The AWARE Project:

Overview and Outcomes

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University of British Columbia

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Canada’s Forest Sector

- 90% Public forest land owned by provinces and territories
- 4% Public forest land owned by federal government: national parks, Department of National Defence land and Aboriginal land
- 6% Privately owned forest land

http://www.nrcan.gc.ca/forests/canada/ownership/17495
Canadian Forest Sector

• Industrial Forest Companies and both Provincial and Federal forestry agencies also key roles in forest management decisions under legislation and for public oversight

• As a result industrial companies, provincial and federal agencies have a history of working together to improve forest inventory and Canadian competitiveness
Forest Inventory in Canada occurs at a range of scales from strategic broad scale assessments to operational inventories driving daily decisions.
The Use of Remote Sensing in Forestry Inventory

• Has a long and well established theory in which Canada is recognized as a leader
• Conventionally, 2 or 3 stage sampling approaches has relied on aerial photography as the spatial base however has some issues:
  – Manually intensive
  – Difficult to scale
  – Static representation of the forest resource
• Which is being pulled way beyond its original intent
## Appendix 1

### Table A-1. VegCAP Contents and Relationships to Oracle Tables

Fields are listed alphabetically

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Advanced Remote Sensing

- Light Detection and Ranging (LiDAR) is a relatively new technology which is being actively adopted by forest companies / agencies globally.

- Can we acquired from the ground, plane or satellite. Aircraft most common – known as Airborne laser scanning (ALS).

- In addition, high spatial resolution imagery, acquired from satellite, aircraft, or drones is also being processed in such a way as to allow 3D representation of forest information.
LIDAR / ALS

• Precise GPS location of aircraft required \((x_p, y_p, z_p)\)
• Precise inertial measurement unit (IMU) of aircraft required (pitch, roll, and yaw)
Digital Aerial Photogrammetry

- Digital manipulation of many aerial imagers with high degree of overlap to produce a 3D point cloud
- Images can be from existing aerial campaigns or drones
Some Early Canadian Successes

• Demonstration of LIDAR Applications for forestry with the forest industry in Ontario and Alberta amongst others
• Wet Area Mapping initiative using large areas of LIDAR coverage in Alberta
In 2010/11 the Federal Government Research agency (NSERC) with advice from the Canadian Wood Fiber Centre / Canadian Forest Service and FP-Innovations indicted advanced remote sensing of wood properties a research priority.
AWARE

AWARE = **Assessment of Wood Attributes from Remote Sensing**

NSERC Collaborative Research and Development 5 year project

Collaboration between Industry and Universities with Provincial / Federal support

In 5\textsuperscript{th} year.
Theme 1: What is the relative impact of ecological drivers such as disturbance, productivity, management practices, and species composition on broad-scale variations in stand structure and wood properties across Canadian forests and how can these be scaled up regionally?
Theme 2: How can advanced remote sensing technologies improve stand-level attribute estimation for strategic forest management?

New Structural Metrics for Forest Stand Descriptions

Predictive Modeling for ecological site classification, habitat and forest health

Hydrological Mapping and Productivity

Growth Rate

What new LiDAR stand structure metrics can be linked to stem characteristics such as lumber grade and log size class?

How well do LiDAR metrics developed in the Eastern mixedwood boreal forests transfer to Western Boreal forest types?

What LiDAR metrics can be derived from full waveform and discrete airborne data and what is their transferability across sites?

How can LiDAR be used to improve pre-harvest ground verification approaches and assess optimum year of thinning?

How can ALS LiDAR be used to assess product mix based on stem class distribution in pine dominated stands?

How can structural metrics from LiDAR of tree crown or stand canopies be used to predict wood fibre properties?

What hydrologic indicators can be derived from a LiDAR-Dem to support land classification schemes relevant for forest management?

How can LiDAR terrain indices be combined with structural and climate data to derive new productivity/site classification schemes?

How can SGM techniques be used, when paired with existing LiDAR terrain models, to predict forest stand growth?

How can multi-temporal LiDAR be used to predict height growth and linked into growth and yield models?

Can we improve forest growth projections with LiDAR-enhanced forest inventory data?

What is the impact of changing site conditions on timber and wood fibre quality over time?

How can airborne LiDAR and optical imagery be used to augment conventional forest health surveys?

What is the best approach to map new “value-based” forest attributes combining conventional forest inventory and LiDAR data?

What landscape level ecosystem goods and service values can be developed with airborne LiDAR data?

How can forest attributes derived from multi-resolution remote sensing data be used to conduct habitat assessment?
Theme 3: What individual tree attributes can be accurately measured from ground-based LiDAR and how can this data be used to scale-up and validate stand level assessments?
Cross-Cutting Theme: Data Acquisition, Modelling, Standards, and Development of Generic Transferable Tools

- How can LiDAR be used in combination with imagery to predict species groups and/or individual species?
- Does contextual data provide additional predictive power to species models?
- How generalizable are methods of species prediction across additional core sites?
- Can UAV technologies provide consistent and accurate remote sensing data for enhanced forest inventory?
- What demonstration datasets, and best practice guidelines can be developed to ensure results from AWARE are well communicated to the industry?
Kaysandra Waldron (Laval)

STRUCTURE AS A DRIVER OF WOOD PROPERTIES
Fire as a driver of stand structure

Stand initiation → Stem exclusion → Understory reinitialisation → Old-growth

Time since the last severe disturbance

Adapted from Bergeron et al. 2002
Mélodie Bujold (Sherbrooke)

SAMPLING STRATEGIES FROM LIDAR TO BROADER AREAS
Direct Strategy

Modelling approaches

Nonparametric approach
Random Forest (RF)

Parametric approach
Regression (OLS)

Satellite and Environmental data

Total volume (TVOL) map

Field Plots
Indirect Strategy

Phase 1

RF: Random forest
ALS Metrics
OLS
Field Plots
Total Volume map in ALS transects

Phase 2

RF
OLS

Satellite and Environmental data

Total volume (TVOL) map

RF: Random forest
OLS: Ordinary least square regression
Indirect approach more accurate for prediction of key attributes

Karin van Ewijk (Queens)

MODEL TRANSFERABILITY
Transferability of LIDAR models
Transferability design

**FRI attributes**
Basal area (BA)
Volume (GTV)
Lorey’s height (LHT)
Diameter (QMD)

**ALS metrics**
Structural height metrics relating to:
dominant trees
gaps and understory
variation in tree height
canopy complexity and crown closure

**Modeling approaches**
- Parametric (OLS)
- Non-parametric (RF)

**Evaluation criteria**
Model output: RMSE (%), Bias (%), $R^2$; Equivalence test
• The best transferability scenarios were within ± 5% relative error and an increase 10% in relative bias.
• The worse were a 23% increase in error and 29% increase in bias.
• The worse thing to do is a straight transfer; combining plots from both models was more successful.

• Overall models of height (such as Lorey’s height) were the most accurately transferred, whereas volume and diameter were the poorest.
SOIL PRODUCTIVITY MAPPING

Shane Furze (UNB)

Predictive Modeling for ecological site classification, habitat and forest health

New Structural Metrics for Forest Stand Descriptions

Growth Rate

Hydrological Mapping and Productivity
Soil Mapping Limitations

- In the past, soils delineated by broad polygons
  - ‘soil associations’

- LIDAR DEM and Terrain Attributes
  - Paradigm shift
    - Map soil properties continuously based on soil-forming factors
    - Models to compare soil properties to climate, geology, and topography
    - Requires “accurate” representations of soil-forming factors
• Numerical prediction of key soil attributes using soil plot information and spatial coverages including LiDAR.
• Roll out predictions across the entire forest estate
• Link these fine scale models with individual tree responses
Spatial Database

Topographic Derivatives

Total:
50+ Data sets

- Topographic and climate based on DEM

Surficial Geology

Climate Data

Parent Material Mode of Deposition
- Ablation
- Ablation/ Glacial
- Ablation/ Residual
- Alluvium
- Basal
- Colluvium & Water-worked In
- Glaciofluvial
- Glaciofluvial & Marine
- Glaciomarine
- Glaciomarine Basal
- Marine
- Organic
- Residual
- Residual & Colluvium

Elevation m
569.3
131.7

Annual Average Temperature
°C
6.45
1.22
LIDAR Curvature Classification

A – 10m resolution, B – 50m resolution, C – 10m resolution with $50m^2$ smoothed, D – 50m resolution with $250m^2$ smoothed.
\[ R^2 = 81.4\% \]
\[ R^2 = 88.4\% \]
\[ R^2 = 88.4\% \]
\[ R^2 = 81.4\% \]
WS Plantations

Avg. Height/ Age
- 0.002 – 0.1
- 0.1 – 0.15
- 0.15 – 0.2
- 0.2 – 0.25
- 0.25 – 0.3
- 0.3 – 0.35
- 0.35 – 0.4
- 0.4 – 0.45
- 0.45 – 0.5
- 0.5 – 0.55
- 0.55 – 0.6
- 0.6 – 0.65
- 0.65 – 0.7
- 0.7 – 0.75
- 0.75+

Waterbodies

Soil Associations
New Structural Metrics for Forest Stand Descriptions

Hydrological Mapping and Productivity

Growth Rate

Predictive Modeling for ecological site classification, habitat and forest health

Sean M. Lamb (UNB), Piotr Tompalski (UBC), Joseph Rakofsky (UBC)

STAND GROWTH
• How can we predict growth with LIDAR data?

✓ Linking LIDAR plot attributes with measured plot attributes and then interpolating
✓ Linking LIDAR to growth modelling
✓ Using two sets of remote sensing data
Spruce Plantations in New Brunswick

1. Impute tree-level inventory for LiDAR grid cells in spruce (Picea sp.) plantations
   - Match plot measurements with LiDAR grid cells based on planted species and 6 inventory variables
   - Use tree-level inventory from matched plot as a surrogate for each LiDAR grid cell

2. Forecast forest inventory using imputed tree lists and a locally calibrated tree-list growth model
   - Input imputed tree lists into tree-list growth model (Open Stand Model) to forecast inventory
   - Compare predicted annual increment from tree lists imputed by plot matching with measured tree lists
Variables generated from imputed tree lists highly correlated with those from measured trees

Imputed and measured tree lists had statistically equivalent basal area distribution by species

Modelled inventory increments from imputed tree lists highly correlated with those from measured plots

Volumes forecasted 3-5 years for 15 test plantations using imputed tree lists statistically equivalent to actual harvest

Linking LIDAR with existing growth models in Alberta (GYPSY)

Slave Lake; mixed wood boreal species

Plot-level stand attributes:
- observed at T1
- predicted at T1
- observed at T2
- predicted at T2

Yield curves matched based on:
- observed at T1
- predicted at T1
- observed at T2
- predicted at T2
- observed at T1 and T2
- predicted at T1 and T2
Using two sets of remote sensing data

Yield Projection

Multi-Temporal Point Clouds

T1 = 2007; T2 = 2017: even if models for two points in time are significant
Growth can be difficult to assess; especially in slow growing stands with high mortality.
PRODUCT MIX

Chris Mulverhill (UBC), Piotr Tompalski (UBC)

Predictive Modeling for ecological site classification, habitat and forest health

New Structural Metrics for Forest Stand Descriptions

Growth Rate

Hydrological Mapping and Productivity
Stem diameter distributions in boreal mixedwoods

Testing different ground-based and ALS-based techniques for separating structurally simple and complex areas and then predicting structurally appropriate models.
Shane Donavan (UNB), Tristan Goodbody (UBC)

FOREST HEALTH

Predictive Modeling for ecological site classification, habitat and forest health
New Structural Metrics for Forest Stand Descriptions
Growth Rate
Hydrological Mapping and Productivity
Abdelmounaime Safia, Van Tho (UQAM)

STRUCTURAL ATTRIBUTES FROM GROUND BASED LIDAR
Ground Based and Mobile LIDAR Systems
Identification of individual trees in the point cloud

Diagram:
- Forest plot
- Connected components research
- Vowel discardment
- Complex
- Labeling connected components
- Simplex or empty
- Connected components neighborhood graph
- Minimum spanning forest
- Segmented forest plot
Identification of individual trees in the point cloud
IDENTIFYING SPECIES

Rachel Perron, Jean-Francois Prieur (UQAM/ Sherbrooke)
SPECIES ID

Fraxinus nigra  Fraxinus amer.  Tilia americana  Fagus grandif.  Abies balsamea  Betula papyrifera

Betula allegh.  Thuya occident.  Larix laricina  Acer sacchar.  Acer rubrum  Quercus rubra

Pinus banksia.  Pinus resinosa  Populus tremu.  Pinus strobus  Picea mariana  Picea glauca
Species Mapping Workflow

Delineate crowns from lidar CHM

Extract lidar XYZI data from LAS files for each crown

Compute features - XYZ - intensity

Database of crowns with features

Classify

Map
Species Mapping at BlackBrook Forest, NB

- **209 000 ha**
- White, red, black and Norway spruce planted stands total more than 40% of the landbase
- Tolerant hardwood stands make up 28%
Table 5. Classification levels.

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<td>Birch (BI)</td>
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Table 9. Confusion matrix for the functional groups using the global model for the entire AOI. Numbers in parentheses are for the 10 species case, the others for the 13 species case.

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Global model, both sectors
Jean-François Prieur (UQAM/Sherbrooke), Bastian Vandendaele (Sherbrooke) Chris Mulverhill (UBC)

NEW DATA AND APPROACHES
Multispectral lidar

The Titan system from Teledyne Optech scans in 3 λ

1064 nm (NIR = C2) @ 0.0°
1550 nm (SWIR = C1) @ 3.5°
532 nm (green = C3) @ 7.0°
Classifying species with multispectral ALS

- Optech Titan 3D and intensity data
- 10 tree species – accuracy 75%
- 1550 nm channel and green normalized difference spectral index were most useful

Petawawa

Standard ALS

Multi-spectral ALS

Single Photon
UAV LIDAR for forest inventory
**Tree Segmentation**

*N* Tree: 532  
Correctly segmented: 78%  
Oversegmented: 5%  
Undersegmented: 17%

Mc Coy Brook deciduous site (NHRI) – 1ha
DAP on the ground

• Two Ricoh THETA S 360° cameras
• 3 different heights: 1.9m, 3m, 5m
• Different locations around individual trees and plots
• 30 individual trees photographed, felled, and measured
The utility of terrestrial photogrammetry for assessment of tree volume and taper in boreal mixedwood forests. Annals of Forest Science 76 (3), 83
Jean-Romain Roussel

ACCESSIBLE, FREE CODE
Jean-Romain Roussel

jean-romain.roussel.1@ulaval.ca

https://github.com/Jean-Romain/lidR

lidR does not aim to provide predefined processes, it is designed to enable users to build their own.

Support for multi-core processing

Processing of Large Datasets

Examples:
  Multiple algorithms to create CHM
  Multiple algorithms to segment crowns
  Custom metrics
- https://github.com/Jean-Romain/lidR/
- https://github.com/Jean-Romain/lidR/wiki
- https://CRAN.R-project.org/package=lidR
Tree crown delineation software for airborne lidar CHMs

- Free, open source, cross-platform, and fast solution for delineating individual trees from lidar CHMs.
- Direct batch production of shapefiles where each polygon represents a tree crown.
- Computes attributes for each crown.
- Provides a key input for tree species ID.
Tree crown delineation software for airborne lidar CHMs

Comes with a graphical user interface.
WRAP-UP
AWARE Legacy:

- Provided funds for 25 Graduate Students, Postdocs and Research Associates
- 9 students have graduated to date, with more completing
- 18 journal review papers to date; 8 in review and more to come
- 25 posters, conference proceedings, reports
- Quarterly newsletter
- Industry – Government – University Collaborations
- Long Term Website for Data / papers / reports being developed

AWARE.FORESTRY.UBC.CA

**University Investigators:**
- Nicholas Coops; Peter Marshall (UBC)
- Alexis Achim (Laval)
- Paul Treitz (Queens)
- Benoit St-Onge (UQAM)
- Richard Fournier (Sherbrooke)
- Paul Arp, Chris Hennigar (UNB)
- Jeff Deck (Nipissing)
- John Caspersen (Toronto)

**Government Investigators:**
- Joan Luther (CFS)
- Oliver van Lier (CFS)
- Adam Dick (CFS)
- Jean-François Côté (CWFC)
- Doug Pitt (CWFC)
- Murray Woods (Govt Ontario / CWFC)
- Chris Bater (Govt. Alberta)
- Joanne White (CFS)
- Udaya Vepakomma (FPI)
- Denis Cormier (FPI)

**International Reviewers:**
- Ross Nelson (Retired / NASA)
- Sorin Popescu (Texas A and M University)
Final Annual General Meeting with Open Showcase Day will be held in Toronto February 19 – 20th 2020
E-LECTURE SERIES: An Update on Canadian Forestry Applications of LIDAR and Digital Photogrammetry. The AWARE Experience.

September 25, 2019
The AWARE Project: Results and Outcomes
Nicholas Comis, Professor, UBC
Canada Research Chair in Remote Sensing
Principal Investigator: Assessment of Wood Attributes from Remote Sensing (AWARE)

Paul Arp, Professor in the Faculty of Forestry and Environmental Management, UNB

Shane Furze, Research Scientist, Forest Watershed Research Center, UNB

Greg Adams, Advisor, Tree Improvement and Research and Development, J.D. Irving

October 2, 2019
Digital Soil Mapping in New Brunswick

Jean-François Prieur, Graduate Student, UQAM

New LIDAR Technologies on the Horizon - SPL and Multi-Spectral LIDAR

Martin Quinet, Graduate Student, UBC

Grant McCartney, Forest Information Systems Coordinator, Chief Forests Group, (Ontario)

Joanne White, Research Scientist, Canadian Forest Service, Natural Resources Canada

October 16, 2019

October 23, 2019
Assessing Non-Timber Values Using LIDAR and Advanced Remote Sensing Data

Richard Fournier, Professor, Department of Applied Geomatics, Université de Sherbrooke

Aless Achim, Professor, Department of Geography and Geomatics, Laval University

Chris Mulherhill, Graduate Student, UBC

Christopher Bater, Forest Management Specialist, Forestry Division, Alberta Agriculture and Forestry, Gov. of Alberta

Sam Hemmink, Graduate Student, UBC

Catherine Frizzle, Graduate Student, Université de Sherbrooke

October 30, 2019
Digital Photogrammetric Applications to Enhanced Forest Inventory

Tristan Goodbody, Postdoctoral Research Fellow, UBC

Adam Dick, Forest Research Project Leader, Canadian Wood Fibre Centre, Canadian Forest Service, Natural Resources Canada

Co-presenters: Chris Mulherhill & Joanne White
Thank you!

aware.forestry.ubc.ca

www.researchgate.net/project/
AWARE-Assessment-of-Wood-Attributes-from-Remote-Sensing

irsslab.forestry.ubc.ca

IRSS_UBC

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