the practice of reducing the amount of flammable material, such as under story vegetation, branches, stumps, and leaf litter, that accumulates beneath the canopy of trees in forested areas. This practice is important for mitigating the risk of fires.

Conventional techniques such as under canopy burning and discing are employed to reduce the understory fuel load. Burning of residues is favoured as it is relatively relative cheap and quick in comparison with other alternatives. However, burning is not ideal as it is constrained by burning windows and is associated with the high risk of wildfires and scorching of trees if inappropriately managed. Whilst discing of residue is effective but damages the lateral roots hindering growth.

Under canopy mulching offers such a solution by lowering fuel loads in risk of fires and also providing a nutritional mulch layer. The aim of this study was to investigate the productivity and cost of a newly developed under canopy mulcher and provide a benchmark for this operation. Relevant data was collected from sites situated in northern KwaZulu-Natal. The study was limited to Eucalyptus grandis x Eucalyptus urophylla pulpwood regimes, focusing mainly on reducing under canopy fuel loads by investigating differences between biomass loads and mulching productivity.

The study included estimating fuel load and remaining stump volumes using a Zigzag sampling and fuel load classification methods. Time and motion studies quantified time consumption and the productivities of the Antonio Carraro TRG 9900 Tractor fitted with the FAE UML175 mulching head. This paper will present the productivity levels achieved and the unit costs of the respective mulching treatments and the versatile utilisation of the base machine.

Discriminating Commercial Forest Plantation Species at the Species Level Using Multi-Temporal Unmanned Aerial Vehicle Imagery

Wandile Khumalo[1], Mthembeni Mngadi[2], Ilaria Germishuizen[3],
1 – School of Agricultural, Earth and Environmental Sciences, Discipline of Geography, University of KwaZulu-Natal, Pietermaritzburg, South Africa.
2 – School of Agricultural, Earth and Environmental Sciences, Discipline of Geography, University of KwaZulu-Natal, Pietermaritzburg, South Africa.
3 – Institute for Commercial Forestry Research (ICFR), Pietermaritzburg, South Africa.

The ability to accurately discriminate forest plantation species at the species level is crucial for effective forest management, monitoring, and conservation efforts. This study aims to explores the use of multi-temporal unmanned aerial vehicle (UAV) imagery to differentiate between commercial forest plantation species. By leveraging the high spatial and spectral resolution of UAVs, we assess their effectiveness in identifying species-specific spectral signatures across various growth stages. Multi-temporal imagery is analyzed to examine how seasonal variations and changes in stand-age influence spectral reflectance patterns.

The study utilizes advanced machine learning techniques to classify species and track temporal changes in plantation health, aiming to enhance precision in species identification and provide insights into forest dynamics. Results demonstrate that UAV-based remote sensing, combined with multi-temporal data, may offer a promising tool for discriminating commercial forest plantation species at a fine scale, contributing to more informed forest management practices and supporting change detection approaches for monitoring forest health at the landscape level.

References

Barry, K., Corkrey, R., Stone, C., Mohammed, C. (2009). Characterizing eucalypt leaf phenology and stress with spectral analysis. Innovations in remote sensing and photogrammetry, 193-209.

The Effect of Training Set Size on the Performance of Machine Learning Models in Detecting Young Pine Trees

Jamie Kok[1], Simon Ackerman[3], Bruce Talbot[2], Justin Erasmus[2*],
1 – York Timbers, Sabie, Mpumalanga, South Africa.
2 – Department of Forest and Wood Science, Stellenbosch University, Stellenbosch, South Africa.
3 – Mondi South Africa, Hilton, KwaZulu-Natal, South Africa.
*__Corresponding author:__ `erasj@sun.ac.za`.

Accurate counts of seedling survival are essential for establishing a measure of mortality rates in replanted sites. Advances in digital aerial photogrammetry obtained from UAVs (Drones) and object detection models have led to increased use of this technology in the forestry industry. Seedlings and juvenile trees are ideal objects to be detected and counted by object detection models, due to their shape and contrast in colour to background in most digital orthomosaics.

In this study, three object detection models were trained using annotated seedlings as their training data to detect and count the number of seedlings in four replanted sites. Nine models were trained, three of each model type (SSD, Faster R-CNN and YOLOv5). The detection rates for each model were assessed and compared to eye count data. The objects causing false detections (false positives) were counted to determine which objects were most likely to confuse the models.

The SSD model performed best, achieving an average recall and precision of 93% and 100%, respectively. An increase in crown diameter showed an increase in detection rates. Vegetation surrounding the seedlings, such as weeds, was the main cause of false detections for the models. The number of annotations influenced model detection rates, with more annotated seedlings increasing model performance. Automated seedling detections for diameters greater than 0.5 m appear commercially viable.

Thursday, 6th February

Pixels, People, and Precision: Aligning Technological Innovation with Human Adaptation in Forestry

Miranda Wilson[1],
1 – Mondi South Africa, Hilton, KwaZulu-Natal, South Africa

Keynote Speaker

Examining the Utility of a Hybrid Approach for Predicting Forest Structural Attributes Using Hyperspectral Data

Mikka Parag[1], Romano Lottering[1],
1 – University of KwaZulu-Natal, South Africa

Mapping the structure of commercial forests using hyperspectral remote sensing techniques produces highly accurate and very fine ecological details that are vital for sustainable forest management and planning. However, the implementation of traditional hyperspectral modelling approaches has been hindered by issues of multicollinearity and data dimensionality. Thus, this study aims to examine the utility of a hybrid partial least squares regression and random forest (PLSR-RF) algorithm in accurately predicting four structural attributes (basal area, diameter at breast height, tree height and site index) amongst varieties of commercial Eucalyptus and Acacia using airborne AISA Eagle hyperspectral imagery (2.4m spatial resolution). Additionally, two traditional hyperspectral modelling methodologies PLSR and RF were utilised alongside the hybrid PLSR-RF.

The best model obtained for study was produced for Acacia Mearnsii using the hybrid PLSR-RF algorithm ($r2 = 0.92$ and RMSE = 0.02). The results of this study indicate that the hybrid approach is a robust and promising model for the estimation and mapping of forest structure for varieties of Eucalyptus and Acacia within a commercial plantation. In addition, the hybrid model predominantly outperformed the use of traditional hyperspectral modelling approaches. Finally, the use of the hybrid approach successfully navigates the issues of multicollinearity and data dimensionality associated with multispectral remote sensing through the combination of PLSR and RF.

Detection of Phytophthora Root Rot in Eucalyptus Using Hyperspectral Leaf Reflectance and Machine Learning

Esterhuizen HJ[1*], Bose T[1,2*], Bosman AS[3], Roux J[4,5], Jones W[6], Slippers B[1], Hammerbacher A[2*],
1 – Department of Biochemistry, Genetics and Microbiology, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, Pretoria 0002, South Africa.
2 – Department of Zoology and Entomology, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, Pretoria 0002, South Africa.
3 – Department of Computer Science, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, Pretoria 0002, South Africa.
4 – Department of Plant and Soil Sciences, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, Pretoria, South Africa.
5 – Sappi Forests Pty. Ltd., Shaw Research Centre, Howick, KwaZulu-Natal, South Africa.
***Corresponding author:** Lihan.esterhuizen@fabi.up.ac.za

Eucalyptus species and hybrids are key exotic trees in South African plantation forestry. However, they are vulnerable to various pests and pathogens. For instance, several Phytophthora species cause root and collar rot, which poses a significant threat to the industry. It is known that the accurate detection of plant diseases plays an integral role in implementing disease management strategies. This has led to the development of new non-destructive disease detection systems that can rapidly and accurately diagnose plant disease in the field before the emergence of symptoms. In this study, we used Phytophthora alticola and Eucalyptus benthamii as a model pathosystem to explore whether leaf reflectance data can serve as a non-invasive method for early detection of root rot disease.

For this, we inoculated 19 commercially important genotypes of E. benthamii with an isolate of P. alticola (CMW48711) using the sand infestation pot method. Three months post inoculation, hyperspectral data from both control and infected trees were collected in duplicate using a leaf clip connected to an ASD FieldSpec 4 spectroradiometer. Following this, dry root weights were also recorded from both sets. The hyperspectral dataset was analysed using a multi-step machine learning pipeline developed in this study. This multi-step pipeline comprised of data normalisation, data visualisation, model optimization, model training, and determining the relevant wavelength for disease detection.

Using this pipeline, we manged to train a model capable of differentiating between infected and healthy plants at a 96% accuracy and identified a hyperspectral index specific for P. alticola infection. This result was corroborated by dry root weight data. This study demonstrates the future potential of using hyperspectral sensing as a tool for the detection of forestry diseases such as Phytophthora root rot. Additionally, our research demonstrates the value of a machine learning pipeline as a platform for efficiently managing large datasets.

Automated Terrain Roughness Assessment Using TLS as a Proxy for Machine-Mounted LiDAR Applications

Gunta Grube[1,2], Bruce Talbot[2], Stefano Grigolato[1,2],
1 – Department of Land, Environment, Agriculture and Forestry, University of Padova, Legnaro, Italy
2 – Department of Forestry and Wood Science, Stellenbosch University, Stellenbosch, South Africa

Accurate estimation of terrain roughness is essential for effective forest operations, especially in complex terrains, as terrain characteristics directly impact planning, machine navigation, and operational efficiency (Davis & Reisinger, 1990). Moreover, detailed terrain data is crucial for precisely assessing operational costs, including fuel consumption.

Traditional roughness assessments, which rely on visual surveys over large areas, often lack the precision and scalability required for detailed planning. This study aims to enhance precision by refining the terrain classification method (Erasmus, 1994) using Terrestrial Laser Scanning (TLS), enabling more automated and accurate roughness assessments.

We employ TLS to capture detailed, high-resolution point cloud data. This data is analyzed using intensity values and deep learning to automatically classify terrain obstacles. The refined data allows for a scalable assessment of terrain roughness using an adapted Erasmus (1994) classification, making it applicable to various forest settings. Additionally, point cloud density was reduced to three different resolution levels to identify the minimum density required for reliable roughness estimation.

Results are compared with UAV-based roughness assessments (Grube et al. 2025) over the same terrain (Figure 1) while also examining how variations in point cloud density affect roughness estimation. Preliminary results indicate that TLS point cloud data provide more detailed roughness estimates than UAV-based assessments, especially for small obstacles. However, the accuracy largely depends on the classification performance and the amount of training data used for the classification model. By refining terrain classification, this study aims to automate roughness assessment using 3D point cloud data, thereby improving navigation and operational planning in complex terrains.

References

Davis, C. J., Reisinger, T. W. (1990). Evaluating terrain for harvesting equipment selection. Journal of forest Engineering, 2(1), 9-16.

Erasmus D. (1994). National Terrain Classification System for Forestry, Version 1.0. ICFR Bulletin Series 117/94. Pietermaritzburg (South Africa): National Terrain Classification Cooperative.

Grube, G., Talbot, B., Grigolato, S. (2025, unpublished). Automated Terrain Roughness Assessment using UAV Remotely Sensed Imagery.

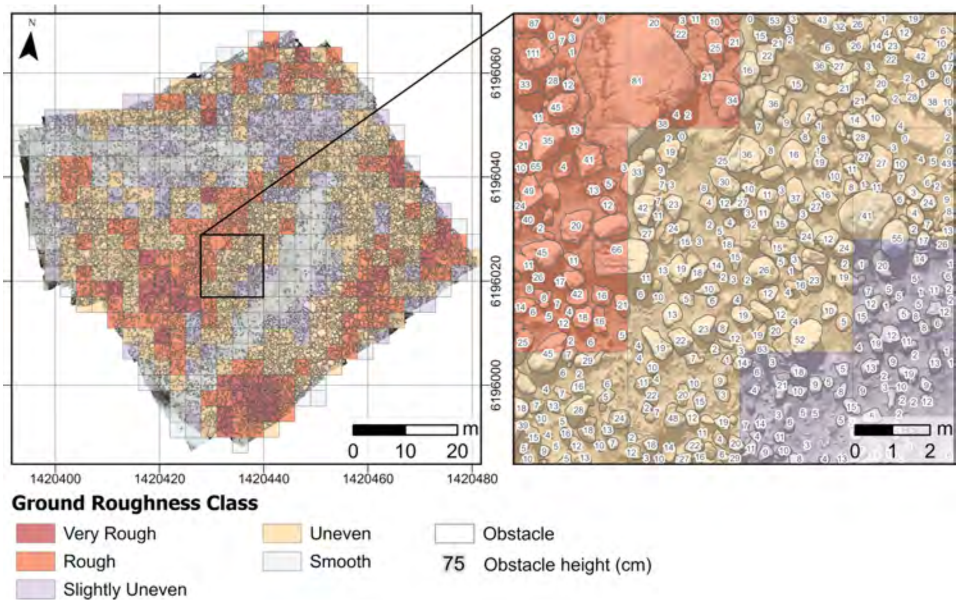


Figure 1: Ground Roughness Classification Map. The left section shows the roughness classification for the entire study area, while the right section provides a detailed 4x4 cell grid example, with detected obstacles annotated by height in centimeters.

The Digital Forester: Leveraging Remote Sensing Technology at Scale

Naeem Agjee[1], Keegan Tasker[1], Kabir Peerbhay[1], Jacob Crous[1],
1 – Sappi Forests, Shaw Research Centre, Howick, KwaZulu-Natal, South Africa

To drive operational innovation, Sappi Forests has developed automated remote sensing tools/systems to monitor its plantation forests. The advantage of implementing satellite-based remote sensing technologies is that it enables inexpensive near real-time monitoring of all Sappi plantations at a landscape level. Strategically Sappi has developed remote sensing tools in three application areas 1) harvest monitoring 2) effective burn mapping and 3) plant health monitoring.

Harvest monitoring:

The primary aim is to monitor harvesting operations which initiates the flow of timber into the Sappi forestry logistics supply chain. Understanding the place and time at which harvesting occurs is critical in facilitating the efficient planning and execution of downstream activities. In addition, remote harvest monitoring is integral as a post-harvest verification tool to verify the completion of harvesting activities at the geolocation stipulated as part of the EUDR process.

Effective burn mapping:

Fire risk management is critical to reducing the risk of fire events damage to Sappi plantations. This is undertaken through controlled burning activities of conservation units and tracer burns prior to the start of the fire season (April / May). Prescribed burning / controlled burning is a practical way to reduce the dangerous accumulation of combustible fuels in conservation units and grassland areas surrounding Sappi plantations. This proactive activity dramatically reduces the risk occurrence of damaging fires and severe economic loss. Burn scar monitoring is imperative to track burn progress and effectiveness of burning activities.

Plantation health monitoring:

At a landscape level, plantation health monitoring at is critical to gain insight into the health status of compartments as well as identify, monitor and manage stress. Stresses could include drought, frost damage, poor site quality, severe wind damage and extreme fire events.

In this regard, an automated, remote measurement and reporting system was developed for the three applications to enhance and validate traditional reporting systems. Measurements are carried out remotely using Sentinel-2 satellite imagery after which the data is uploaded to databases, processed in-house, combined with data from existing reporting systems and fed into a browser-based map viewer and dashboard summary. Results show an overall accuracy > 80% on all applications.

A Severity Index for Forestry Machine Impact in Mountains Using Machine Learning

Alberto Udali[1], Davide Imperiali[1], Nicolò di Marzio[1], Stefano Grigolato[1],
1 – Department of Land, Environment, Agriculture and Forestry, Università degli Studi di Padova, Italy.

Mountainous regions are prone to large-scale disturbance events such as wildfires, landslides, and windstorms, which can significantly impact forest ecosystems (Seidl et al., 2017). In the aftermath of such events, salvage logging operations and forestry machines, including harvesters and forwarders, play a crucial role in post-disturbance forest management and recovery (Lindenmayer 2006). However, the passage of these machines can result in soil compaction and erosion, further exacerbating the ecological vulnerability of the affected areas (Prats et al. 2021).

This study aims to assess the impact of forestry machines on mountain areas following large disturbance events, with a specific focus on developing a severity index based on wheel rut depth and the exposure to potential erosion risks. To achieve this, a combination of LiDAR data for the pre-event scenario and close-range photogrammetry from drones for the post-event scenario will be utilized to quantify the degree of change and the specific impacts associated with the passage of forestry machines. Additionally, the computation of Depth-To-Water (DTW) maps will be employed to evaluate the risk of erosion in the affected areas (Labelle et al., 2022).

This study plans to integrate a machine learning approach to handle machine-derived data acquired via the CAN-BUS protocol to identify the extraction trails and defining the trafficked area (i.e., the machine footprint). This model will learn to identify and classify trail segments based on the number of passages, allowing for automated detection and extraction of their features. The extracted information will then be used to retrieve the position of wheel ruts and their depth, increasing the precision in the quantitative measure of soil compaction and disturbance severity.

By leveraging LiDAR data, the pre-event forest structure and topography will be reconstructed, enabling a baseline assessment of the environment before the disturbance event. The subsequent collection of close-range photogrammetry data from drones, combined with machine learning and deep learning models, will facilitate the accurate identification and measurement of wheel ruts caused by forestry machines.

To evaluate the erosion risk, a DTW model will be employed, incorporating parameters such as slope, soil type, vegetation cover, and topography. By integrating the severity index based on wheel rut depth and the erosion risk exposure, a comprehensive assessment of the impact of forestry machines on mountain areas following large disturbance events will be achieved.

The results of this study will contribute to a better understanding of the vulnerability present in the area of operations and identify highly vulnerable spots, moreover it will be possible to monitor the change in exposure due to the passage of operating machines. Also, the results will contribute to obtain a broader knowledge of the possible ecological consequences of post-disturbance forest management practices in mountainous regions, helping to address possible management solutions for forest managers and practitioners. The severity index developed based on machine trafficability and wheel rut depth will serve as a valuable tool for assessing the extent of disturbance caused by forestry machines. Moreover, the incorporation of the DTW map will enable the identification of areas at high risk of erosion due to machine passage, aiding in the development of sustainable management strategies to mitigate environmental degradation.

References

Labelle, E. R., Hansoon L., Hogbom L., Jourgholami M., Laschi A. (2022) ‘Strategies to Mitigate the Effects of Soil Physical Disturbances Caused by Forest Machinery: a Comprehensive Review’, Current Forestry Reports, 8(1), pp. 20–37. doi: 10.1007/S40725-021-00155-6/TABLES/2.

Lindenmayer, D.B., Noss, R.F. (2006). Salvage logging, ecosystem processes, and biodiversity conservation. Conservation Biology. https://doi.org/10.1111/j.1523-1739.2006.00497.x

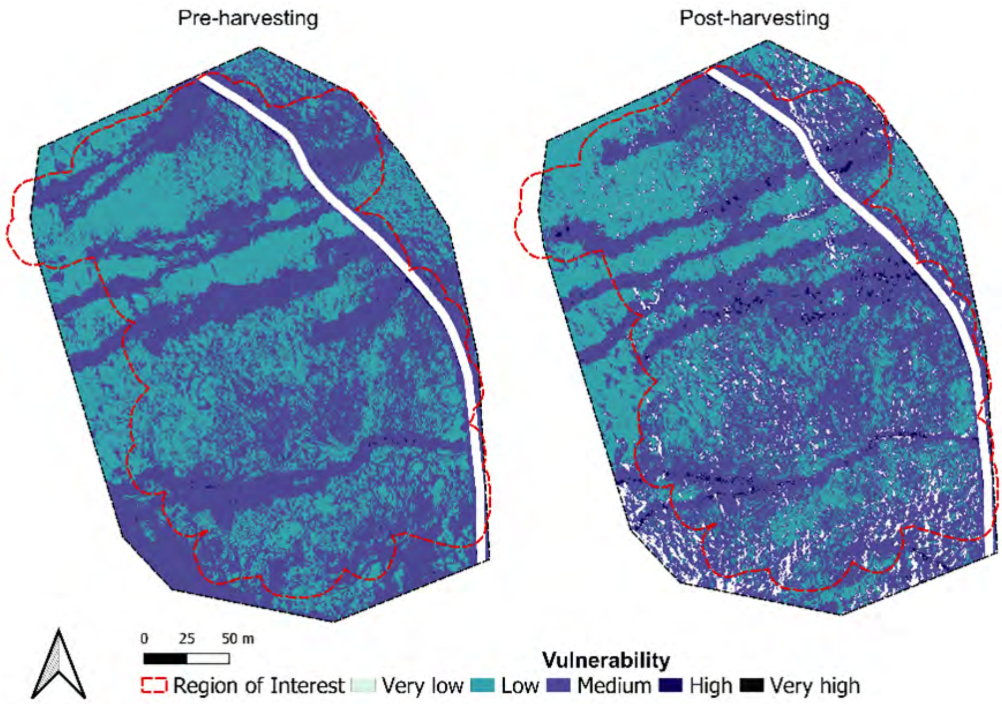


Figure 1: The vulnerability computed over the study area before the harvesting operations (left) and after the harvesting (right). The vulnerability is depicted from Very low to Very high following a blue scale.

Prats, S.A., Malvar, M.C., Wagenbrenner, J.W. (2021). Compaction and cover effects on runoff and erosion in post-fire salvage logged areas in the Valley Fire, California. Hydrol Process 35. https://doi.org/10.1002/hyp.13997

Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., Wild, J., Ascoli, D., Petr, M., Honkaniemi, J., Lexer, M.J., Trotsiuk, V., Mairota, P., Svoboda, M., Fabrika, M., Nagel, T.A., Reyer, C.P.O. (2017). Forest disturbances under climate change. Nat Clim Chang 7, 395–402.

Davis, C. J., & Reisinger, T. W. (1990). Evaluating terrain for harvesting equipment selection. Journal of forest Engineering, 2(1), 9-16.

Assessing Stand Heterogeneity in Plantations Using UAV-Derived Data and Deep Learning for Crown Segmentation

Michelle Jordaan[1], Kabir Y. Peerbhay[2], Bruce Talbot[1],
[1] Department of Forestry and Wood Science, Stellenbosch University, Stellenbosch, South Africa.
[2] Sappi South Africa, Hilton, KwaZulu-Natal, South Africa.

The aim of this project is to use deep learning models to identify trends in tree growth with a focus on stand heterogeneity and performance. Convolutional neural networks (YOLOv8 and Mask R-CNN) are employed in combination with manual and semi-automatic annotations (using the SamGeo model) to segment exact crown areas from UAV images. The trees, corresponding to segmented crown areas are used to extract height from a canopy height model and other terrain features such as slope and aspect from a digital terrain model.

From this the stand uniformity is determined using the Lorenz curve and Gini-index with crown area and heights as input, as well as variations of the PV50 equation (PH350). These are compared to evaluate the calculation of stand heterogeneity from either input parameters. The tree locations, calculated stand uniformity and corresponding terrain features, provide a tree-level and stand-level overview with environmental context for a representation of overperforming and underperforming areas in the forest stand.

Assessing Gonipterus sp. n. 2 Defoliation Levels Using Multispectral Unmanned Aerial Vehicle (UAV) Data in Eucalyptus Plantations

Phumlani Nzuza[1,2], Michelle L. Schröder[1], Rene J. Heim[2,3], Louis Daniels[2], Bernard Slippers[4], Brett P. Hurley[1], Ilaria Germishuizen[5], Benice Sivparsad[5], Jolanda Roux[6,7], Wouter H. Maes[2],

1 – Department of Zoology and Entomology, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, South Africa.
2 – UAV Research Centre (URC), Department of Plants and Crops, Ghent University, Belgium.
3 – Institut für Zuckerrübenforschung, An der Universität Göttingen, Germany.
4 – Department of Biochemistry, Genetics and Microbiology, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, South Africa.
5 – Institute for Commercial Forestry Research (ICFR), PO Box 100281, Scottsville, Pietermaritzburg, South Africa.
6 – Sappi Forests, RPN, Shaw Research Centre, Howick, RSA.
7 – Department of Plant and Soil Science, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, South Africa.

Invasive insect pests like Gonipterus sp. n. 2 (Coleoptera: Curculionidae) pose a significant threat to the Eucalyptus (Myrtaceae) industry. Damage caused by feeding of both the adult and larval stages lead to defoliation and yield reduction. The presence of epicormic shoots and damage of growth tips are symptoms of defoliation (Tooke, 1955). Early detection of Gonipterus sp. n. 2 is important for timely intervention to prevent pest outbreaks, but conventional insect pest monitoring methods are time-consuming and spatially restrictive (Chen and Meentemeyer, 2016; Oumar and Mutanga, 2011).

The aim of this study was to assess the potential of multispectral imagery obtained with Unmanned Aerial Vehicles (UAVs) for monitoring canopy damage caused by Gonipterus sp. n. 2. Across seven different sites, 14 datasets of multispectral UAV imagery were collected from young stands of Eucalyptus dunnii with varying levels of Gonipterus sp. n. 2 infestation. Reference damage levels were obtained through visual assessments of a sample of trees (n = 80-100) at each site (Figure1).

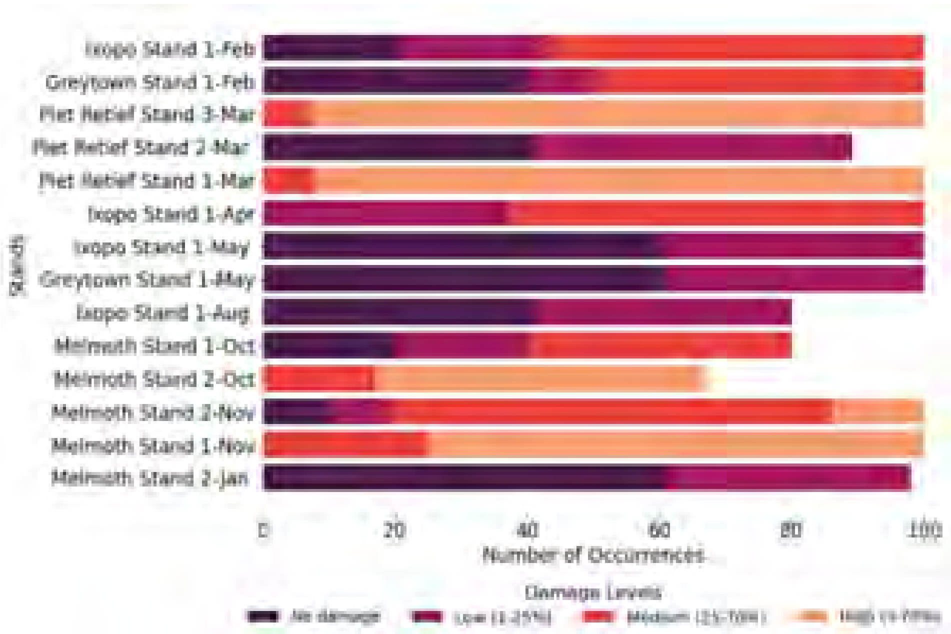
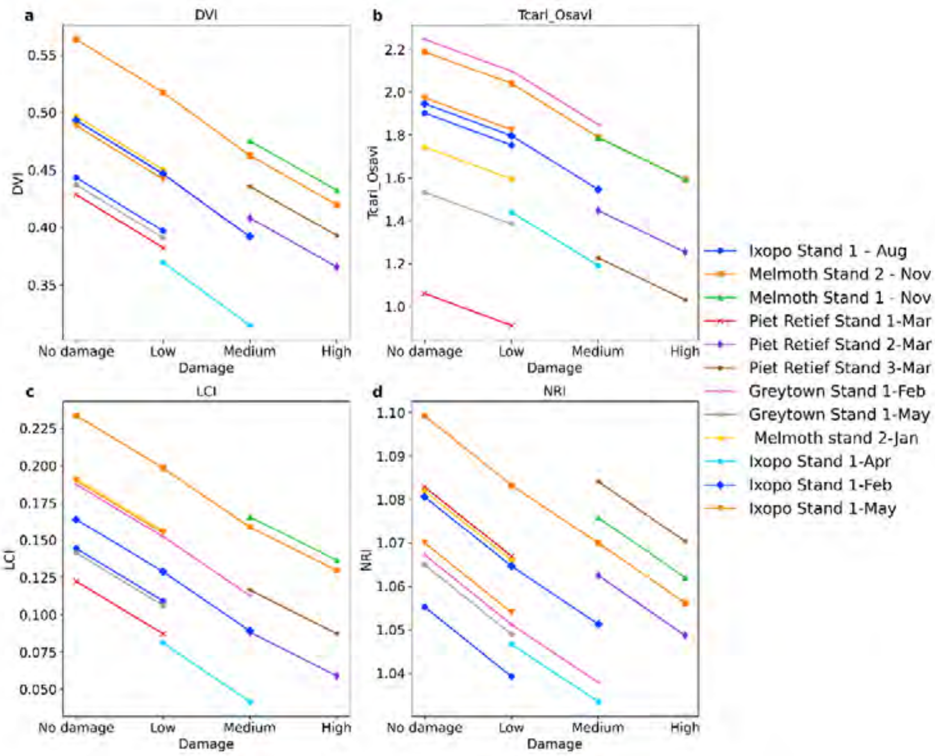


Figure 1: Distribution of damage classes across sites.

Across sites, a decrease in canopy reflectance in both the visual and the near-infrared domains with increasing damage levels was consistently observed. Several vegetation indices showed consistent patterns but none of them showed site independence (Figure 2).



)

Figure 2: Estimated marginal means of selected vegetation indices between site and damage across all sites.

Xtreme Gradient Boosting (XGBoost) was used as a machine learning method to model damage levels across sites. Five different types of input data were tested. The best performing models included reflectance, vegetation indices and grey level co-occurrence data. When data from 10 different wavelengths were used, a classification accuracy of 90% across all sites in classifying defoliation levels was reached. With a classical 5-band multispectral camera, the accuracy reduced to 82%, and this model was less able to differentiate medium damage from absence of damage (Figure 3).

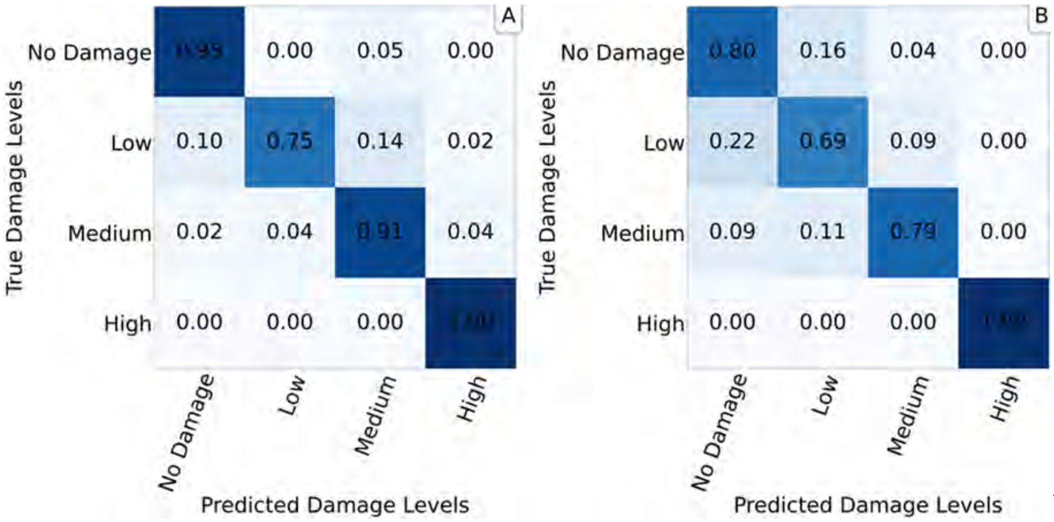
The method was less reliable when trained and validated on separate fields. This study demonstrates the feasibility of assessing Gonipterus sp. n. 2 levels with UAV-based multispectral imagery, but larger training datasets across multiple damage levels, as well as further image corrections, are still required. Nevertheless, the method can already be used to reliably upscale individual tree assessments to the stand scale.

References

Chen, G., Meentemeyer, R.K., 2016. Remote Sensing of Forest Damage by Diseases and Insects. Remote sensing for sustainability 145–162.

Oumar, Z., Mutanga, O., 2011. The potential of remote sensing technology for the detection and mapping of Thaumastocoris peregrinus in plantation forests. Southern Forests: a Journal of Forest Science 73, 23–31. https://doi.org/10.2989/20702620.2011.574814

Tooke, F.G.C., 1955. The Eucalyptus Snout.beetle, Gonipterus scutellatus Gyll. A Study of its Ecology and Control by biological Means. The Eucalyptus Snout.beetle, Gonipterus scutellatus Gyll. A Study of its Ecology and Control by biological Means.



)

Figure 3: Confusion matrices of the full datasets: (a) VIS + spectral+ texture 10-band data (Micasense-MX Red Edge Dual) camera, (b) VIS + spectral+ texture (Full 5-band data).

Friday, 7th February

Big Data in the Agriculture Sector

Kanshukan Rajaratnam[1],
1 – School for Data Science and Computational Thinking, Stellenbosch University, South Africa

Keynote Speaker

Detecting and measuring tree stumps in UAV-derived imagery

Alan Hubbard[1], Simon Ackerman[2], Bruce Talbot[1],
1 – Department of Forestry and Wood Science, Stellenbosch University, Stellenbosch, South Africa.
2 – Mondi South Africa, Hilton, KwaZulu-Natal, South Africa.

Accurate biophysical data from stumps left on post-harvested sites is required to ascertain volume loss from inefficient harvesting techniques or volume gain from biomass utilisation. Recently advances in digital aerial photogrammetry data from unmanned aerial vehicles (UAVs) and machine learning, and object detection algorithms, have led to the increased use of this technology in forestry for remote sensing.

Stumps, being mostly uniform in distribution and shape, are ideal objects for machine detection on digital orthomosaics. Resultant data from machine learning algorithms enables the possibility of estimating stump diameter and heights from virtual sources. In this study we trained three different machine learning model types, namely, Faster Region based Convolutional Neural Network (R-CNN), Single Shot Multibox Detector (SSD) and You Only-Look-Once (YOLO).

We assessed the detection rates of each model and compared metrics by using similarly annotated images. The resultant bounding boxes that encapsulated detected stumps were used to calculate diameters and compared to actual. Stump heights were determined using multiple methods which were also compared to actual height values. We found that visible stumps in post-harvested sites could be detected with high rates of accuracy, with almost perfect precision from some object detection models, albeit at low levels of recall.

Overall, all three model types had an F1-score of above 73% with the best model attaining an F1-score of 89%. Diameters, although successfully calculated, produced an overestimation from actual in most cases. Similarly, calculated stump heights were underestimated in most cases. The objectives of this study were met in that insights into using machine learning algorithms for stump detection were broadened. The ability to process photogrammetry data quickly and accurately, with good estimations of diameter and height values, provides a useful tool to industry for estimating biomass volume from stumps left on post-harvested sites. Future development in technology will certainly improve accuracy and turn-around time of available data.

Precision Weed Detection with Machine Learning

Jina Park[1], Luca Steyn[2], Bruce Talbot[1],
1 – Department of Forestry and Wood Science, Stellenbosch University, Stellenbosch, South Africa.
2 – Department of Statistics and Actuarial Science, Stellenbosch University, Stellenbosch, South Africa.

This research investigates the integration of Unmanned Aerial Vehicle (UAV)-based Red-Green-Blue (RGB) imaging with deep learning (DL) techniques for weed detection in South African commercial Eucalyptus plantations. The study specifically examines the effectiveness of the U-Net architecture in conjunction with vegetation indices (VIs), addressing the critical need for automated weed management solutions in commercial forestry. The research is motivated by the growing need for efficient, cost-effective, and sustainable weed management solutions in commercial forests, where traditional methods are time-consuming and labour-intensive.

The methodology employed high-resolution RGB imagery captured via UAV platforms, complemented by various vegetation indices, including TGI, ExB, BI, RGI, vNDVI, and BGI. The U-Net DL model was implemented for image segmentation, with training conducted on RGB-only and RGB+VI datasets. Performance evaluation utilised comprehensive metrics, including F1 score, Jaccard index, precision, recall, and AUC, enabling thorough assessment of model effectiveness across different sites and conditions.

Results show remarkable success in weed detection, achieving the highest F1 scores of 0.94 under optimal conditions. However, while VIs theoretically offered enhanced spectral information, their practical contribution to model performance proved limited, particularly considering overfitting for complex datasets with small volumes of data. These research findings convey that the quality and quantity of the dataset are more critical to model performance than the addition of vegetation indices. Moreover, the various model performances across different training datasets emphasise both dataset diversity and the quality of the model training. Distinct challenges were identified through the results; environmental conditions and data attributes affect detection accuracy. The models trained with one research site had a higher risk of overfitting, which could restrict their usefulness in different forest environments. In contrast, training different research site images, even those of inferior quality improved the robustness and generalisation of the models. The findings of this research suggest an emphasis on acquiring diverse, high-quality training data rather than complex feature engineering through vegetation indices. This research also highlighted the need for standardised data collection protocols and adaptive training methods. Future research should focus on refining segmentation algorithms, including adaptive thresholding techniques and alternative loss functions. Additionally, improving data collection methods and integrating multiple data sources should be enhanced to increase the quality of training datasets.

This study contributes to precision forestry by establishing a practical framework for automated weed detection in Eucalyptus stands. The performance of the best model demonstrates the potential of deep learning approaches in automated forestry applications, paving the way for robotic management systems, including weed detection and herbicide application.

Adapting Computer Vision Technologies for Measuring Plant Quality and Vitality at Sappi's Largest Commercial Nursery

Kabir Peerbhay[1,2], Markus Maresch[1],
1 – Sappi South Africa, Hilton, KwaZulu-Natal, South Africa.
2 – University of KwaZulu-Natal, South Africa.

Plant quality is a difficult parameter to objectively quantify and should take into account morphological, physiological and growth performance measurements. Sappi's plant quality index (PQI) provides for a reliable indicator of quality incorporating key plant phenotypic traits as well as the fitness and potential of an individual plant to survive when planted out in-field. Currently, the measuring capacity of nurseries are limited since PQI is a comprehensive manual measurement (i.e. plant height, diameters) that is time-consuming, subjective, and prone to human error, is an additional handling phase in the plant production cycle and most importantly, costly.

Measuring a typical batch of nursery trays (n = 100), each consisting of approximately 128 plant cuttings, could take about 4 labor units 2 hours to measure a sample of 0.2%. Using computer vision techniques, Sappi capitalized on the opportunity of measuring objects from normal RGB images and developed an in-house smart conveyor with a camera, to automatically detect these plant parameters (i.e. heights, stem diameters) including their variability. Results indicate better height predictions (R2 > 0.9) for Pine cuttings rather than Eucalyptus (R2 > 0.7), where stem width detections showed best results (R2 > 0.8) when compared to measured datasets. This system, a first of its kind, is now in operation at one of the biggest nurseries in the southern hemisphere, allowing a larger proportion of plants leaving the nursery to be measured, thus providing the business with confidence in production quality. The system ensures plants are dispatched at the best timing for increasing survival potential, decreasing blanking risk and promoting early growth performance of each planted tree (Figure 1).

Figure 1: Sappi's smart computer vision mechanical photobooth that can automatically measure plant quality in a commercial nursery.

Harnessing Near Infrared Spectroscopy for Advancing Smart Forest Management: Innovations and Applications

Ilaria Germishuizen[1],
1 – Institute for Commercial Forestry Research, Pietermaritzburg, South Africa.

Near Infrared (NIR) spectroscopy, paired with AI, offers valuable opportunities to improve plantation forest management and nursery operations by providing efficient screening tools for various applications. In disease management, NIR spectroscopy can facilitate pre-symptomatic disease screening by detecting pathogen DNA or biochemical changes induced by the pathogen before visible symptoms emerge. This early detection enables timely, selective interventions, helping to minimize disease spread, reduce pesticide use, and prevent yield loss. Additionally, NIR spectroscopy can be applied to assess key soil properties such as texture and organic carbon content, providing valuable information for optimizing plantation growth conditions, and evaluating the impact of forestry operations on these properties, ensuring their sustainability.

In nursery management, NIR can assist inaccurately identifying clones and supporting the correct labeling of production hedges, which is critical for maintaining genetic integrity and ensuring the correct deployment of germplasm from nursery to site. Furthermore, NIR spectroscopy can streamline processes such as seed vitality testing, reducing processing time and enhancing efficiency. The ICFR has been developing important tools for nursery and plantation management, with potentially high technology transfer uptake, based on both benchtop and portable NIR spectrometers.

By applying the Random forests algorithm, NIR spectroscopy predicted the presence of Uromycladium acaciae DNA, the pathogen causing wattle rust disease, with an R2 of 0.97. The pre-symptomatic pathogen detection iscritical for effective disease management, making DNA-based detection essential. The utility of NIR for discriminating clonal variety was tested on five Eucalyptus clones using spectra collected with both the benchtop and portable NIR spectrometers. Using the Partial Least Squares method, the benchtop model achieved a classification accuracy of 96%, while the portable spectrometer, used with fresh leaf material, requires further development and achieved an accuracy of 75%.

Nevertheless, both methods show potential as cost-effective options for bulk screening in commercial nurseries. Using Partial Least Squares, NIR spectra accurately predicted N and K content in Eucalyptus seedlings (R2 values of 93.6 and 91.3, respectively), while results for P were less accurate (R2 of 75.6). Further development is underway to expand these proof-of-concept studies through broader sampling strategies and more advanced modeling tools, preparing them for deployment at the operational level.

The versatility of NIR in these applications promises better-informed decision-making, increased productivity, and more sustainable, cost-effective forest management practices.

Stump to Mill: Leveraging UAV-Based Technologies for Precision Forestry Operations

Kegan Tasker[1],
1 – Sappi South Africa, Hilton, KwaZulu-Natal, South Africa.

This study explores the application of UAV-based technologies, including photogrammetry, thermal imaging, and LiDAR, to enhance key operational decisions and field assessments within commercial forestry. Photogrammetry, applied through a computer vision model trained for seedling detection, enables scalable monitoring of early crop stages to inform blanking decisions, ensuring timely replanting efforts across extensive forested areas. UAV-mounted thermal payloads support fire management operations by assisting with mop-up procedures along firebreaks and providing real-time visibility into fire intensity at the base, improving firefighting response and risk mitigation.

Additionally, UAV-based LiDAR is used to measure individual stem heights in commercial trials, with an observed 80% correlation between UAV and ground-based measurements across two trial sites, underscoring its accuracy for forestry applications and improving traditional field operations. Beyond the forest, UAV support is leveraged to assess stockpiles and monitor fugitive emissions at manufacturing plants, expanding UAV utility in forest product manufacturing. This multi-faceted approach demonstrates UAVs' potential in advancing precision forestry, fire safety, and industrial operations through innovative, data-driven insights.

Evaluation of Integrated Multi-satellite Retrievals for GPM (IMERG) in South African Forest Plantations

Noxolo Kheswa[1], Shruti Upadhyaya[2], Miranda Wilson[1],
1 – GIS Department, Mondi South Africa, Hilton, KwaZulu-Natal, South Africa.
2 – Cooperative Institute for Mesoscale Meteorological Studies, Norman, Oklahoma, United States.

The "precision forestry" principle encourages the use of advanced technologies and related products to gather extensive information, potentially increasing value through better forest management. These steps can help mitigate the uncertainties caused by pests and diseases, wildfires, and climate change. While there is a wealth of historical data on forest hydrology and extensive climate models, precisely capturing spatial and temporal precipitation patterns at the granular level remains challenging. The ground-based rain gauges give reliable, localized observations that may be insufficient for larger regions with varying terrain, as rainfall patterns can change dramatically across small areas owing to microclimate effects. Fortunately, recent advances in remote sensing have supported the collection of precipitation estimates, one of which is the Integrated Multi-satellite Retrievals for GPM(Global Precipitation Measurement). This is a unified satellite precipitation product produced by NASA to estimate surface precipitation using inter-calibrated estimates from an international constellation.

It provides global surface precipitation rates at a 0.1-degree precision with varying latency requirements. Although IMERG products are substantially validated for detecting global extreme precipitation events, application in South Africa lacks specific studies. This work examines the daily estimates from the IMERG Final Run (v07) alongside data from 29 automatic weather stations across 201 forest plantations of Mondi, spanning from 2020 to 2023. The analyses include point-to-pixel validation and contingency tables, while metrics such as Root Mean Square Error (RMSE), correlation coefficients (CC), and F1 score were computed against the ground-based measurements.

Results indicated averages of 7.33 RMSE, 0.62 CC, and a 0.72 F1 score, underlining IMERG's utility despite its tendency to underestimate the dry days while overestimating the wet ones. Notably, IMERG accurately estimated the days that received Very light, Light, and Moderate daily rainfall with categories based on the National Center for Hydrology and Meteorology(NCHM) standards. Another approach the study employed includes applying machine learning techniques to generate error-corrected IMERG precipitation products at a daily time scale. The results underscored the importance of incorporating additional variables, such as solar radiation, relative humidity, and temperature, to enhance its precipitation accuracy. We establish IMERG's potential to improve existing models with rainfall inputs while suggesting that errors and biases in the data can be corrected and adjusted to bolster its applicability in forestry. Finally, harnessing satellite data and integrating GIS tools empowers a nuanced approach to studies empowering more effective ways of addressing spatial and temporal unpredictability within ecosystems to enhance data-driven decision-making.

References

Bhuiyan, M.A.E.; Yang, F.; Biswas, N.K.; Rahat, S.H.; Neelam, T.J. (2020). Machine Learning-Based Error Modeling to Improve GPM IMERG Precipitation Product over the Brahmaputra River Basin. Forecasting 2020, 2, 248-266. https://doi.org/10.3390/forecast2030014

Choudhry, H.; Kelly, G.O. (2018). Precision Forestry: A Revolution in the Woods. McKinsey & Company. Available at: https://www.mckinsey.com/industries/packaging-and-paper/our-insights/precision-forestry-a-revolution-in-the-woods/ (Accessed: 29 April 2024).

Huffman, G.J.; Tan, J.; National Center for Atmospheric Research Staff (Eds). (2023). The Climate Data Guide: IMERG Precipitation Algorithm and the Global Precipitation Measurement (GPM) Mission. NCAR Climate Data Guide. Retrieved from https://climatedataguide.ucar.edu/climate-data/gpm-global-precipitation-measurement-mission on 16 May 2024.

Maranan, M.; Fink, A.H.; Knippertz, P.; Amekudzi, L.K.; Atiah, W.A.; Stengel, M. (2020). A Process-Based Validation of GPM IMERG and Its Sources Using a Mesoscale Rain Gauge Network in the West African Forest Zone. J. Hydrometeor. 21, 729-749.

Log Identification Using Computer Vision Techniques

James Kok[1], JP Van Der Merwe[1],
1 – York Timbers, Sabie, Mpumalanga, South Africa.

Computer vision, a subfield of artificial intelligence, has revolutionized the way we interpret and analyse visual data. By leveraging advanced algorithms, computer vision systems can automatically extract meaningful information from images and videos. One particularly impactful application is in forestry, including the utilization of artificial intelligence for log species detection and classification. Open-source software allows access to easy-to-use models such as YOLOv8 (You Only Look Once, version 8) and exemplifies the accessibility and power of modern computer vision techniques. YOLOv8, known for its real-time object detection capabilities, provides a streamlined solution for identifying specific species of logs. By processing images from a camera or dataset, YOLOv8 can quickly and accurately classify logs into species such as Pinus elliottii and Pinus patula and can potentially facilitate efficient inventory management and resource planning. Logs are classified according to bounding boxes, produced by the model. Furthermore, the log diameters can be determined by bounding boxes and specific species can be identified according to inherent log characteristics. The user-friendly interface of YOLOv8 makes it an ideal tool for forestry professionals seeking to harness the benefits of artificial intelligence without extensive technical expertise. This integration of computer vision with forestry operations promises to enhance productivity, accuracy, and sustainability in the management of forest resources. Furthermore, production constraints can be further characterised by determining the inherent quality of round logs processed in York's mills.

Holmström et al. (2023) aimed to use computer vision techniques to identify and classify logs using deep Convolutional Neural Networks (CNNs). Images containing logs of various lighting and aging effects were scrutinised. Their model was tested on an independent set of log images and achieved accuracies of 84% when log rotation was allowed and 91% when the log remained fixed. The study demonstrated that computer vision technology can be used to characterize log optical characteristics.

The results for an early version of the model indicate good precision results for the model, while recall can be improved. The Patula class is the highest performer in the recall, while the Tag class is the worst performer, Table 1.

Table 7: *Detection results per class*

Class	Images	Instances	P (Box)	R (Box)	P (Mask)	R (Mask)
All	10	42	100	86.11	100	86.11
Elliottii	10	6	100	83.33	100	83.33
Patula	10	16	100	94.45	100	94.45
Tag	10	20	100	79.16	100	79.16

The diameter predictions are made by taking the actual length of the tag and dividing it by the number of pixels making up the tag located on the log face (Figure 1). This ratio is the cm/pix ratio of the image which can then be scaled up to the diameter of the log, Figure 1.1.

References

Holmström, E. et al. (2023) 'Tree log identification using convolutional neural networks', Smart Agricultural Technology, 4, p. 100201.

Figure 1: Example of AI-based log species classification and diameter measurement using YOLOv8. The bounding boxes and labels indicate detected log species and their respective diameters.

Useful Information

Conference Venue

The **International Precision Forestry Symposium 2025** will take place from the **3rd to the 7th of February 2025** in **Stellenbosch, South Africa**. The meeting is supported by two divisions: **3.04 Forest Operations Management** and **3.10 Forest Robotics and Digital Forest Operations** of the **International Union of Forestry Research Organizations (IUFRO)**.

Additionally, the symposium has support from the **Southern African Institute of Forestry (SAIF)** and the **Department of Forest and Wood Product Science, Stellenbosch University**.

Conference Venue and Location

The **International Precision Forestry Symposium 2025** will take place at **Stellenbosch University**, with the primary venue being the **Paul Sauer Building**, located in **Stellenbosch Central**:

Paul Sauer Building, Stellenbosch University, 7599, South Africa
Google Maps Coordinates: **-33.9275, 18.867**

Due to electronic booms restricting parking access, the **Paul Sauer Building can only be approached from the south via Bosman Street**.

Internet Access

- **Eduroam:** Eduroam is available throughout the conference venues for attendees affiliated with institutions that support Eduroam.

How to Get to the Conference Venue

The **Paul Sauer Building** at Stellenbosch University is easily accessible by various modes of transportation. Below are estimated travel times and options from key locations:

From Cape Town International Airport (CPT)

- **By Taxi/Ride-hailing (Uber/Bolt):**

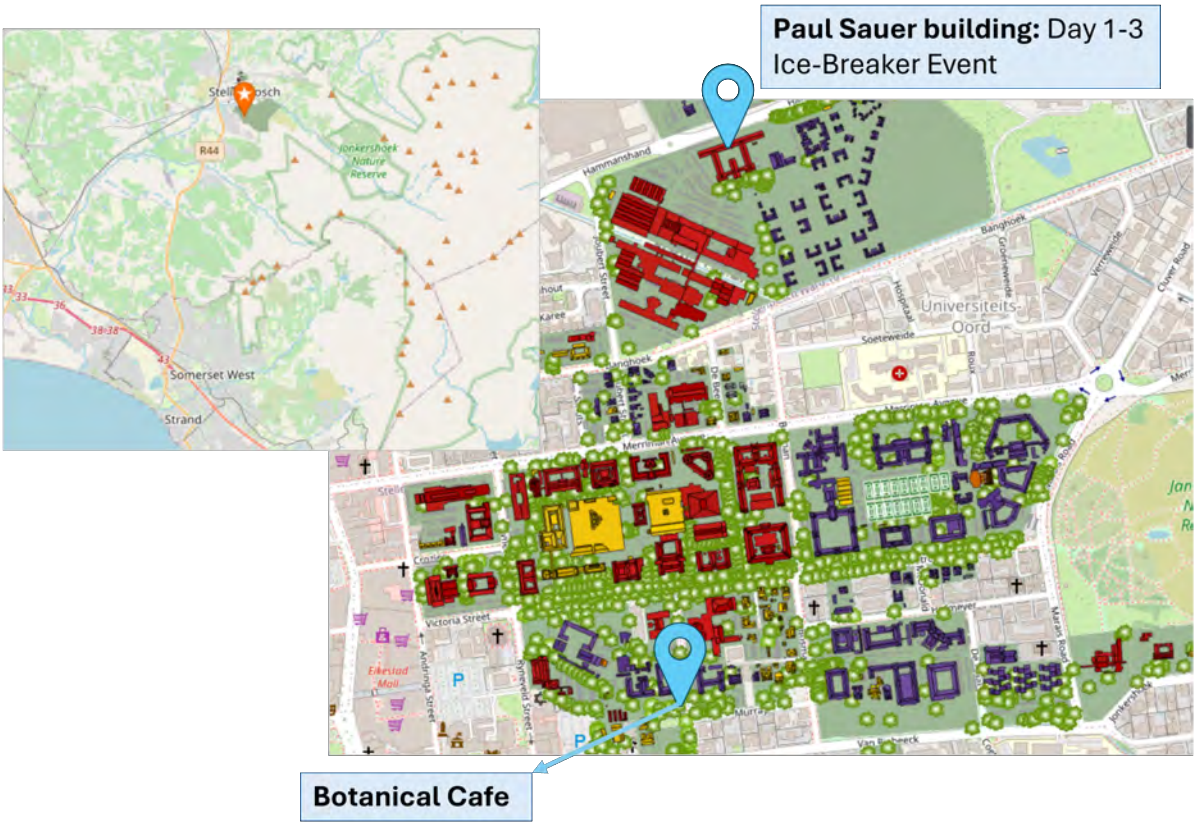


Figure 1: Conference venue locations at Stellenbosch University.

  - Approximate travel time: **30–40 minutes**
  - Estimated cost: **ZAR 350–450** ($20–25 USD)
- **By Rental Car:**
  - Driving distance: **40 km** (30 minutes via N2 and R310)

From Cape Town City Center

- **By Taxi/Uber:**
  - Approximate travel time: **45–60 minutes**
  - Estimated cost: **ZAR 450–600** ($25–35 USD)
- **By Rental Car:**
  - Driving distance: **50 km** (45 minutes via N1 and R304)

From Somerset West

- **By Taxi/Uber:**
  - Approximate travel time: **20–25 minutes**
  - Estimated cost: **ZAR 200–300** ($10–15 USD)

- **By Rental Car:**
  - Driving distance: **18 km** (20 minutes via R44)

From Stellenbosch Central

- **By Taxi/Uber:**
  - Approximate travel time: **5 minutes**
  - Estimated cost: **ZAR 50–100** ($3–5 USD)
- **By Walking:**
  - Walking distance: **1–1.5 km** (15–20 minutes)
  - The venue is accessible on foot from most accommodations in the town center.

Catering and Social Events

Coffee breaks and lunches will be served in the **Main Lobby and Courtyard**.

Excursion: A special excursion with lunch packs will take place at:

Delheim Estate, Knorhoek Rd, Stellenbosch, 7599 (16-minute drive from Stellenbosch)

Conference Dinner: The official conference dinner will be held at:

Botanical Café, inside Stellenbosch Botanical Gardens

It is a **20-minute walk** from the department or a **4-minute car ride**.

Date & Time: 6 February 2025, at 18:30.

Dinner Venue: Botanical Café (inside Stellenbosch Botanical Gardens) **Address:** Neethling & Van Riebeeck St, Stellenbosch, 7602

Local Transportation and Parking

- **Public Transport:** No formal public bus service in Stellenbosch; Uber and Bolt are recommended.
- **Car Rental:** Most international rental companies operate at Cape Town International Airport and in Stellenbosch.
- **Parking Restrictions:** Due to limited on-campus parking and electronic booms, visitors **must approach the Paul Sauer Building from the south via Bosman Street**.
- **Walking:** Many key locations, including restaurants, accommodations, and the conference dinner venue, are within walking distance.

FEBRUARY 3 - 7, 2025

Proceedings of the 5th International
Precision Forestry Symposium

Stellenbosch, South Africa

More info:
https://www.sun.ac.za/english/faculty/agri/forestry
https://saif.org.za/

ORGANIZED BY

SPONSORED BY