Krishna K. Pandey · V. Ramakantha
Shakti S. Chauhan · A.N. Arun Kumar
Editors

Wood is Good

Current Trends and Future Prospects in Wood Utilization

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Preface

Wood, with its unparalleled versatility, is a fabulous gift of nature. Having a wide range of applications, it has played an important role in the progress of human civilization. Greater technological innovations may further render wood as the single most important natural resource in the times to come. In the current scenario of global climate change, unlike any other non-renewable material, wood can be sustainably produced, processed, and converted into a range of products with the least of carbon footprints. Wood is Good.

Wood is a highly variable and complex material. The inherent variability in wood between species, within a species, and also within a tree poses challenges in its processing and utilization. Short-rotation plantation-grown timber has been further added to this challenge. In this backdrop, the Institute of Wood Science and Technology (IWST), Bengaluru, India, organized an international conference on "Wood is Good: Current Trends and Future Prospects in Wood Utilization" on November 21–23, 2014.

The Institute of Wood Science and Technology is a premier research institute under the aegis of Indian Council of Forestry Research and Education (ICFRE) of the Ministry of Environment, Forests and Climate Change, Government of India. With a specialized team of scientists, the institute has been carrying out frontier research in wood identification, processing, wood composites, wood modification, wood energy, wood quality, and tree improvement. The conference provided a platform to academicians, researchers, and industry professionals across the globe to present and discuss the recent innovations, trends, and future prospects. More than 100 research papers covering a wide range of topics were deliberated in the conference.

This book is a collection of selected papers presented during the conference. The papers are grouped in five major themes, namely wood properties and variability, wood protection, wood-based composites, wood utilization pattern, and wood and climate change.

We are thankful to the Ministry of Environment, Forests and Climate Change, Government of India, for the support rendered. We are grateful to the Director General, ICFRE, for his guidance and encouragement. We express our sincere

gratitude to all our colleagues at IWST for their immense help. We duly acknowledge the contribution of all the authors and reviewers.

Bengaluru, India

Krishna K. Pandey
V. Ramakantha
Shakti S. Chauhan
A.N. Arun Kumar

Contents

Part II Wood Protection

Part III Wood-Based Composites

About the Editors

Dr. Krishna K. Pandey is a senior scientist at the Institute of Wood Science and Technology, Bengaluru, India, having more than 30 years of research experience. He was postdoctoral researcher at Kyoto Institute of Technology, Japan; and senior researcher at Helsinki University of Technology, Finland. Dr. Pandey has published more than 50 papers in peer-reviewed journals. He is an elected fellow of International Academy of Wood Science and a recipient of National Award for Excellence in Forestry Research by the Indian Council of Forestry Research and Education, Government of India. Presently, he is a member of Environmental Effects Assessment Panel of UNEP.

Dr. V. Ramakantha was the Director of the Institute of Wood Science and Technology, Government of India, and he retired as Principal Chief Conservator of Forests, Manipur, India. He is well known in the fields of Forestry Research and Education, Wildlife Conservation, and *Ex-situ* Conservation of flora and fauna. As a prolific writer, he is an author for two books and has published several articles in peer-reviewed journals and magazines. He was the chairman of the Committee on National Strategy and Working Scheme for the Management of Red Sanders (*Pterocarpus santalinus*). Dr. Ramakantha is a fellow of the Society for Applied Biotechnology and a Guest Faculty in several reputed institutions in India. He has received international recognition in the field of wildlife photography.

Dr. Shakti S. Chauhan is a senior scientist at the Institute of Wood Science and Technology, Bengaluru, India, with more than 20 years of research experience. He was a Ph.D. scholar, postdoctoral researcher, and FAO fellow at University of Canterbury, Christchurch, New Zealand. Dr. Chauhan is recognised internationally for his work on wood quality assessment and wood polymer composites. He has published more than 50 papers in peer-reviewed journals and co-authored two books on wood science. He is a reviewer for several international journals in the field of wood and material science. He is a member, Committee for Timber Storage, Bureau of Indian Standards. Dr. Chauhan received Appreciation Award for his contribution in the field of wood technology, conferred by the Honourable Governor of Karnataka.

Dr. A.N. Arun Kumar is a senior scientist of the Institute of Wood Science and Technology, Bengaluru, India. Having research experience of more than two decades, he has published several articles in peer-reviewed international journals and has also been a reviewer for many high-impact journals on forestry. Dr. Arun has carried out pioneering research work on heartwood and oil variation in the Indian Sandalwood (*Santalum album*), the most valued tree species of India. His extensive research on growth and wood quality variability of several commercially important tree species such as *Pterocarpus santalinus, Chloroxylon swietenia, Hardwickia binata and Melia dubia* is a significant contribution in the field of tree improvement.

Part I
Wood Properties and Variability

Optimizing Wood Utilization Based on Whole Tree Inherent Property Maps

Mathew Leitch and Scott Miller

Abstract The forest industry is in a state of change currently in Canada. The past strengths of the industry have been a steady supply of high-quality lumber and paper products for over a century. More recently, as we move to second-growth forests and plantations, we are recognizing that wood properties have changed and are extremely variable across the landscape. To this end, the government of Ontario created a Forest Resource Inventory to better deal with the resource and supply a map of the resource to be used by industry in their management planning practices. This has lead government and industry to realize the inventory of basic parameters such as species composition and general heights which is not adequate in today's global economy and markets. Competition from other regions of the world has forced the industry in Canada to look at how we do business and how we can remain competitive in global markets with fast-growing southern hemisphere plantations of pines and eucalypts. In order to better utilize every stick of wood we cut, a better knowledge of the inherent wood properties for trees and whole landscapes is required. In addition, a method of collecting this information efficiently and cost-effectively is also required where data are collected and stored without losses or errors being introduced to the database system. This paper presents a method of both collecting the data accurately while bringing human error to a minimum and nondestructively lessening the cost of collecting the data. This method represents a new way of looking at inventory where inherent properties dictate the inventory and how we assess the forest across a landscape. We have shown that we can produce landscape property maps using a newly developed Wood Science App that both collects data in the field and controls it but also is linked to the information database in our laboratory eliminating the need for people to enter data. In addition, the App controls the testing equipment in the laboratories,

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which removes another level of potential error in the database system. The whole mapping system developed in the Lakehead University Wood Science & Testing Facility (LUWSTF) is designed to allow a better system both to test wood properties in the laboratories and also to collect field information in a nondestructive manner to map wood properties across the landscape. This will not only assist current industries in managing their forest resources but also act as a promotional tool for attracting new investment into the region.

Keywords 3D mapping · Eastern larch · Nondestructive testing · Wood properties · Wood utilization

Introduction

Where We Are Now

In 2013, the Canadian forest industry contributed $19.8 billion to Canada's GDP and directly employed 216, 500 people (Natural Resources Canada 2014). The forest industry in Canada and many parts of the world has been struggling for the last several years due to the global down turn that occurred in around 2004–2008 (Ontario Ministry of Natural Resources 2012). The forest sector in Canada was particularly hard hit due to the sudden down turn in the US housing market, where the USA also represents roughly 80% of the export market for Canadian forest exports (Industry Canada 2009). It was clearly realized in Canada that we needed to look at the industry as a whole and begin making some changes. One of the changes seen as a means of protecting the industry from such a severe financial hit is to make the industry more competitive and expand to diversify the industry so we are not so dependent on commodity products such as sawn lumber and pulp. This is particularly important when you look at the changes in the operating surplus of the wood products industry sector in Ontario that was at $1.9 billion in 2004 and at $808 million by 2008 (Ontario Ministry of Natural resources 2012). During this same period, investment into the industry dropped from $1.2 billion to $857 million (Ontario Ministry of Natural resources 2012). In order to move from a commodity-based industry in Northern Ontario where lumber and pulp and paper are the mainstays to a more diversified industry including secondary processing such as value-adding industries and industries working in the bio-economy, more detailed information about the resource is required. The value-added sector in Ontario was worth $12.2 billion in 2004 and $9.1 billion in 2008 (Ontario Ministry of Natural resources 2012). Much of this capacity is located in the Southern reaches of the province while much of the Northern part of the province is commodity-based.

The current industry relies on the provincial Forest Resource Inventory to manage the parcel of land (forest tenure license) to supply their mills. This inventory is now seen as insufficient and inaccurate to allow industry to maximize its efficiency and competitiveness. This is particularly important as Ontario alone has 72 million hectares of forestland, which makes up 16% of Canada's forest (Ontario Ministry of Natural Resources (OMNR) 2009). Many studies have looked at the competitiveness of our lumber industries (Nautiyal and Singh 1985; Constantino and Townsend 1986); however, no one has looked at increasing competitiveness through improving the inventory to increase efficiency and therefore competitiveness. The Ontario Wood Supply Strategy has identified "Quality of Wood Supply Information" as one of two issues that need to be addressed, with improving the forest inventory and increasing utilization of available wood as two means of fixing this issue (OMNR 2004). This report also encourages integration between mills, which is also an idea that lends itself to the research presented here where collaboration between mills combined with better information about the resource will increase productivity, efficiency, profits, and competitiveness.

Where We Need to Be

In order to improve our knowledge of the inventory, the LUWSTF at Lakehead University began a whole-tree-mapping program in 2007 where initially under-valued commercial tree species were studied and their inherent properties mapped on the ecosites across the landscape where they are present (Miller et al. 2013). This program led to an expansion where we included the main commercially harvested trees that were more relevant to industry. Once we began this process, we realized many inefficiencies in the whole resource inventory system that needed attention. In order to complete our intensive tree and landscape property maps, we needed to address issues such as field data collections, data transfer, data storage and data retrieval, essentially data management optimization (DMO). This issue lead to a new project to develop a Wood Science App to collect and control data both in the field and in the laboratory. This then led to the requirement of a data management system in the laboratories that worked with the field system. Finally, a system was required to allow using the data and sharing it easily across networks.

The remainder of this paper will discuss mapping tree properties; evidence of the value in mapping tree properties; Wood Science App and data management system; data sharing and reporting; and landscape wood property maps.

How We Get There

The goal of this research was to create a database that stored all pertinent information required to maximize the utilization of species across the landscape and to ensure the best and highest value product could be produced. In addition, the goal was to create landscape maps to identify where a species grew across the landscape and how its properties varied based on site conditions (i.e., ecosites). This led to an issue in the industry and research field, which was how to deal with large amounts of data. This is a particularly difficult issue as most field work involves field notes or tablets that eventually have to be re-entered into a database by hand or some sort of transfer of data. This is fine as long as the person inputting the data is taking care to be accurate, but also requires that the data collected in the field are also accurate. This is an issue everywhere where data are collected and then require someone to move it to another storage place, such as a database system. Then of course is how you control the data in a database so it is accessible easily and quickly.

Our approach to solving these issues of property mapping, large amounts of data and how to use our resources was to incorporate all levels into one system where field collections, material processing, testing and then data analysis, and storage are all controlled in a similar manner using one system.

Mapping Tree Properties

Mapping inherent tree properties is an area that is growing in order for countries to better utilize the forest resources they have and to encourage new investment by being able to display not only the inventory from the point of view of species and volumes but also to display the wood quality expected across landscapes. To accomplish this is an incredible undertaking in a country like Canada that is expansive with many different forest types (Natural Resources Canada 2014). The LUWSTF began a whole tree inherent property-mapping program in 2007 to increase the opportunities for under-valued commercial species in Northern Ontario, Canada. This program began as a destructive tree-harvesting program to gain the inherent properties we required to map the species at the tree level and at the landscape level (Miller et al. 2012; Leitch et al. 2012). This required a shift in how we measure tree properties to include defects as well as all parts of the tree (radially and axially) instead of the traditional standards tests that had samples collected in the N, S, E, W azimuth directions at breast height. Figure 1 displays the quadrant sample labeling system where all parts of the stem are tested radially and axially using this quadrant system. This intensive destructive system requires at least 3 large trees are collected from each ecosite across the landscape. Figure 2 displays the level of measurements used in destructive sampling to create whole tree property maps (Miller 2010).

The importance of mapping properties is becoming more important as global competition increases and countries realize that utilizing the forest resources they have should include maximizing value, which can be attained through understanding the resource, its properties and how they can best be utilized in industry.

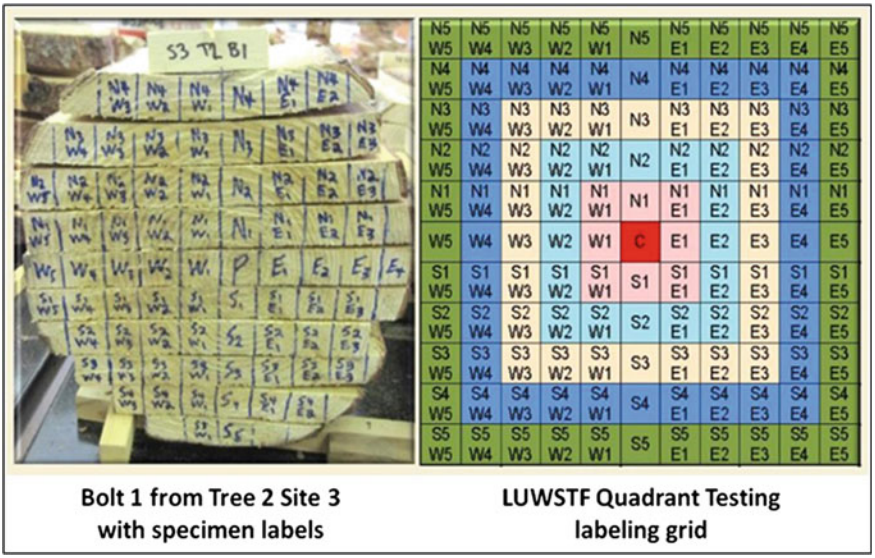


Fig. 1 Quadrant system for labeling sample logs for mapping tree properties developed in the LUWSTF

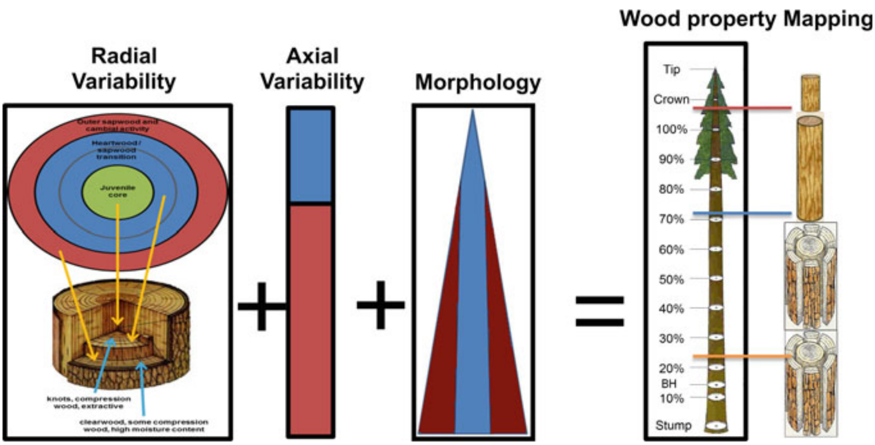


Fig. 2 Tree property maps include radial and axial variability plus morphology to create wood property maps

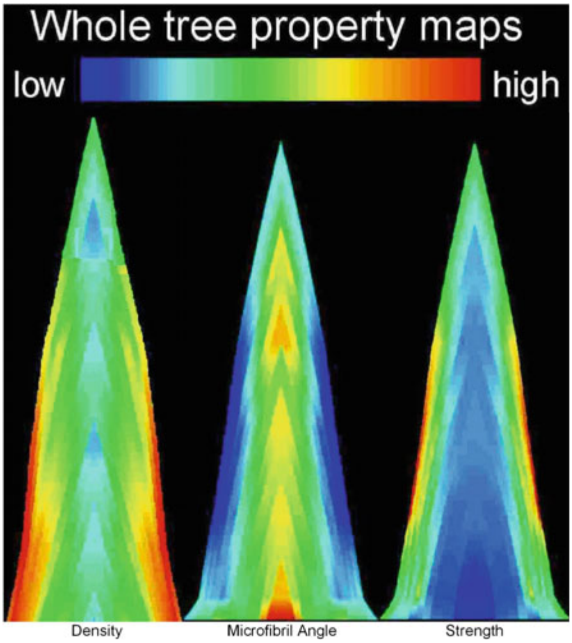


Fig. 3 Property maps of eastern larch for density, microfibril angle, and strength radially and axially in the stem on one of the ecosites larch grows on

Studies looking at aspects of wood properties within trees are present in the literature (i.e., Wilhelsson et al. 2012; Torquato et al. 2014, Cortini et al. 2011; Lessard et al. 2014; Xiang et al. 2014). Many, however, look at individual trees or one location, few look at landscape mapping of tree/wood properties (Lessard et al. 2014).

In the LUWSTF, we began mapping individual trees for each ecosite at the start of this program and have developed new ways to use this information to create landscape property maps. Figure 3 displays some tree maps for a particular property on one of the ecosites where eastern Larch grows in Northwestern Ontario (Miller 2010). These maps for individual trees are the bases for our landscape property-mapping program. Following these studies is also when data control was recognized as an issue and led to our data storage and handling systems.

Evidence of the Value in Mapping Tree Properties

We have shown clearly in an initial study that by recognizing the inherent properties of a tree and sending the appropriate parts of that tree to the right processing facility, the value of every tree cut can be increased by up to as much as 25–30% (Fig. 4; Leitch et al. 2011). On a landscape scale, these can amount to huge

Model 1 Value (CAD $/ha)					
Section	Log 1	Log 2	Log 3	Other Vol	Total
Whole tree log	19,944	8,582	1,810	29	30,363

Model 2 Value (CAD $/ha)					
Section	Log 1	Log 2	Log 3	Other Vol	Total
A	1,454	581	113	0	2,148
B	4,363	1,743	339	0	6,445
C	8,362	3,228	636	0	12,226
D	11,707	4,519	891	0	17,117
Other	0	0	0	120	120
Total	25,885	10,072	1,979	120	38,056

Whole tree	30363.702	Model 1
Section all	38,056.22	Model 2
% Change	25.33	

Fig. 4 Buck optimization software to display how sending logs to the right mill to optimize value creates an increase in value of the tree over traditional methods of milling

increases in the value of every tree cut and processed; however, it does require mills to integrate and cooperate with respect to resource sharing.

Wood Science App and Data Management

The LUWSTF has developed a data storage and handling system that allows easy transfer of all field data and laboratory-produced data to be transferred and stored easily and efficiently with little opportunity for human error.

LUWSTF and Central Computer Services Inc. (CCS) developed the Wood Science Data Management Application (WS App.), Lakehead University Natural Resource Management Network-Assisted Storage (LUNRM-NAS), Wood Science Intranet (lacie) and Lakehead University Forest Resource Analysis Database (LU-FRAD), to assist in the management and analysis of forest resource inventory data. LUNRM-NAS and lacie provide the infrastructure for data management of LU-FRAD, from data capture and storage to data sharing and collaboration through web-based ftp and cloud functions.

The Forest Resource Analysis Database (FRAD) initiative strives to develop technologies and processes which will assist resource managers, manufactures, communities, and government agencies to identify opportunities to increase the value of the forest resource and forest products.

The WS App. is a database program, which provides the interface for data collection, manipulation, analysis, storage, and reporting. Field collection activities are completed using the WS App. on computer tablets, which are then uploaded to lacie when wood samples are brought to LUWSTF for testing. Lacie then allows the WS App. to import test data directly from test equipment so that the continuity of merging field data with the corresponding destructive testing results is assured. Once data collection has been completed, the WS App. transfers the project database to LU-FRAD for all further activities.

In addition to wood properties mapping of standing timber, the WS App. links forest products testing to forest inventory, thus allowing for cost–benefit analysis of forest products optimization and end-use prediction testing. The functionality of the WS App. and the adaptability of the program were tested in the summer of 2013 in partnership with industry and other agencies. The results of these studies are currently being published.

The NAS/lacie system for storage is a system where by the data collected in the field or laboratories through the WS App. are processed and stored in the NAS. An intranet with WiFi was established as the backbone of the data storage system. Lacie is a central electronic storage devise needed to allow automatic data export from multiple testing machines in the laboratories to the central data storage system (LU-FRAD).

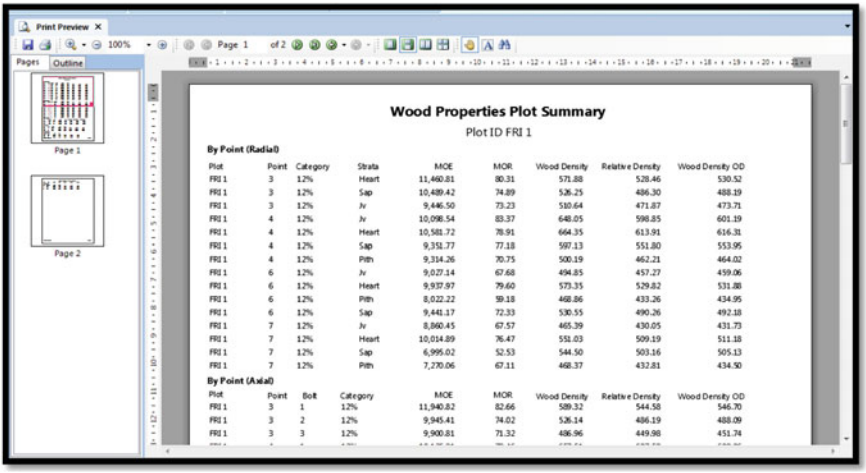
The data in the NAS are then accessible to anyone who is registered and has access to this system. All research partners have a secure folder specific to them on the NAS and can access it anywhere in the world from a computer. The WS App. has been Beta-tested on 6 projects so far, and all test partners have a folder on the NAS to access and move data around. The LU-FRAD system is therefore able to take captured data from the NAS and create 3D models of the forest resource with customized label metrics. Gerema Software, which is embedded into the WS App., is a tool that is used for reporting and query functions. It is able to set modeling attributes like product design criteria for resource optimization and end-use forecasting as well as follow changes in the resource from standing timber through to processing and finished products. The LU-FRAD can also produce landscape maps for land-use planning activities and total resource optimization including abilities to integrate management of both timber and nontimber products and services. An additional ability of the WS App. is that it can upload other laboratories/agencies databases, point cloud data, any comma or tab delimitation data for incorporation into LU-FRAD. The system is also designed to allow expansion into other fields of research. For example, the WS App. can be used to create data for optimization studies and valuation studies using 3D optimization software allowing estimations of standing forest values and lumber volumes per grade; using maps for attracting investment; fiber property maps for pulp and rayon mills; advancing the forest resource inventory; product development and resource monitoring to name a few.

Data Sharing and Reporting

The NAS is a powerful tool for data sharing, and the WS App. and LU-FRAD are powerful tools for dealing with data and creating reports. Sharing data securely is a top priority in research and with partners. The NAS allows partners to be able to go online and access a secure folder in the NAS specific to the partner to either place information in the folder or take information we have put there. Each partner has a specific password to gain access to their folder. This is particularly useful for these types of studies where data files can be very large and greater than email systems allow, the NAS has a 3-terabyte capacity to move data so size is not an issue.

The reporting functions of the App allow for very specific reports to be produced from the entire database or whole file reports. Reports incorporate standard methodologies for reporting, for example, site quality, harvestable timber volume, and wood product grades and are all based on legally defendable statistical methods. An example of a Standard Report could be a Wood Properties Plot Summary as shown in Fig. 5. Query reporting allows a more focused search of the data to suit report needs specifically from a large database (Fig. 6). Tabular export is a reporting function that allows simple access and transfer of raw data (Fig. 7).

In addition to these functions, the WS App. can mine every study within LU-FRAD for data. For example, we can make a query that tells the WS App. to incorporate the following studies or all studies for site attributes or tree height and



Wood Properties Plot Summary

Plot ID FRI 1

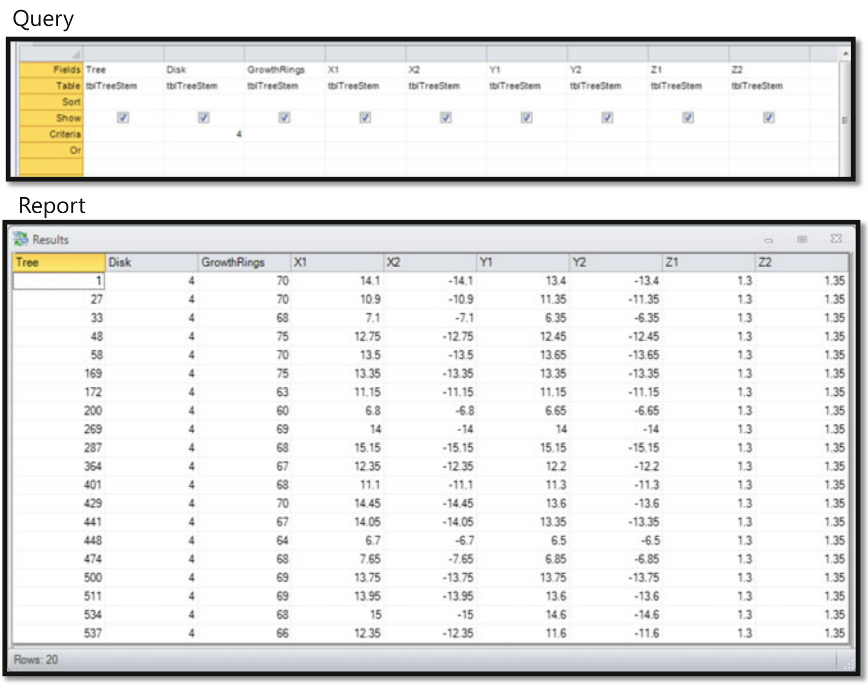
By Point (Radial)

Plot	Point	Category	Strata	MOE	MOR	Wood Density	Relative Density	Wood Density OD
FRI 1	3	12%	Heart	11,460.81	80.31	571.88	528.46	530.52
FRI 1	3	12%	Sap	10,489.42	74.89	526.25	486.30	488.19
FRI 1	3	12%	Jv	9,446.50	73.23	510.64	471.87	473.71
FRI 1	4	12%	Jv	10,098.54	83.37	648.05	598.85	601.19
FRI 1	4	12%	Heart	10,581.72	78.91	664.35	613.91	616.31
FRI 1	4	12%	Sap	9,351.77	77.18	597.13	551.80	553.95
FRI 1	4	12%	Pith	9,314.26	70.75	500.19	462.21	464.02
FRI 1	6	12%	Jv	9,027.14	67.68	494.85	457.27	459.06
FRI 1	6	12%	Heart	9,937.97	79.60	573.35	529.82	531.88
FRI 1	6	12%	Pith	8,022.22	59.18	468.86	433.26	434.95
FRI 1	6	12%	Sap	9,441.17	72.33	530.55	490.26	492.18
FRI 1	7	12%	Jv	8,860.45	67.57	465.39	430.05	431.73
FRI 1	7	12%	Heart	10,014.89	76.47	551.03	509.19	511.18
FRI 1	7	12%	Sap	6,995.02	52.53	544.50	503.16	505.13
FRI 1	7	12%	Pith	7,270.06	67.11	468.37	432.81	434.50

By Point (Axial)

Plot	Point	Bolt	Category	MOE	MOR	Wood Density	Relative Density	Wood Density OD
FRI 1	3	1	12%	11,940.82	82.66	589.32	544.58	546.70
FRI 1	3	2	12%	9,945.41	74.02	526.14	486.19	488.09
FRI 1	3	3	12%	9,900.81	71.32	486.96	449.98	451.74

Fig. 5 Example of a standard report produced from LU-FRAD



Query

Fields	Tree	Disk	GrowthRings	X1	X2	Y1	Y2	Z1	Z2
Table	tblTreeStem	tblTreeStem	tblTreeStem	tblTreeStem	tblTreeStem	tblTreeStem	tblTreeStem	tblTreeStem	tblTreeStem
Sort									
Show	☑	☑	☑	☑	☑	☑	☑	☑	☑
Criteria		4							
Or									

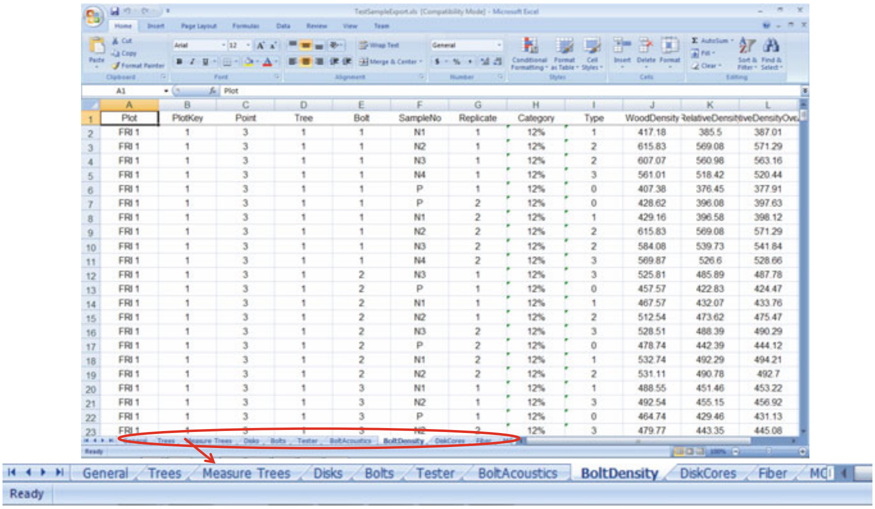
Report

Results

Tree	Disk	GrowthRings	X1	X2	Y1	Y2	Z1	Z2
1	4	70	14.1	-14.1	13.4	-13.4	1.3	1.35
27	4	70	10.9	-10.9	11.35	-11.35	1.3	1.35
33	4	68	7.1	-7.1	6.35	-6.35	1.3	1.35
48	4	75	12.75	-12.75	12.45	-12.45	1.3	1.35
58	4	70	13.5	-13.5	13.65	-13.65	1.3	1.35
169	4	75	13.35	-13.35	13.35	-13.35	1.3	1.35
172	4	63	11.15	-11.15	11.15	-11.15	1.3	1.35
200	4	60	6.8	-6.8	6.65	-6.65	1.3	1.35
269	4	69	14	-14	14	-14	1.3	1.35
287	4	68	15.15	-15.15	15.15	-15.15	1.3	1.35
364	4	67	12.35	-12.35	12.2	-12.2	1.3	1.35
401	4	68	11.1	-11.1	11.3	-11.3	1.3	1.35
429	4	70	14.45	-14.45	13.6	-13.6	1.3	1.35
441	4	67	14.05	-14.05	13.35	-13.35	1.3	1.35
448	4	64	6.7	-6.7	6.5	-6.5	1.3	1.35
474	4	68	7.65	-7.65	6.85	-6.85	1.3	1.35
500	4	69	13.75	-13.75	13.75	-13.75	1.3	1.35
511	4	69	13.95	-13.95	13.6	-13.6	1.3	1.35
534	4	68	15	-15	14.6	-14.6	1.3	1.35
537	4	66	12.35	-12.35	11.6	-11.6	1.3	1.35

Rows: 20

Fig. 6 Example of a query and subsequent report produced from LU-FRAD



	A	B	C	D	E	F	G	H	I	J	K	L
1	Plot	PlotKey	Point	Tree	Bolt	SampleNo	Replicate	Category	Type	WoodDensity	RelativeDensi	tiveDensityOve
2	FRI 1	1	3	1	1	N1	1	12%	1	417.18	385.5	387.01
3	FRI 1	1	3	1	1	N2	1	12%	2	615.83	569.08	571.29
4	FRI 1	1	3	1	1	N3	1	12%	2	607.07	560.98	563.16
5	FRI 1	1	3	1	1	N4	1	12%	3	561.01	518.42	520.44
6	FRI 1	1	3	1	1	P	1	12%	0	407.38	376.45	377.91
7	FRI 1	1	3	1	1	P	2	12%	0	428.62	396.08	397.63
8	FRI 1	1	3	1	1	N1	2	12%	1	429.16	396.58	398.12
9	FRI 1	1	3	1	1	N2	2	12%	2	615.83	569.08	571.29
10	FRI 1	1	3	1	1	N3	2	12%	2	584.08	539.73	541.84
11	FRI 1	1	3	1	1	N4	2	12%	3	569.87	526.6	528.66
12	FRI 1	1	3	1	2	N3	1	12%	3	525.81	485.89	487.78
13	FRI 1	1	3	1	2	P	1	12%	0	457.57	422.83	424.47
14	FRI 1	1	3	1	2	N1	1	12%	1	467.57	432.07	433.76
15	FRI 1	1	3	1	2	N2	1	12%	2	512.54	473.62	475.47
16	FRI 1	1	3	1	2	N3	2	12%	3	528.51	488.39	490.29
17	FRI 1	1	3	1	2	P	2	12%	0	478.74	442.39	444.12
18	FRI 1	1	3	1	2	N1	2	12%	1	532.74	492.29	494.21
19	FRI 1	1	3	1	2	N2	2	12%	2	531.11	490.78	492.7
20	FRI 1	1	3	1	3	N1	1	12%	1	488.55	451.46	453.22
21	FRI 1	1	3	1	3	N2	1	12%	3	492.54	455.15	456.92
22	FRI 1	1	3	1	3	P	1	12%	0	464.74	429.46	431.13
23	FRI 1	1	3	1	3	N2	2	12%	3	479.77	443.35	445.08

Fig. 7 Example of a tabular export for transfer of raw data from LU-FRAD

diameter and report on the findings by ecosite and/or species, making LU-FRAD a growing mega database over time.

Landscape Wood Property Maps

The final landscape wood property maps display the properties of the trees individually as well as across the landscape. Figure 8 displays a simple tree map with the attributes juvenile and mature wood zones marked on it. This is a 3D map that is fully controllable on a computer where it can be rotated to look at the stem features from any angle. Figure 9 displays a map created in ArcMap that displays the variability of specific gravity in Eastern Larch in Northwestern Ontario. At a stand level, there will be some variation; however, it is very apparent the average specific gravity of the species varies significantly across the landscape. More studies have looked at tree properties (Morrow et al. 2013; Bendtsen and Senft 1986; Duchesne 2006; Mvolo et al. 2015), how to rapidly measure properties (Evans et al. 1995) and

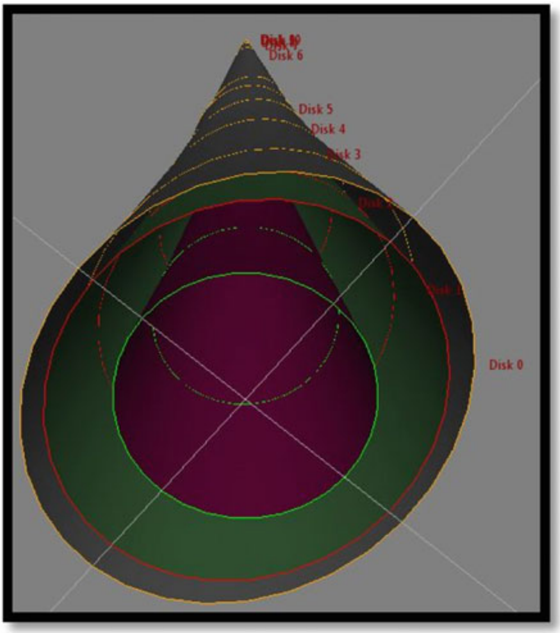


Fig. 8 3D mapping of wood properties showing the juvenile core and the outer mature wood on a measured tree

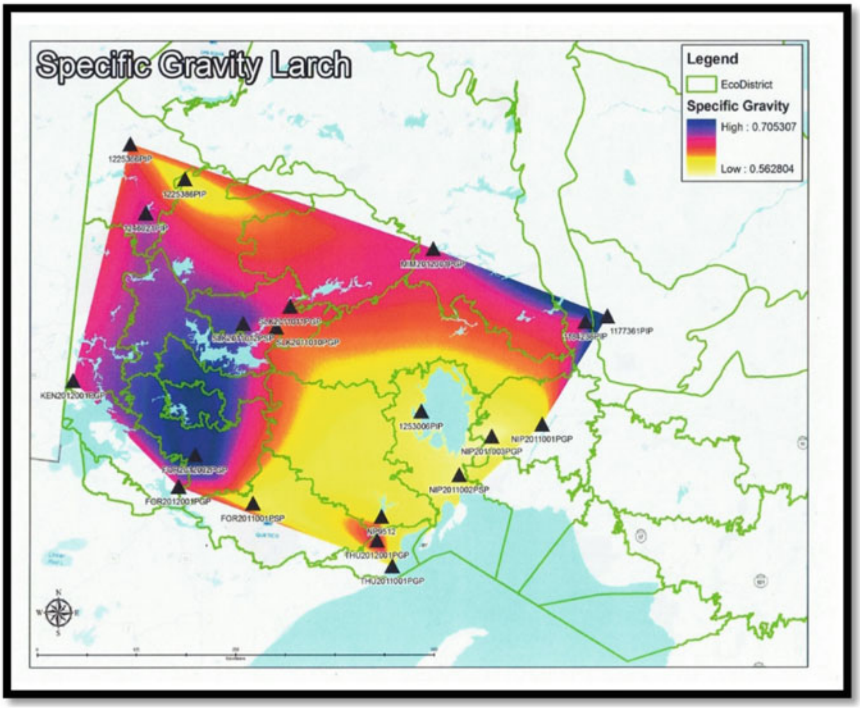


Fig. 9 Map for Eastern Larch specific gravity showing the variation across the landscape in Northwestern Ontario

how to use this to optimize utilization (Lundqvist 2001); however, none look at the landscape level and at the intensity of our data collection system. The full landscape maps will look like Fig. 10 where polygons of stands with the same properties will be identified and labeled with the lumber grades that are found on that site. Figure 10a is a polygon created using the existing Forest Resource Inventory where a large area has been identified as one polygon. When you look at Fig. 10b, it can be seen that through intensive landscape property mapping using our WS App., more detail about the resource becomes apparent where a once single polygon has become 3 polygons of very different wood properties.

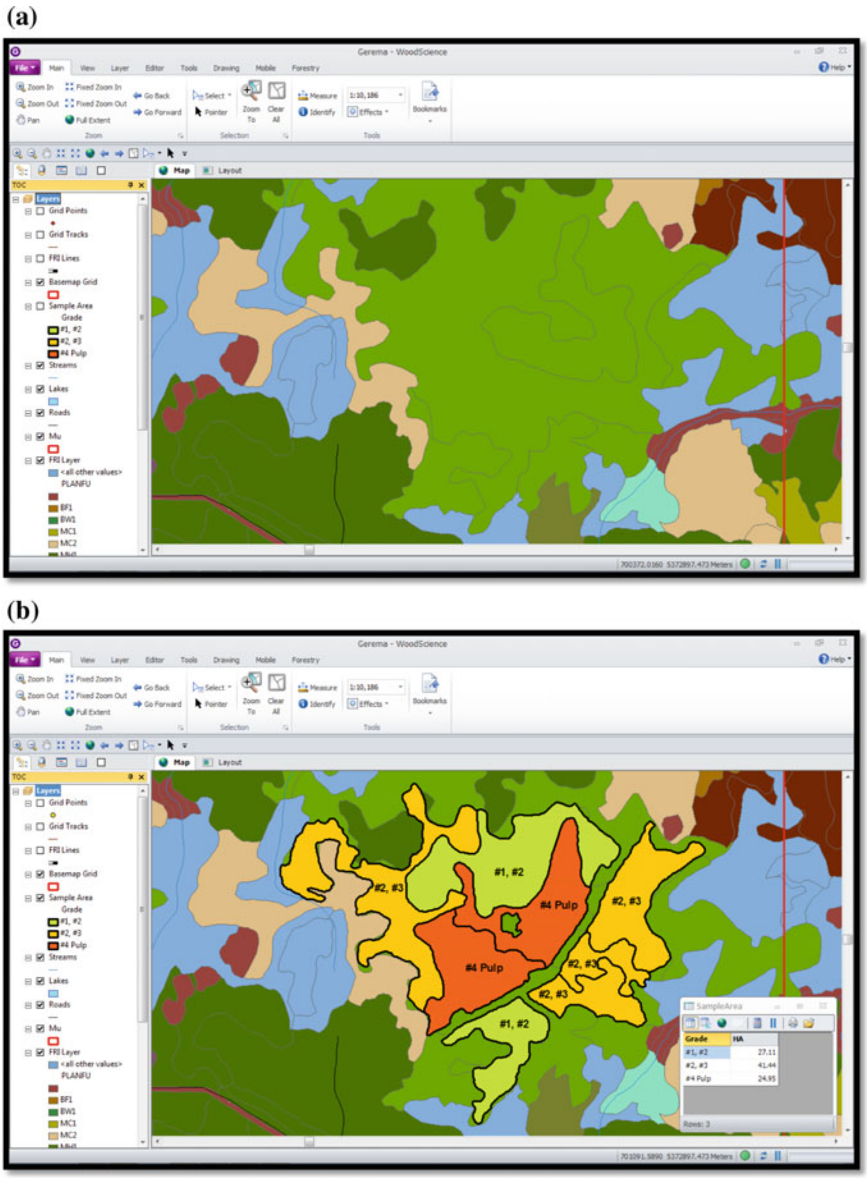


Fig. 10 Landscape map of **a** traditional inventory where the block is classified as one type, and **b** our mapping based on wood properties and re-labeling based on NLGA lumber Grades

Conclusions

The LUWSTF has developed a very efficient system of collecting, controlling, and creating reports for resource inventory research. The system eliminates many issues that exist in research where field and laboratory work create huge data files that need to be put in a storage system that allows easy entry of data and easy recovery of that data for further research or reporting. The LUWSTF Wood Science App, LU-FRAD, and the LU-NAS all combine and work together to allow this efficient system to control data. The opportunities in the forest resource inventory area are enormous both for government to have a good description of the forest resource including wood quality and also for industry to more effectively manage their holdings and react to market demand more efficiently. The ability to recognize where the wood quality varies across the landscape is very useful to allow Canadian producers to be more competitive in a global market where time to meet market demand is critical. In addition, other opportunities to utilize this system are many and the commercialization of our Wood Science App will hopefully help others in their activities.

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Screening Corewood of Pine for Wood Properties

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Abstract Conventional breeding requires long breeding cycles which limits selection intensity due to large tree sizes and high costs associated with assessing properties. In contrast very early selection offers a short cycle and assesses corewood which is the poorest wood in the tree. Young *Pinus radiata* trees were deliberately leant to produce separately opposite wood (OW) and compression wood (CW). The two distinct wood types were evaluated for dynamic modulus of elasticity, basic density, longitudinal shrinkage and volumetric shrinkage. A subset was also characterised for microfibril angle and mechanical properties using dynamic mechanical analyser to understand property–structure relationships in OW and CW. The wood properties of the two wood types differ significantly. We observed, for example, higher stiffness and density of CW which implies that selection in a nominally vertical stem would inadvertently result in a biased selection in favour of trees that happened to have abundant CW. This is avoided by focusing on the properties of OW in leant stems.

Keywords Radiata pine · Early selection · Compression wood and opposite wood

Introduction

Conventional tree breeding of radiata pine examines the wood quality in 8–11-year-old trees. Ostensibly this is desired as it gives a high age–age correlation between properties at selection age and at the harvest age. However, outerwood properties are of little concern. Apiolaza et al. (2013) argued that the main problem in radiata pine is the high per cent of poor-quality corewood, formed in the first 5–10 growth rings. Corewood has undesirable properties such as low basic density, high

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