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RYAM Forest Management

Sampling and Generation of Enhanced Forest Inventory (EFI) attributes from Single Photon LiDAR

Forestry Futures Trust Committee – KTTD Webinar Series

18th March 2021

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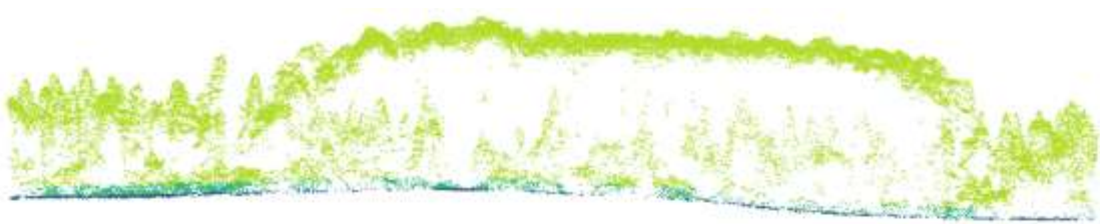

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Project Context:

- The Province of Ontario has committed to a wall to wall coverage of LiDAR data for Forestry and an array of additional uses
- Data is being acquired using single photon LiDAR (SPL)
- Future Forests supported research demonstrating the application of SPL data for development of Enhanced Forest Inventories (EFI)

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This project has four main objectives:

(i) propose a structurally guided sampling design for locating and collecting FRI calibration plots for model development for the 2018 SPL.

(ii) Coordinate procurement and delivery of field data collection services using the draft Integrated Monitoring Framework (IMF) design specifications,

(iii) develop an EFI and examine the utility of both Area Based Approach (ABA) and Individual Tree Detection (ITD) approaches using SPL data and

(iv) assess differences with previously acquired 2005 LIDAR data.

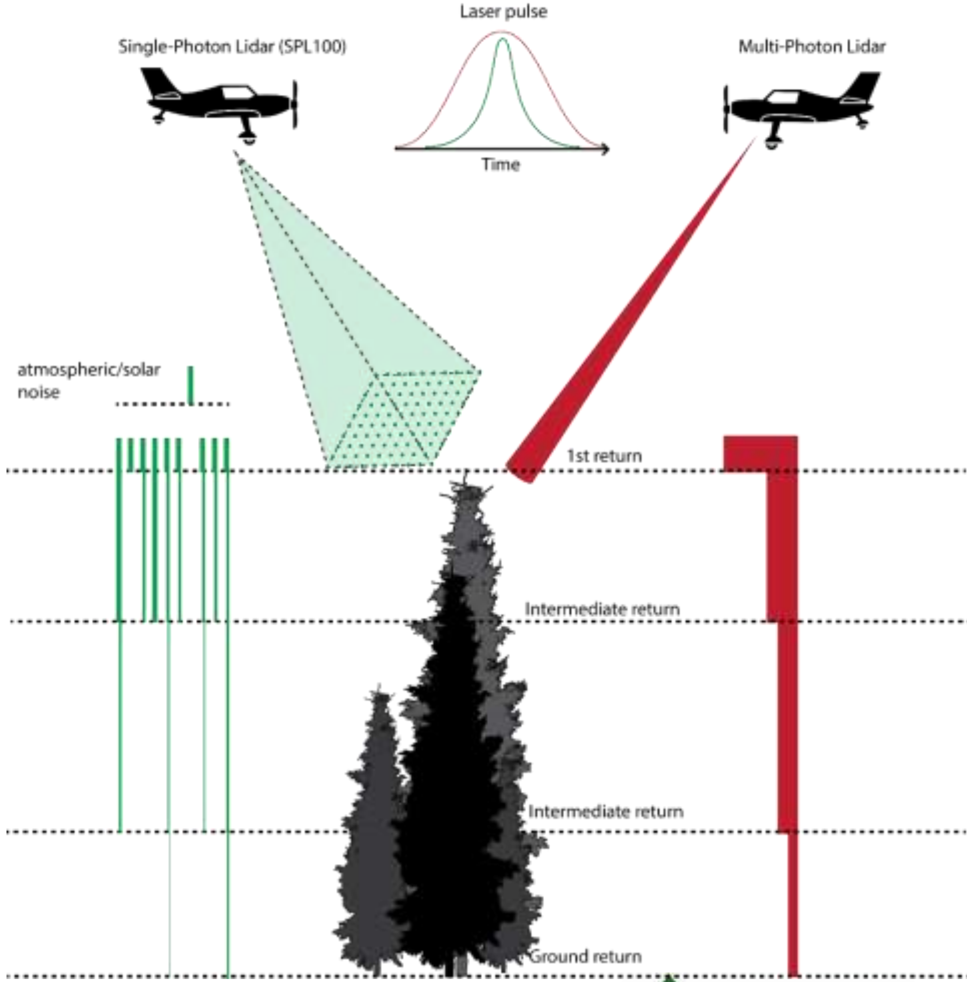
What is SPL Data and how does it differ from conventional linear-mode LiDAR ?

Linear-mode lidar:

- Record the amount of photons returned in a single beam
- Discrete returns from returned signal above threshold
- Require high energy pulses

Single-photon lidar:

- Record individual photons (binary signal) from the reflected pulse
- Multiple simultaneous low energy pulses can be used



	SPL100	Conventional linear-mode LiDAR
Wavelength	532 nm (green)	1064 nm (NIR)
Pulse width	0.4 ns	2 – 10 ns
Beam arrangement	10 x 10 array of beams	Single beam
Point density	~ 20 pts / m^2 @ 4,000 m a.g.l and 100 m/s	0.5 – 10 pts / m^2
Beam divergence	0.08 mrad	0.25 – 2 mrad
Max number of returns per beam	5	2 – 5

Advantages and drawbacks of SPL100

\+ Coverage (km^2/h)

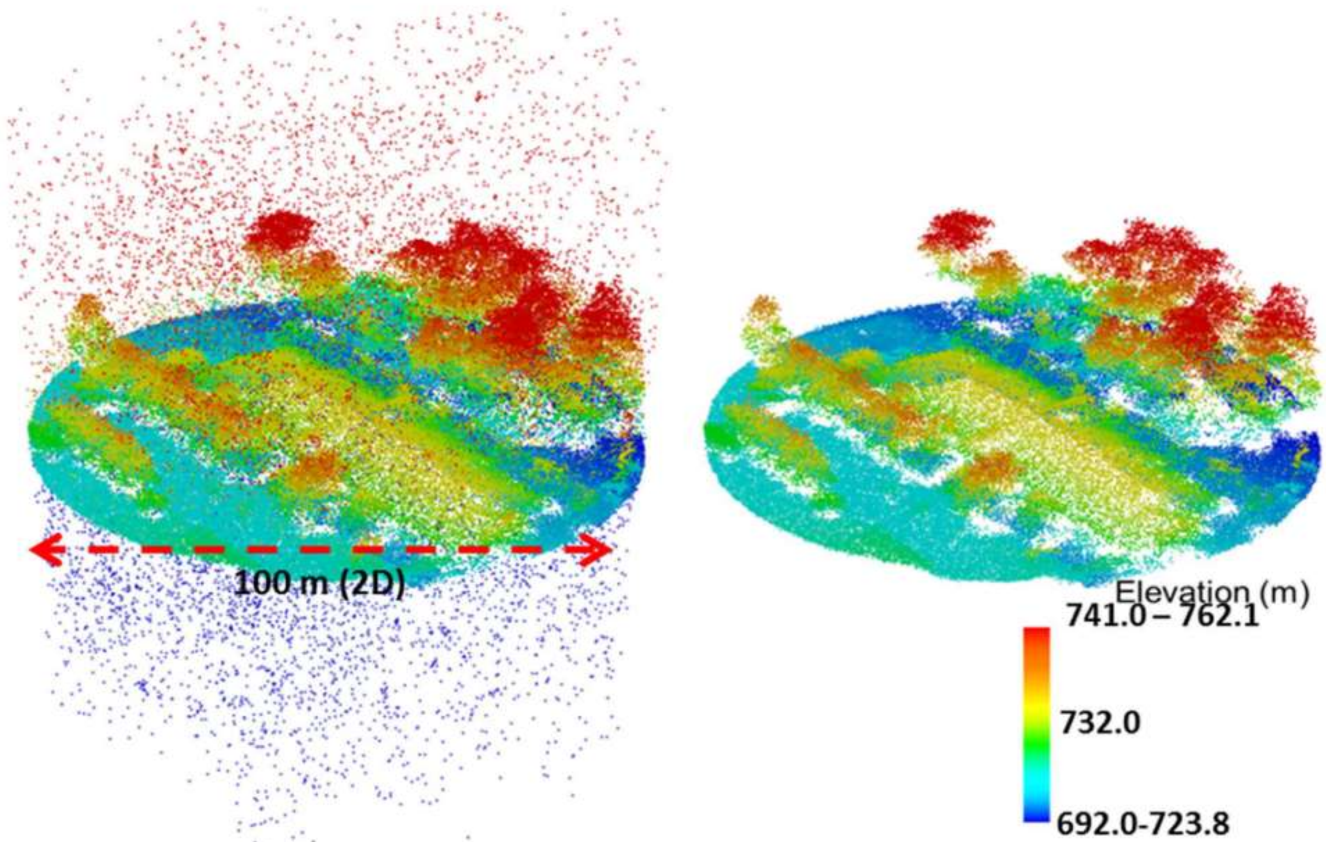
\+ Point cloud density

\- Low signal to noise ratio

? Range accuracy

? **Penetration of pulses through the canopy (because of low energy pulses and green wavelength)**

Noise in SPL data



Swatantran, A., Tang, H., Barrett, T., DeCola, P., & Dubayah, R. (2016). Rapid, high-resolution forest structure and terrain mapping over large areas using single photon lidar. *Scientific reports*, *6*(1), 1-12.

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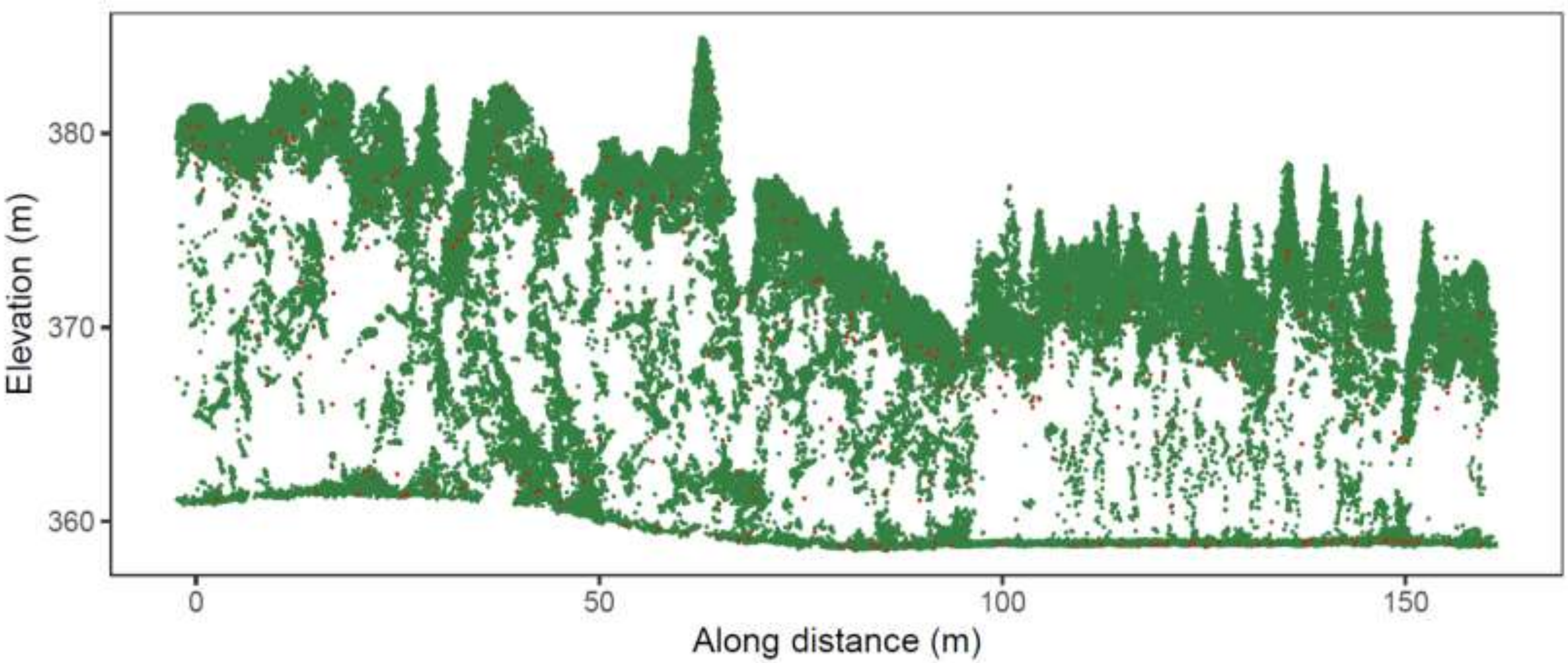
Comparison of SPL100 and 2004-2005 LiDAR



Transect width: 5 m

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Focus Forest Management Area:

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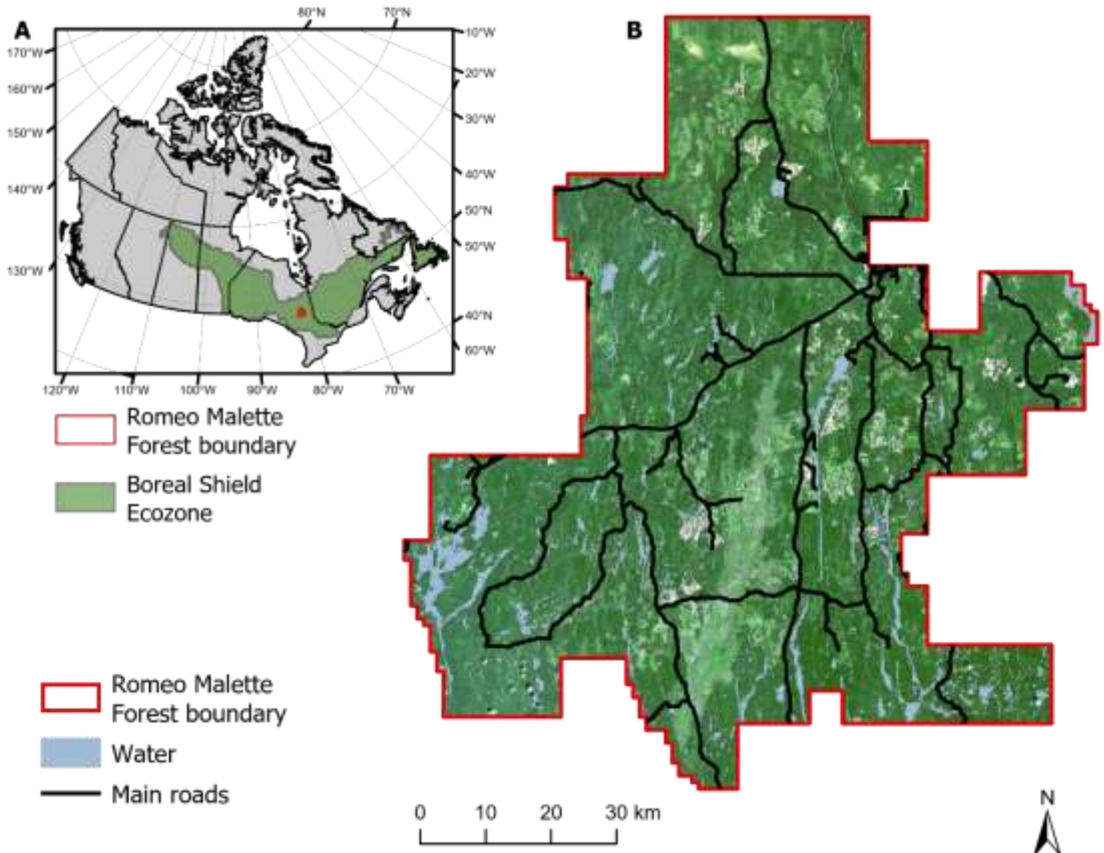
- Romeo Malette Forest in Ontario, Canada
- ~ 630,000 ha managed boreal forest
- Flat terrain, many wetlands



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ABA SPL data Processing

Computed 20 standard LIDAR metrics in 20x20m cells including:

- measures of central tendency (mean, median), dispersion (coefficient of variation, skewness, kurtosis)
- percentiles of vegetation returns height above 1.3 m (5^{th}, 10^{th}, 20^{th}, 30^{th}, 40^{th}, 60^{th}, 70^{th}, 80^{th}, 90^{th}, 95^{th} and 99^{th} percentiles).
- Canopy cover (proportion of first returns above 2 m, 5 m, 10 m and 15 m thresholds).

Selection of plots

Existing field data:

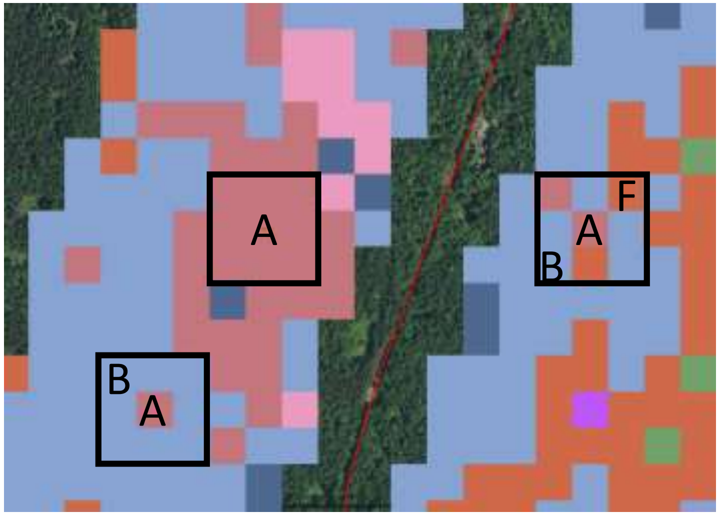
- 136 circular 400 m^2 forest inventory plots were available from a previous inventory program (Woods et al, 2011). These plots were established and measured in 2008.

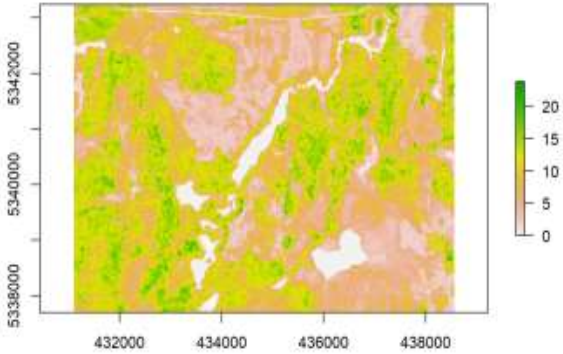
For the SPL EFI:

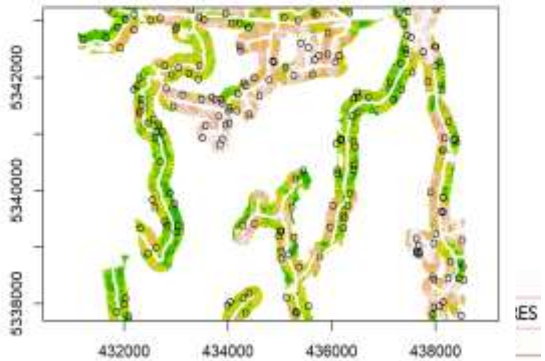
- Which of the 2008 plots should be re-measured ?
- Where are new plots needed to cover the variation in structure over the RMF?
- We can use the SPL coverage to select new plot locations

Structurally Guided Sampling

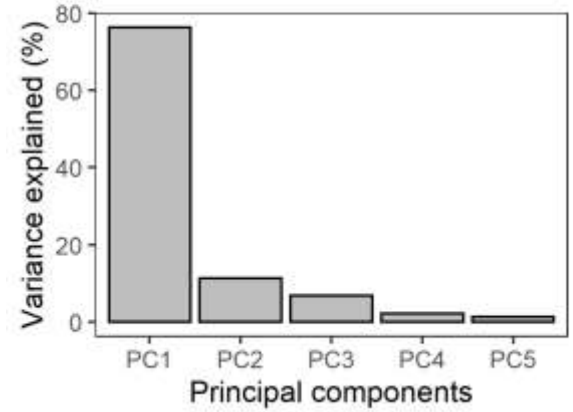
- Compute a PCA on the 20 LiDAR 20x20m summaries
- Stratify the first two PCA into 39 classes and ensure plots are placed within each class.
- Select an existing plot in each class, before establishing a new one
- When selecting new plots within a class, select the stand which minimizes travel and maximizes stand size.

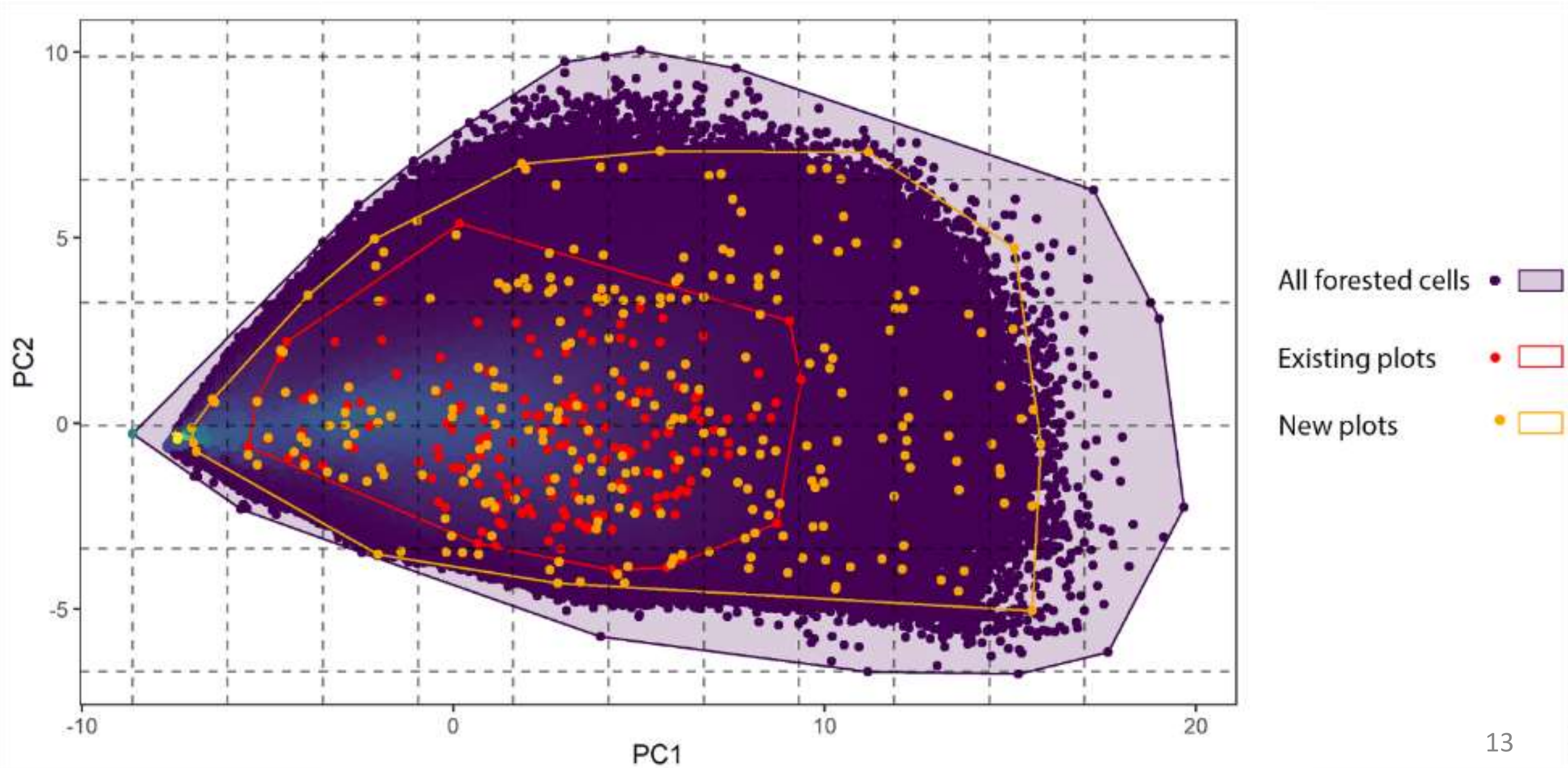


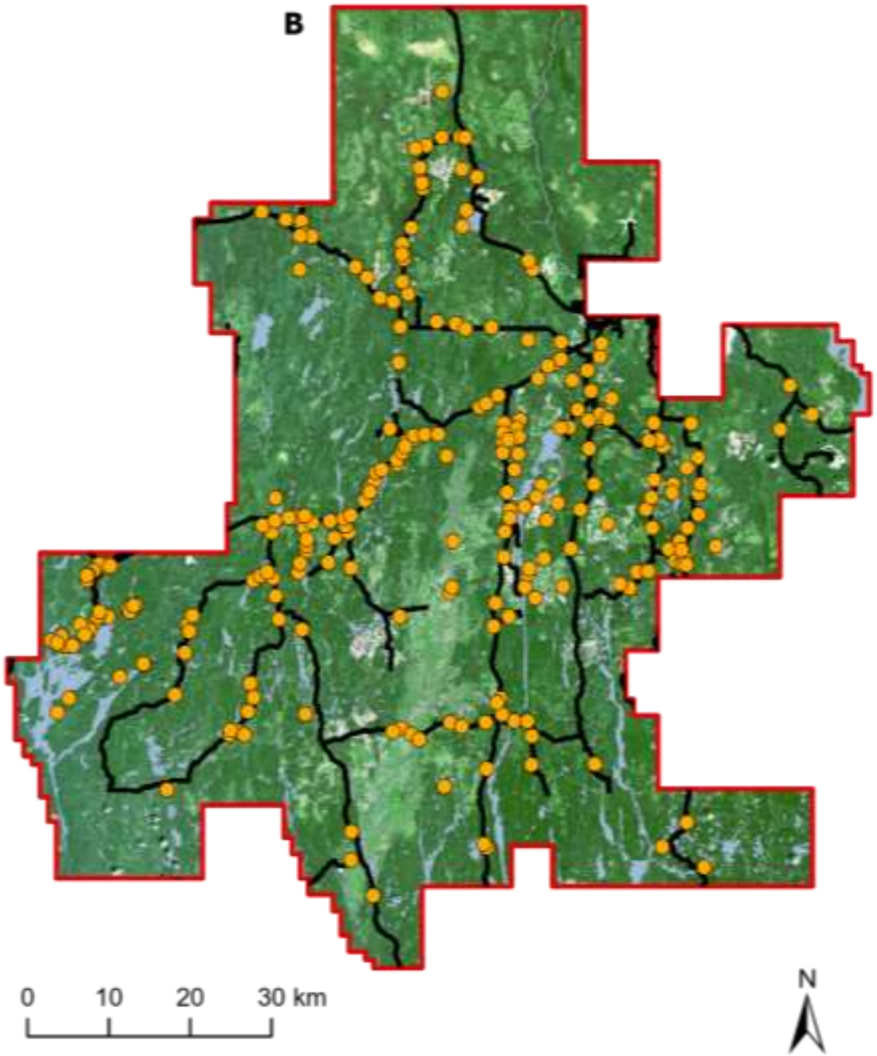




Results - SGS


Variance explained (%)
80
60
40
20
0
PC1
PC2
PC3
PC4
PC5
Principal components


10
5
0
-5
PC2
-10
0
10
20
PC1
All forested cells
Existing plots
New plots



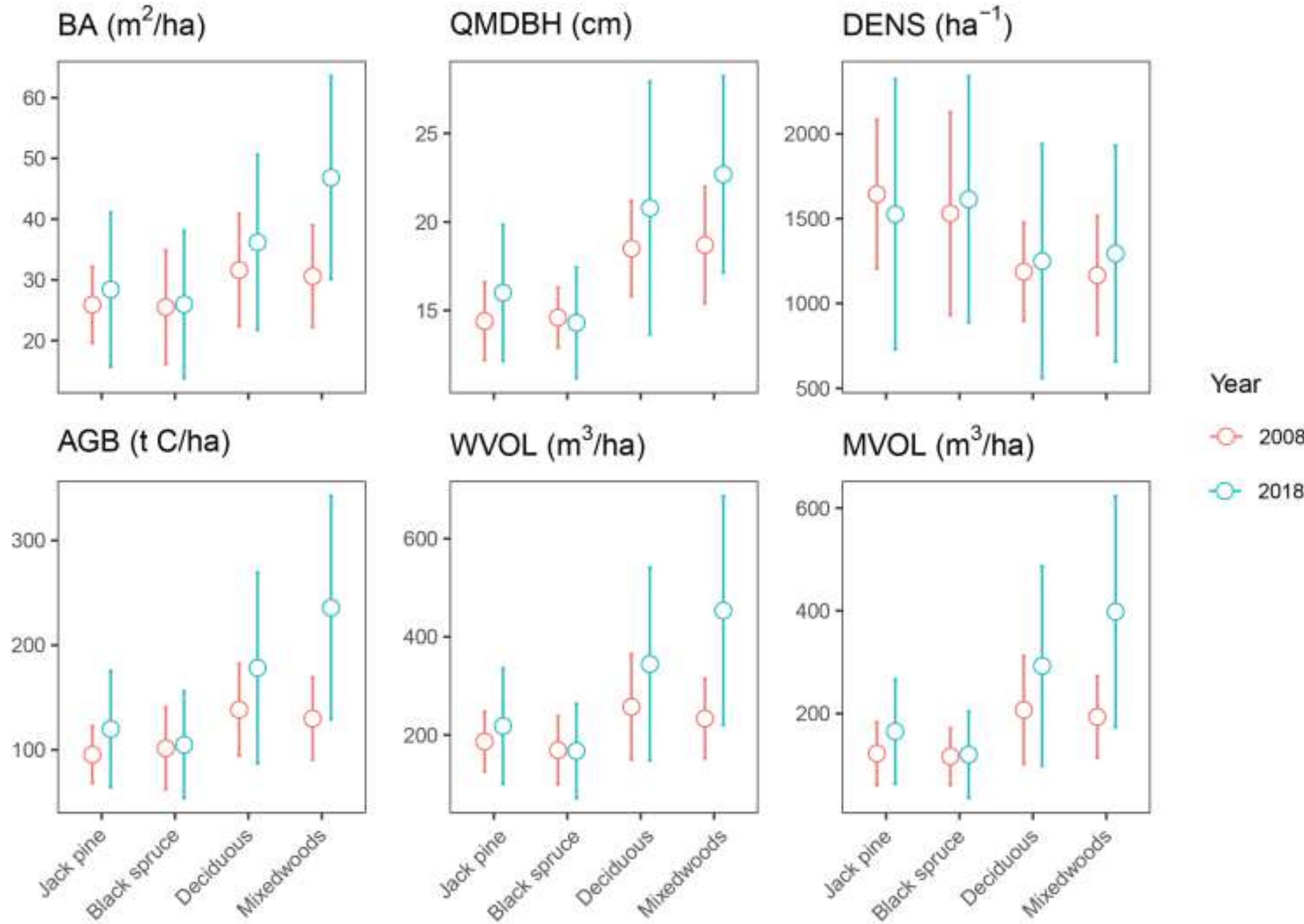
- 258 plots selected
- Visited between June and December 2019 by Sumac Geomatics
- Height, DBH and species of trees with DBH > 7.1 cm
- Subset of 59 plots with stem mapping

Predicted forest attributes

Forest attribute	Description	Calculation or modeling method	Unit
Basal area (BA)	Tree cross sectional area (approximated as a circle) at breast height (1.3 m)	$\frac{\pi}{4}\sum_i^n DBH_i^2 \times \frac{1}{A}$, where n is the number of stems and A the plot area in ha	m^2/ha
Lorey's height (L)	Average tree height weighted by basal area	$\frac{1}{n} \times \sum_i^n h_i \times BA_i$, where n is the number of stems and h is the tree height	m
Quadratic mean DBH (QMDBH)	Quadratic mean of DBH	$\sqrt{\frac{\sum_i^n DBH_i^2}{n}}$, where n is the number of stems	cm
Stem density (DENS)	Number of stems with DBH > 7.1 cm per ha	$\frac{n}{A}$, where n is the number of stems and A the plot area in ha	ha^{-1}
Whole stem volume (WVOL)	Total whole stem volume per hectare	Honer, (1983) and (Ung, Guo and Fortin, 2013)	m^3/ha
Merchantable stem volume (MVOL)	Total merchantable stem volume per hectare. Merchantable volume is defined as the stem volume between stump height (0.1 m) stem height at a bark diameter of 10 cm.	Honer, (1983) and (Ung, Guo and Fortin, 2013)	m^3/ha
Above-ground biomass (AGB)	Total tree biomass per hectare	Ter-Mikaelian & Korzukhin, (1997) and C.-H. Ung, Bernier, & Guo, (2008)	t C / ha

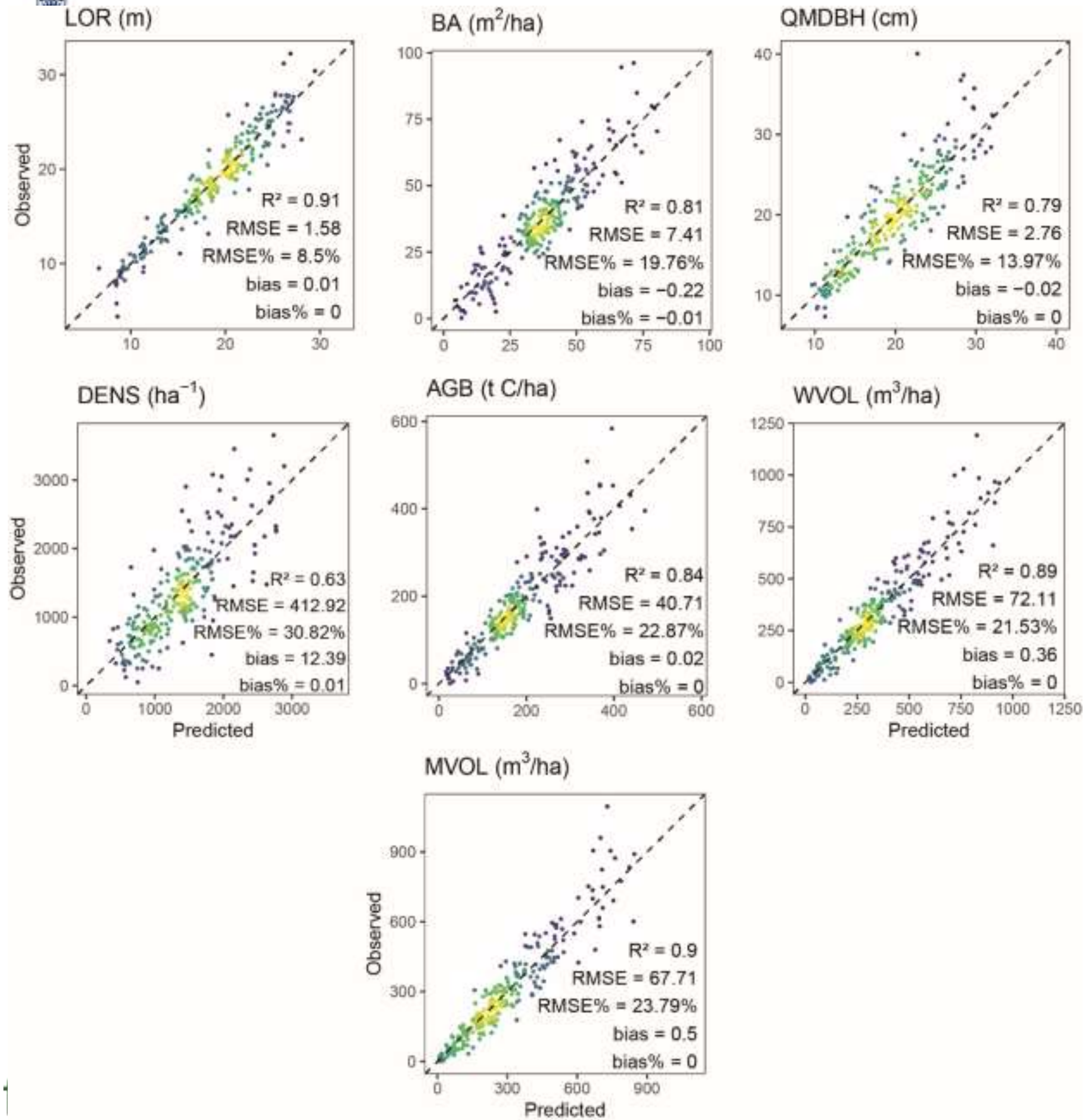
Same allometric equations as Woods et al (2011)

Mean ± SD of forest attributes at plots in 2008 EFI and SPL EFI



RF models development

- One global random forest model (500 RF trees)
- Only SPL metrics with pairwise $r < 0.9$ with other metrics included
- Model accuracy assessed using 5-fold cross-validation (1 fold held-out from model training at each iteration)



LOR:

- $R^2 = 0.91$
- RMSE% = 8.5%

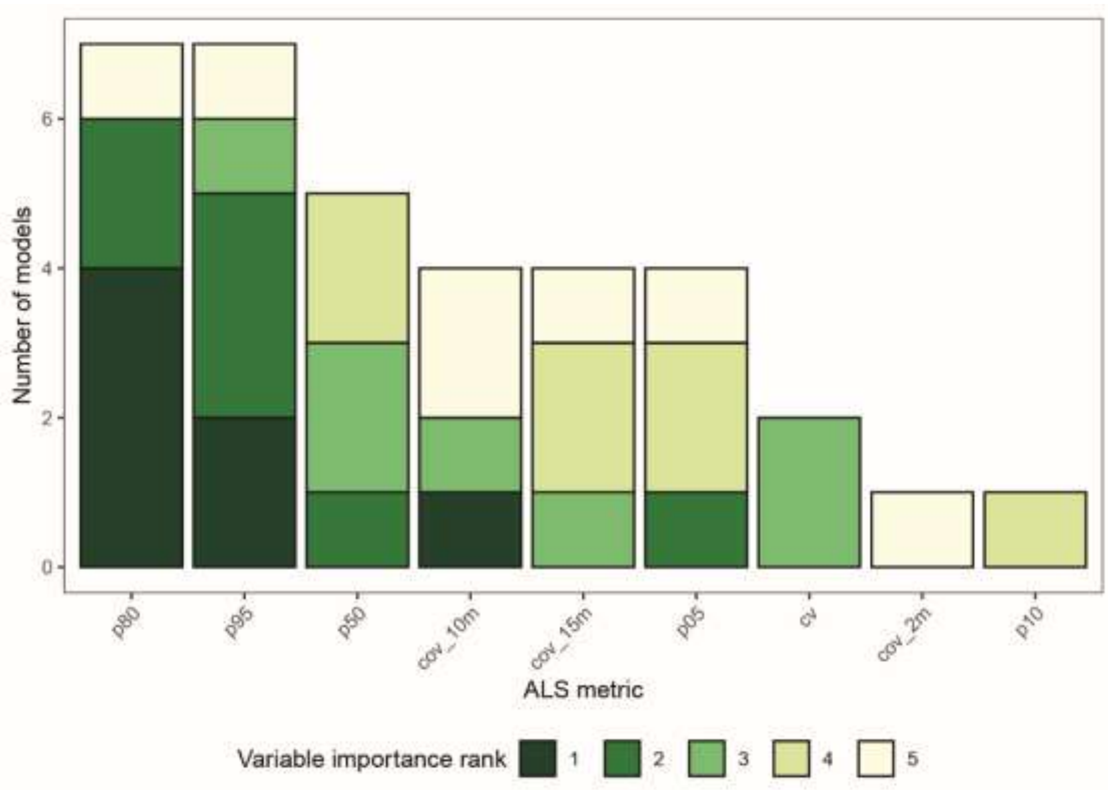
BA, QMDBH, WVOL, MVOL, AGB:

- $R^2 = 0.79 – 0.9$
- RMSE% = 13.97% - 23.79%

DENS:

- $R^2 = 0.63$
- RMSE% = 30.82%

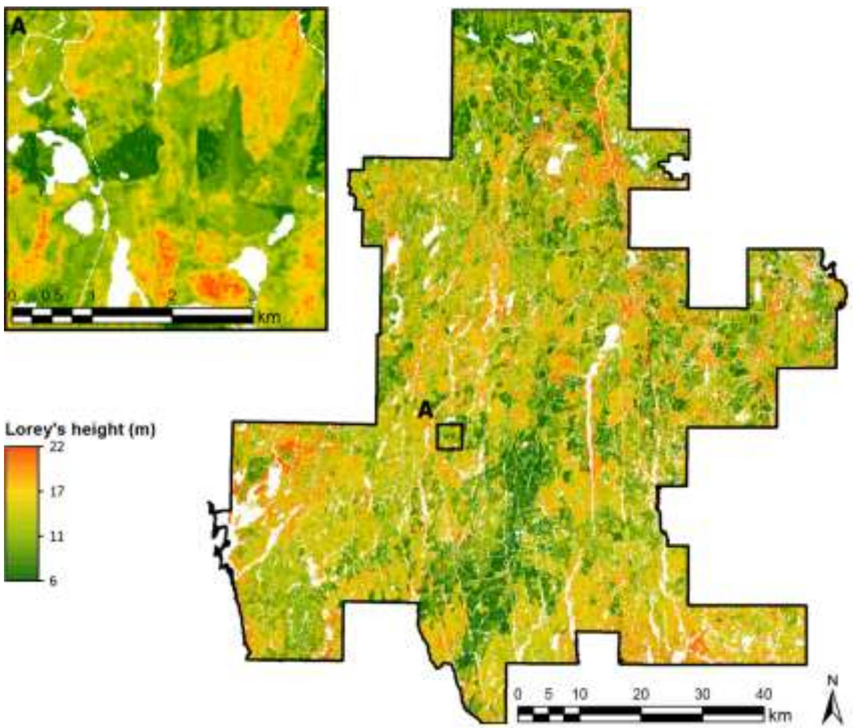
RF models variable importance



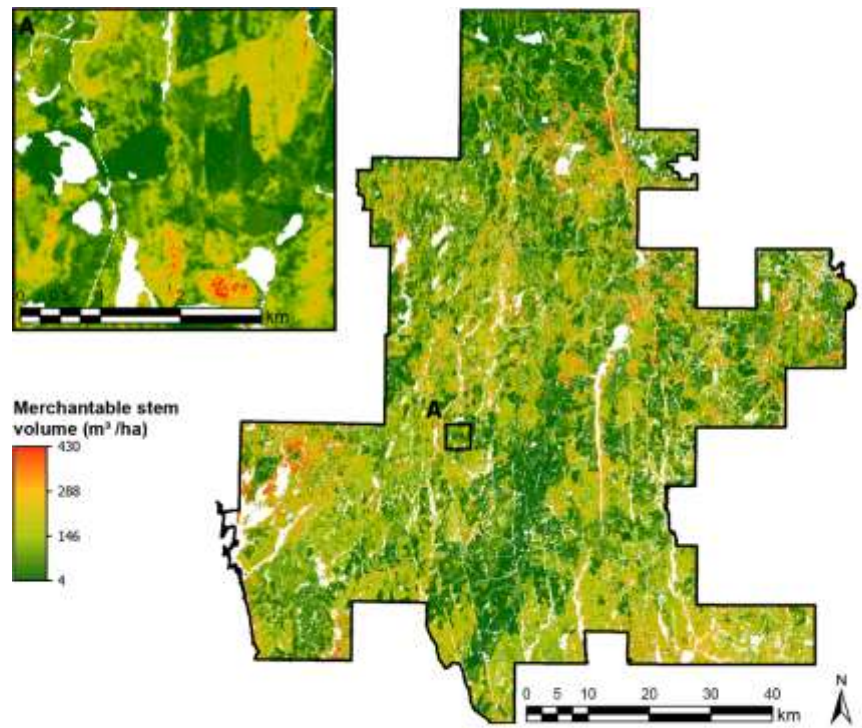
- 80th and 95th height percentiles always among the 5 most important variables
- Canopy cover more important when calculated from high thresholds (10 m / 15 m) compared to 2 m

Wall-to-wall forest attributes

LOR (m)



MVOL (m^3/ha)



Comparison to 2008 EFI

- Models accuracy of the SPL EFI very similar to the existing 2008 EFI with linear-mode lidar (Woods el al, 2011)

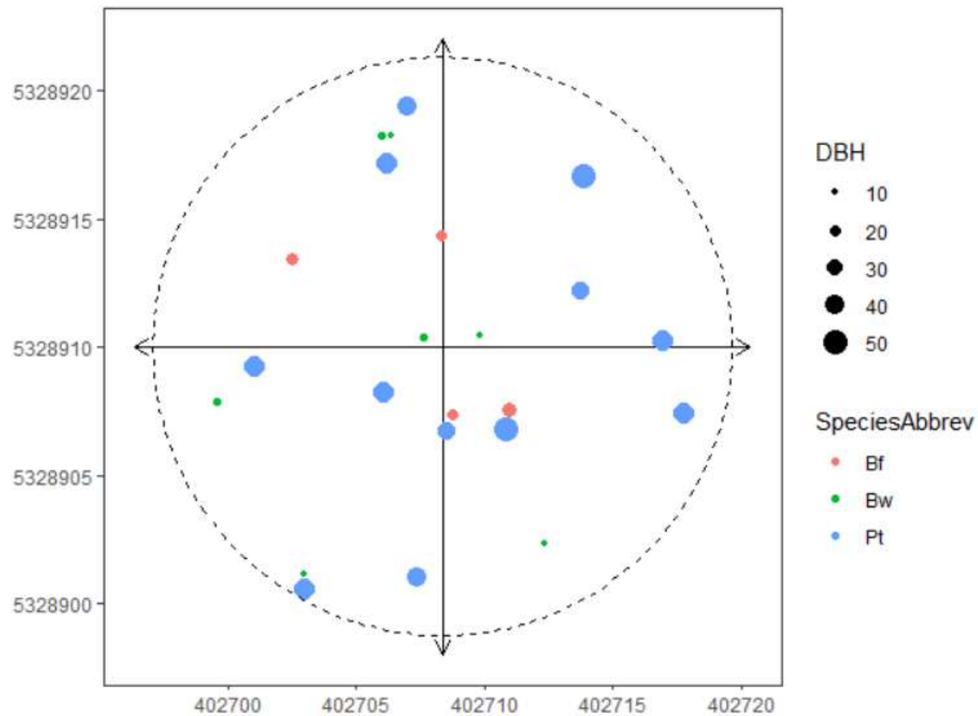
- The SPL EFI covers a wider range of forest attribute values

- Additional point density of the SPL did not result in improved ABA model predictions

- However, low point density of the linear-mode lidar would not allow for individual tree attributes extraction

ITD Based Approaches

- 59 plots also had individual tree data collected and 5 with UAV LiDAR



For more information, contact:

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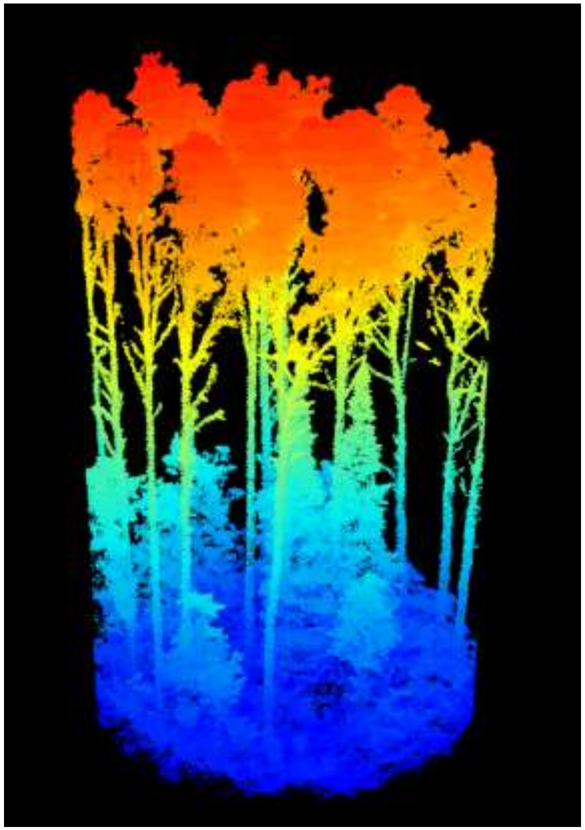
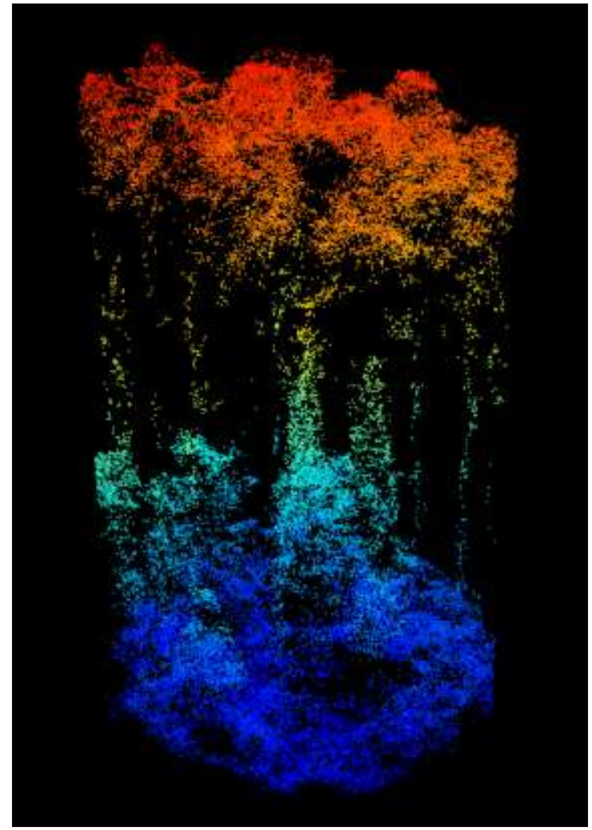
3D Plot Sample (Aspen)

UAV



11.28m

SPL



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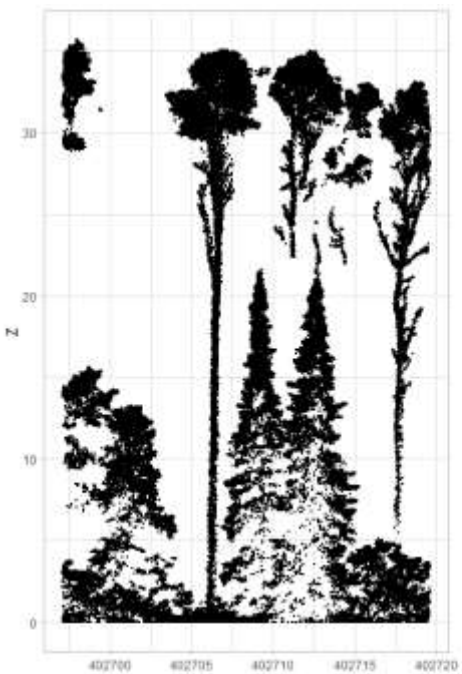
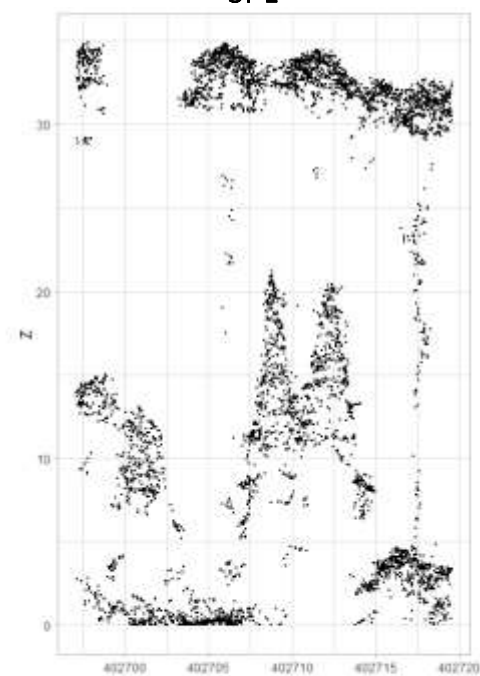
2m Plot Cross Section (Aspen)

UAV Lidar



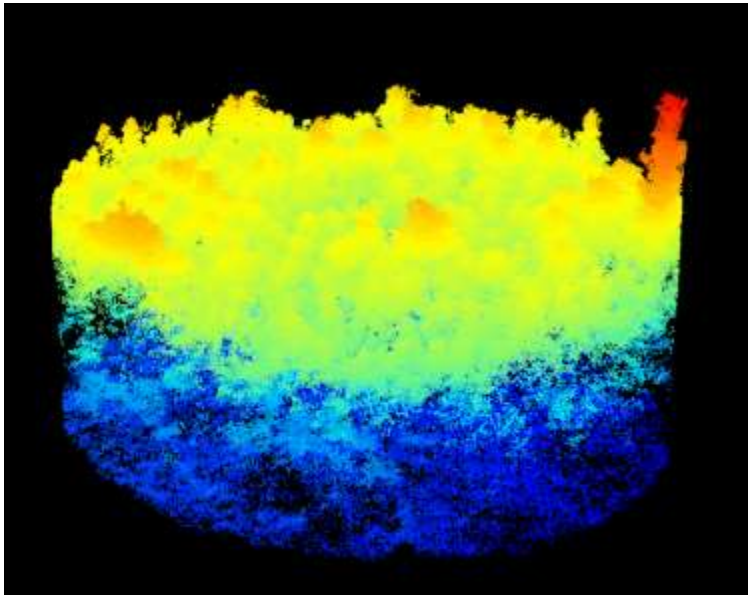
SPL



Liam Irwin (UBC)

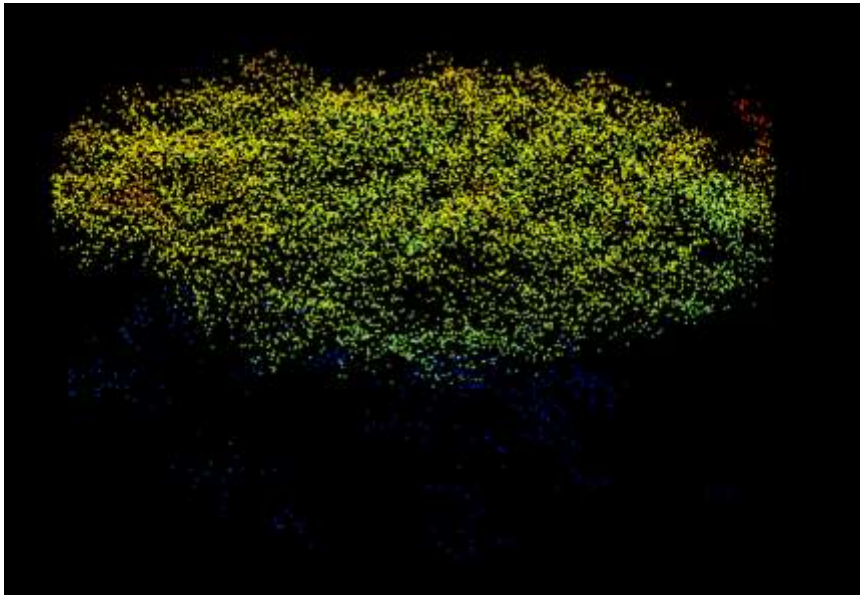
3D Plot Sample (Paper Birch)

UAV Lidar



11.28m

SPL



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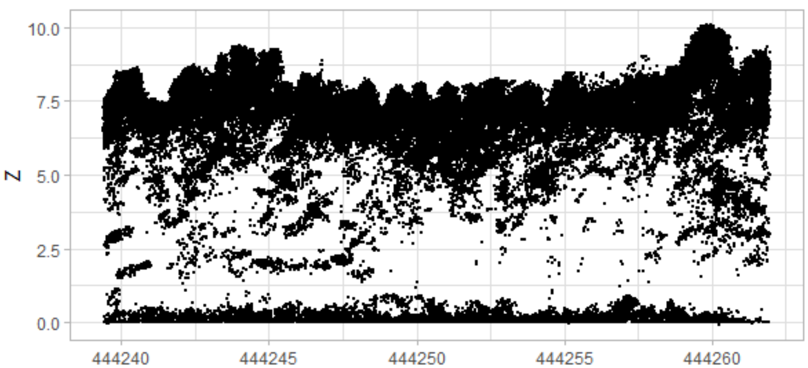
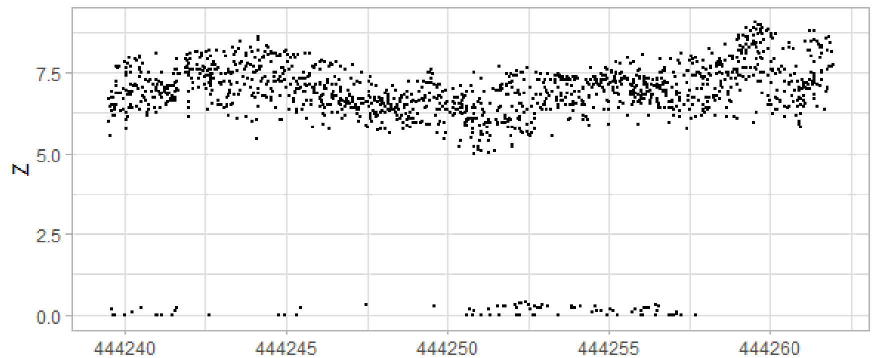
UAV Lidar



SPL



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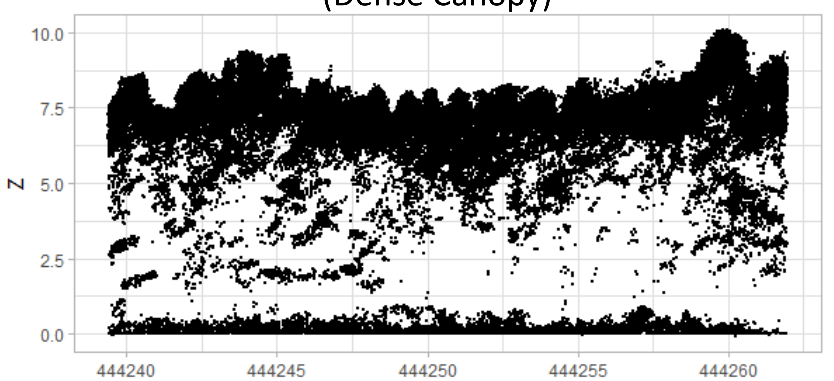
Methods

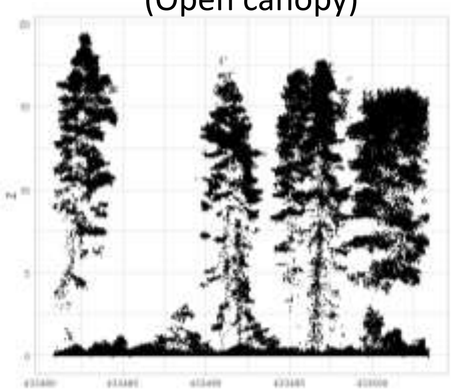
- Determine vertical depth of individual SPL returns in canopy layer.
  - Difference between top 25% and lowest 25% of returns to estimate penetration.

- Use UAV Lidar as a reference of vertical forest structure
  - Very-high density point clouds (>2500 pts/m^2) achieved vertical characterization across forest types.
  - UAV Lidar density ratio derived to stratify SPL coverage and examine distributions of returns between canopy configuration classes.

Density Index < 0
(Dense Canopy)



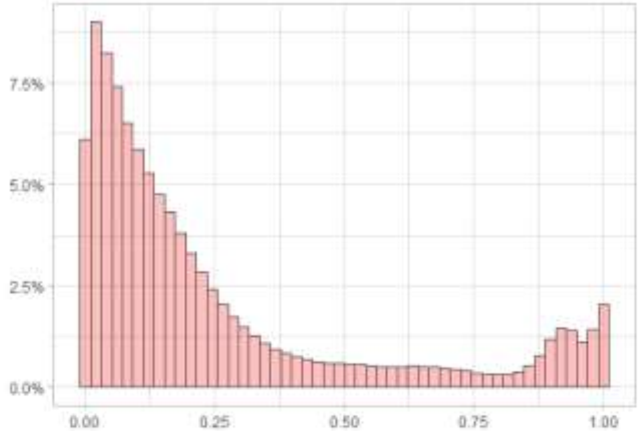
Density Index > 0
(Open canopy)



Using UAV Lidar to Assess SPL Penetration

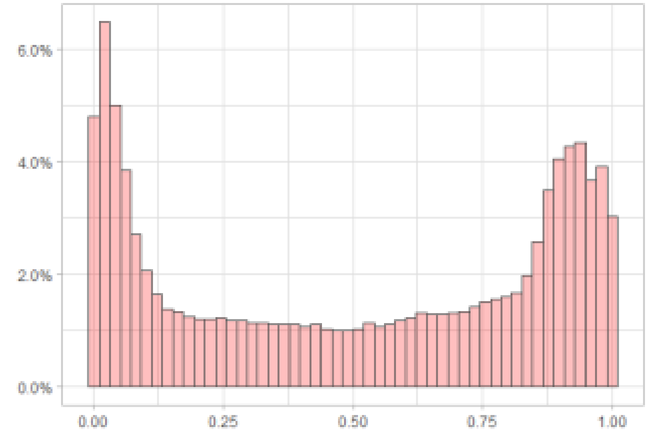
- Our results show that UAV Lidar was able to determine areas where SPL penetration was limited and produced few returns in mid-elevations of the forest profile
  - These findings may be relevant for applications which seek to model vegetation in the lower canopy (Understory, crown base height)

Density Index < 0 (Closed canopy)



SPL Penetration Depth
(% of Canopy)

Density Index > 0 (Open canopy)

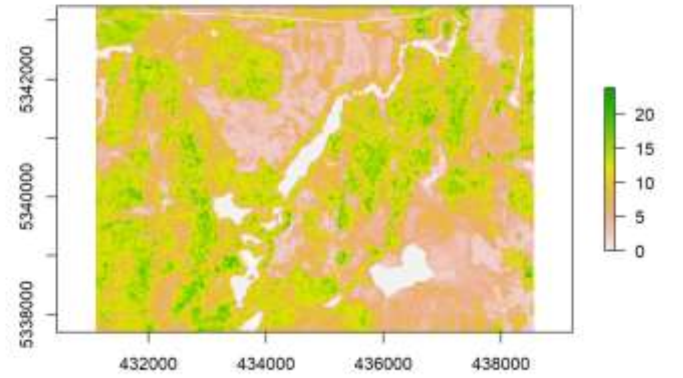


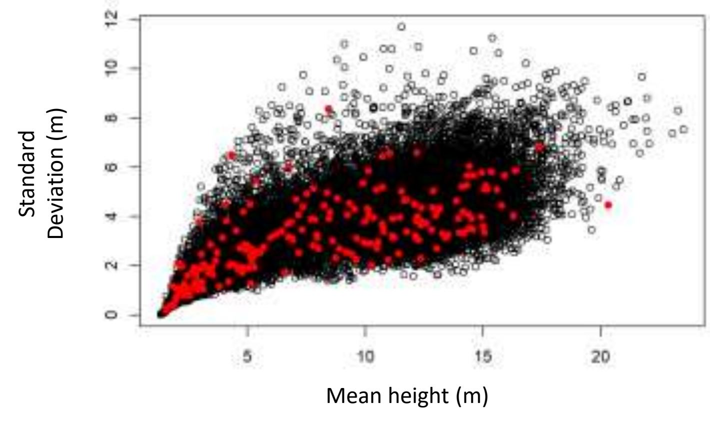
SPL Penetration Depth
(% of Canopy)

A Tool for Structurally Guided Sampling

- Exploit wall-to-wall coverage of SPL metrics.
- Use these metrics to partition our landbase to ensure representative sampling strategies.
- Approaches in the literature thus far have stratify the area (like we did here) or algorithms which find representative sites in the data (such asLatin Hypercube Sampling)

ALS mean height – 20 m pixel





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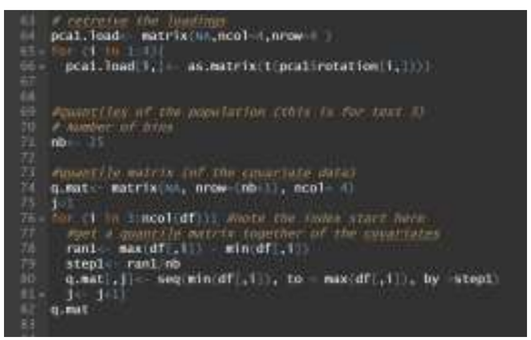
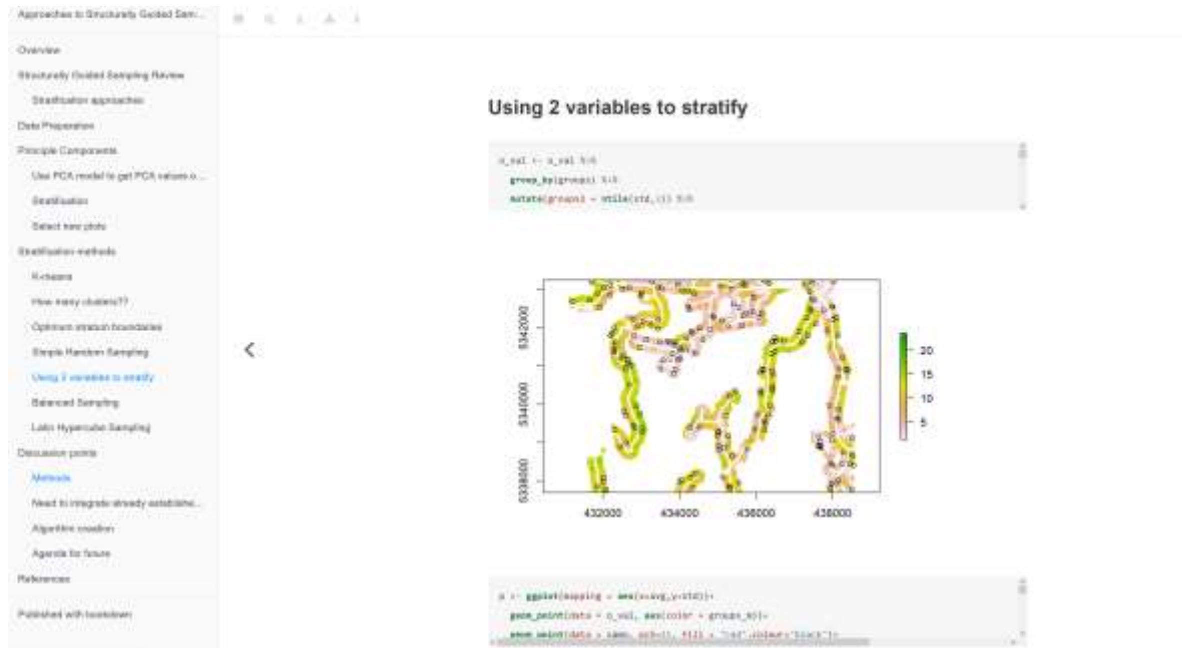
Development of an SGS R package

- Developing new R package for implementing SPL / ALS driven structurally guided sampling frameworks for forestry.
- If you're interested, have data you think maybe be useful for contributing, or want to learn more please feel free to reach out!

Tristan Goodbody – goodbody.t@gmail.com





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Natural Resources Canada Ressources naturelles Canada

Canada

Canadian Wood Fibre Centre | Centre canadien sur la fibre de bois

NSERC CRSNG

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Summary

- SPL ABA models are just as accurate as in previous EFI
- But cover a much wider range of variation in the forest stand
- Increased density allows for additional attributes to be estimated
- SPL is more cost effective as it rolls out over the province
- SGS offers a way of finding which plots should be re-measured vs where old plots can be discontinued
- We are building a tool to automate this for any forest management area in Ontario

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