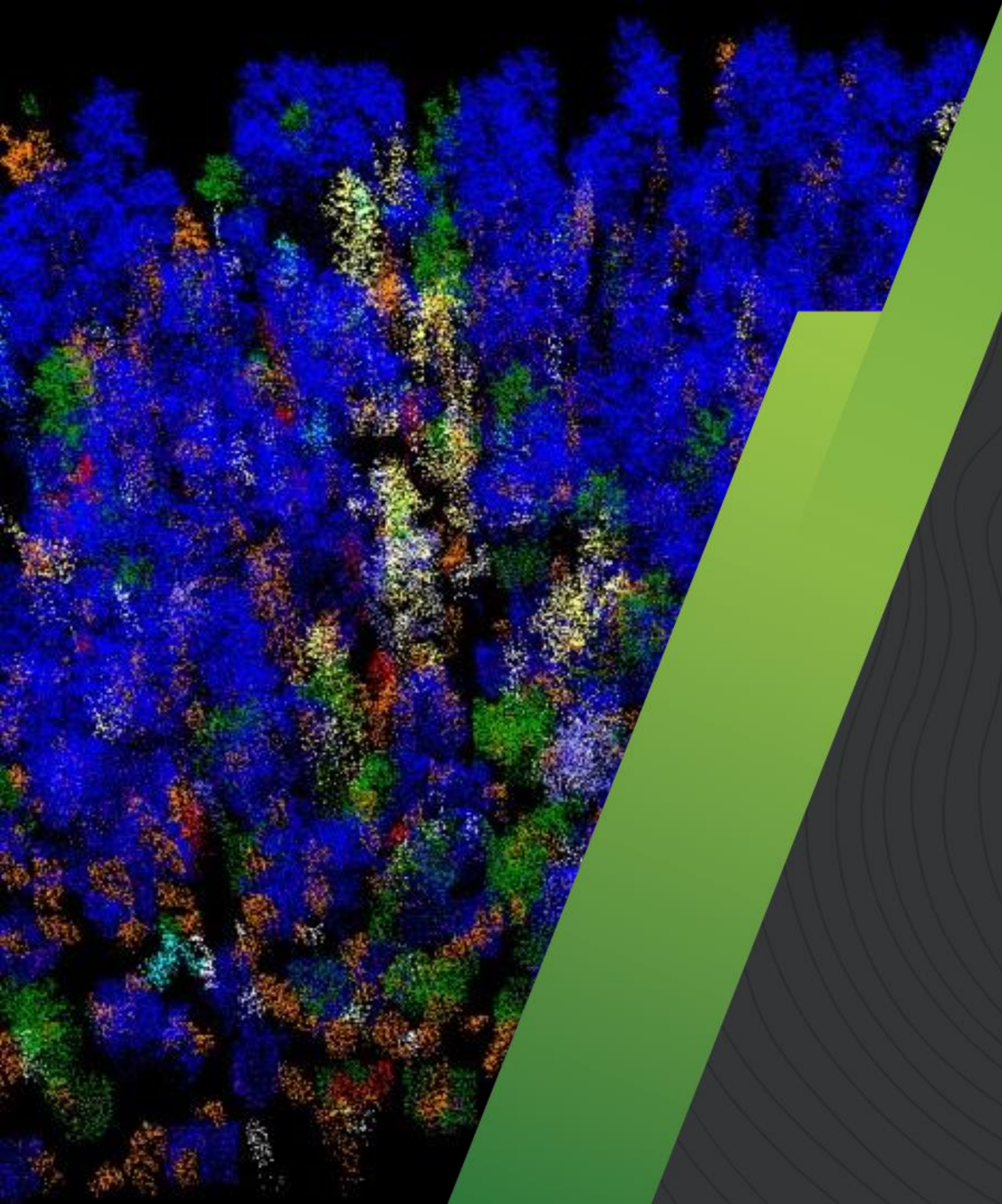


Forest Management Specialists

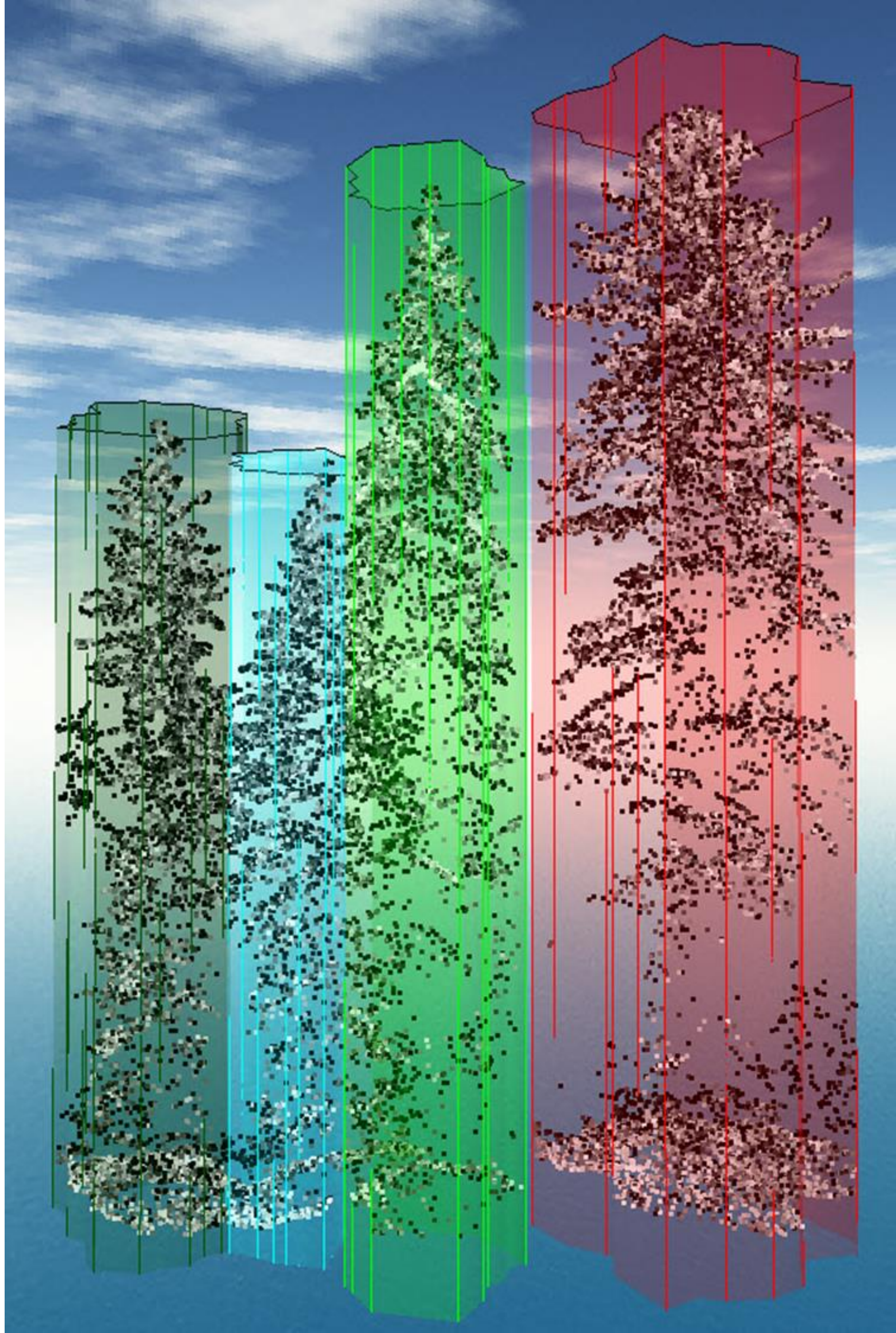
LiDAR Derived Individual Tree, Hexagon, and Polygonal Forest Inventories

Romeo Malette Forest

July 13, 2023

Outline

- Project Recap
  - Individual Tree Inventory (ITI)
  - Hex Inventory (EFI)
- Polygon Inventory (eFRI)



Project Overview

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Strategic Inventory

- Used to assist with Timber Supply Analysis

Hex (Hybrid)

Operational Forest Inventory

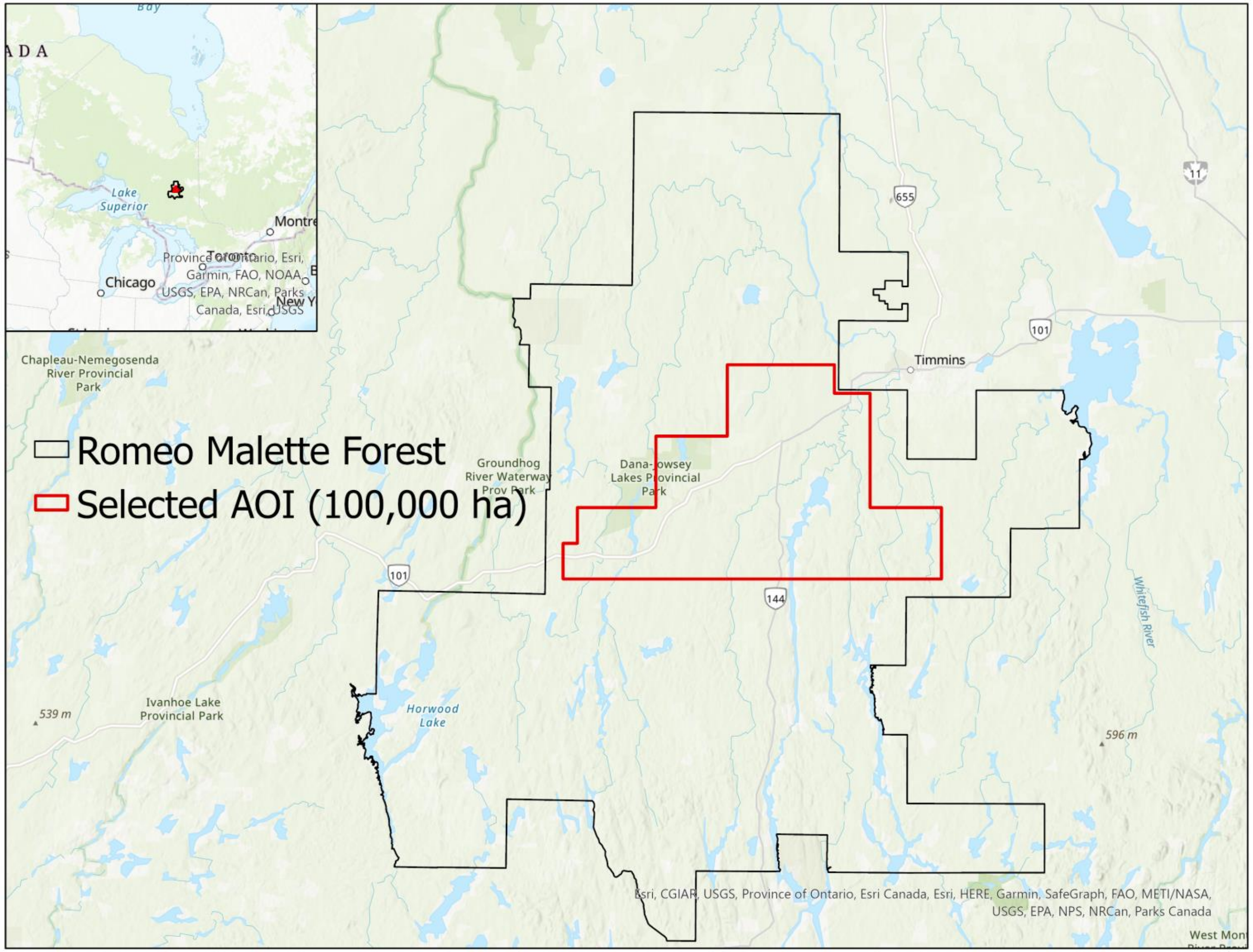
- Field Plot creation & processing
- Area-based Analysis integrated with and built upon the Individual Tree Inventory foundation

Individual Tree Inventory

- Stereo Imagery to capture Stems and sample Areas
- Machine-learning Model Validation
- Segmentation of individual trees from the point cloud
- Analysis and Production of each segmented Tree in the AOI

Romeo Malette Forest

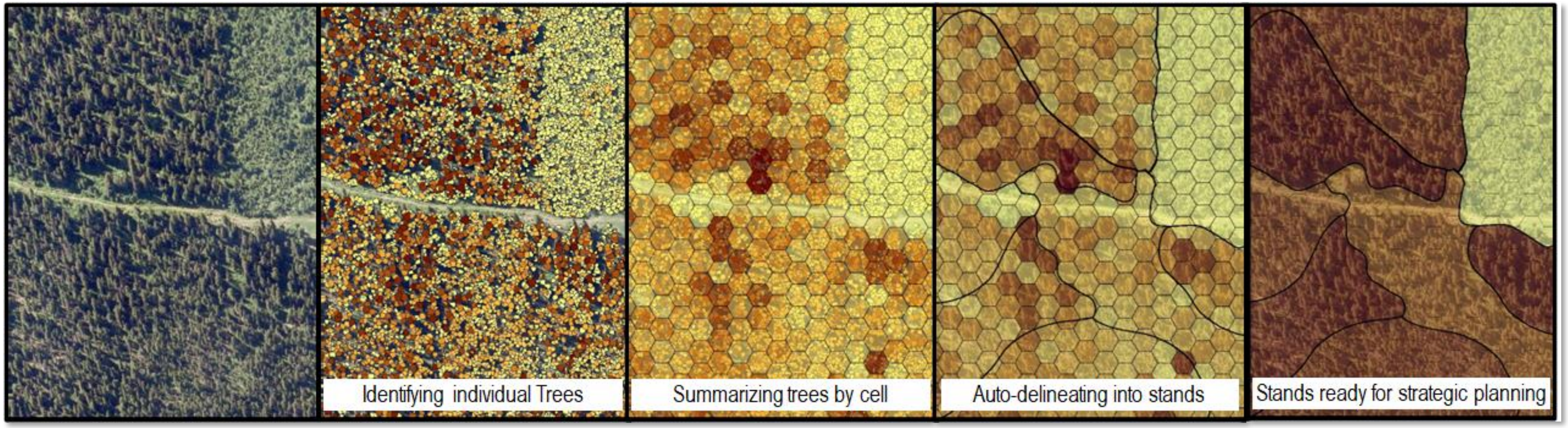
Study Area



Operational to Strategic

Linked Inventories – Different Uses, Same Data

- Individual Tree Inventory
- $400m^2$ hexagons
- Auto-Delineated Polygons
- Assign Attributes



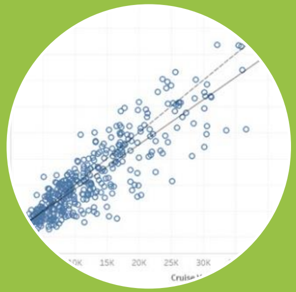
Tree Species Identification Process

Project Area segmented to individual trees

≈ 72 million trees

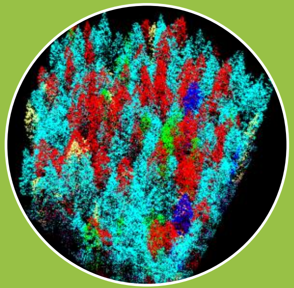
Stereo Sample Collection & Processing

5,097 trees



Model Validation

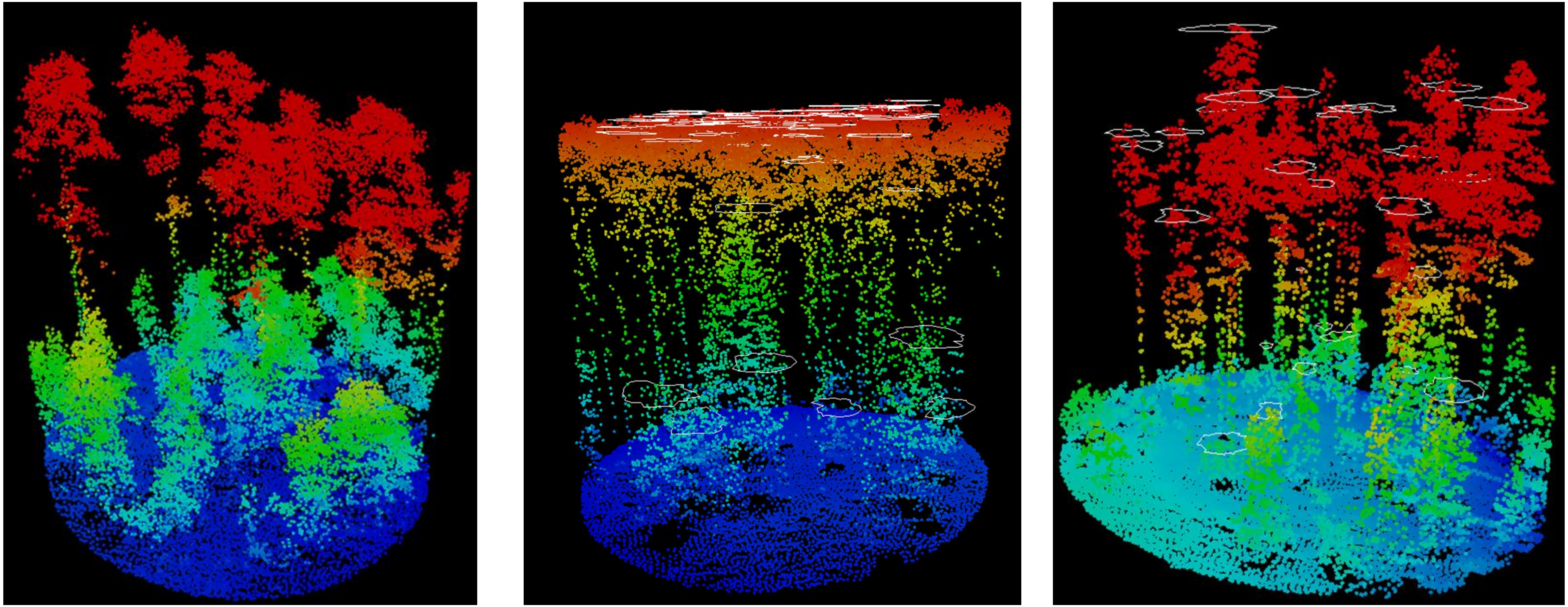
TSI Analysis of Project Area



Attributed Tree Population Produced

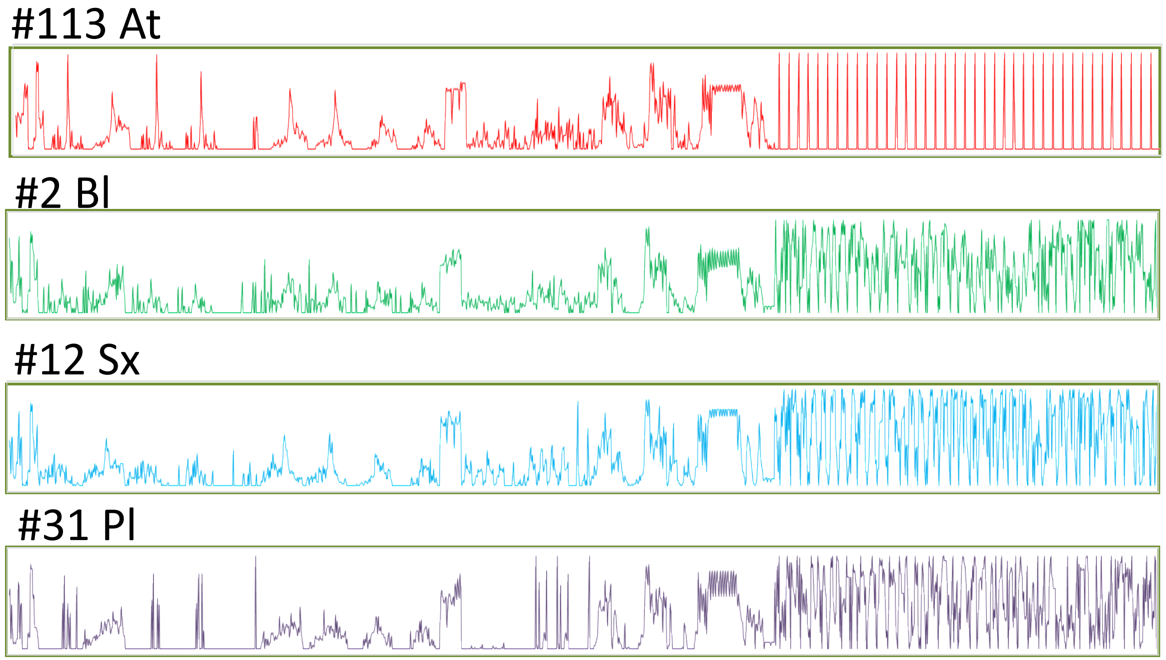
ITI - Example Segmentations

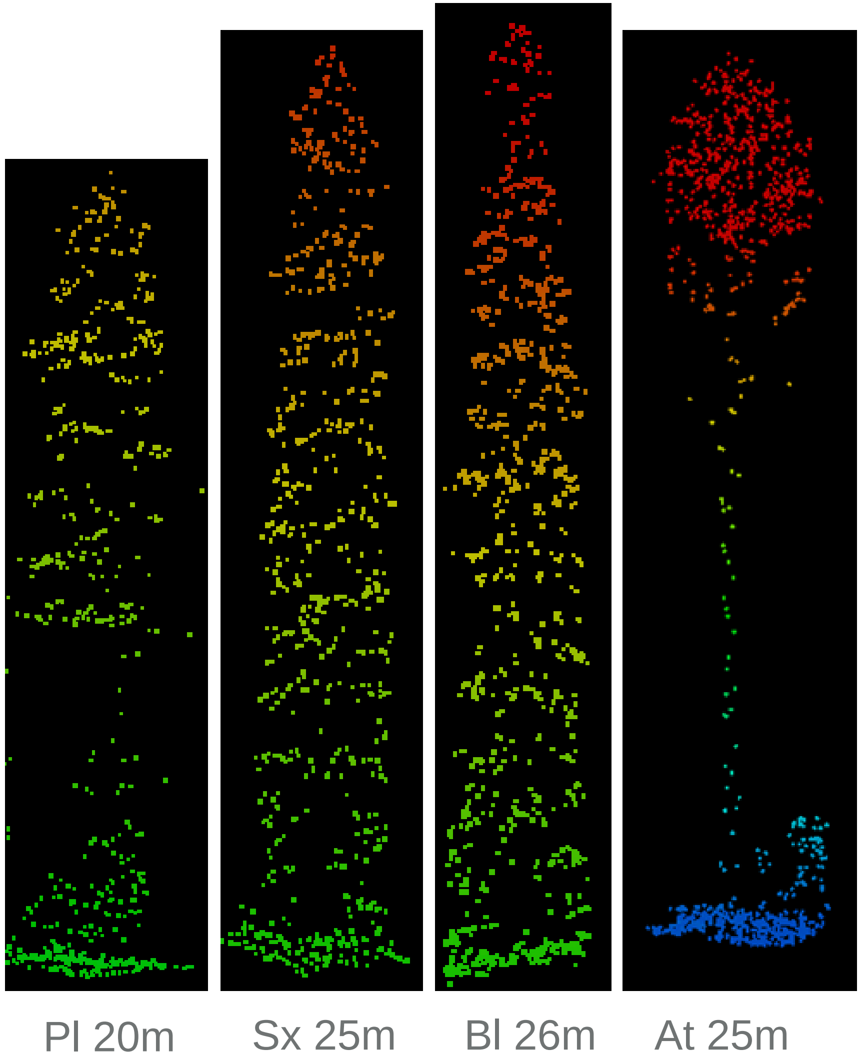
Finding Trees in Lidar Point Clouds



Assigning Species (Tree by Tree)

- Crown metrics taken from the point cloud - crown shape, size, and density, and colour (intensity)
- Species assigned using machine learning algorithm and ground-truthed tree library





Assessing Accuracy: Stem Test

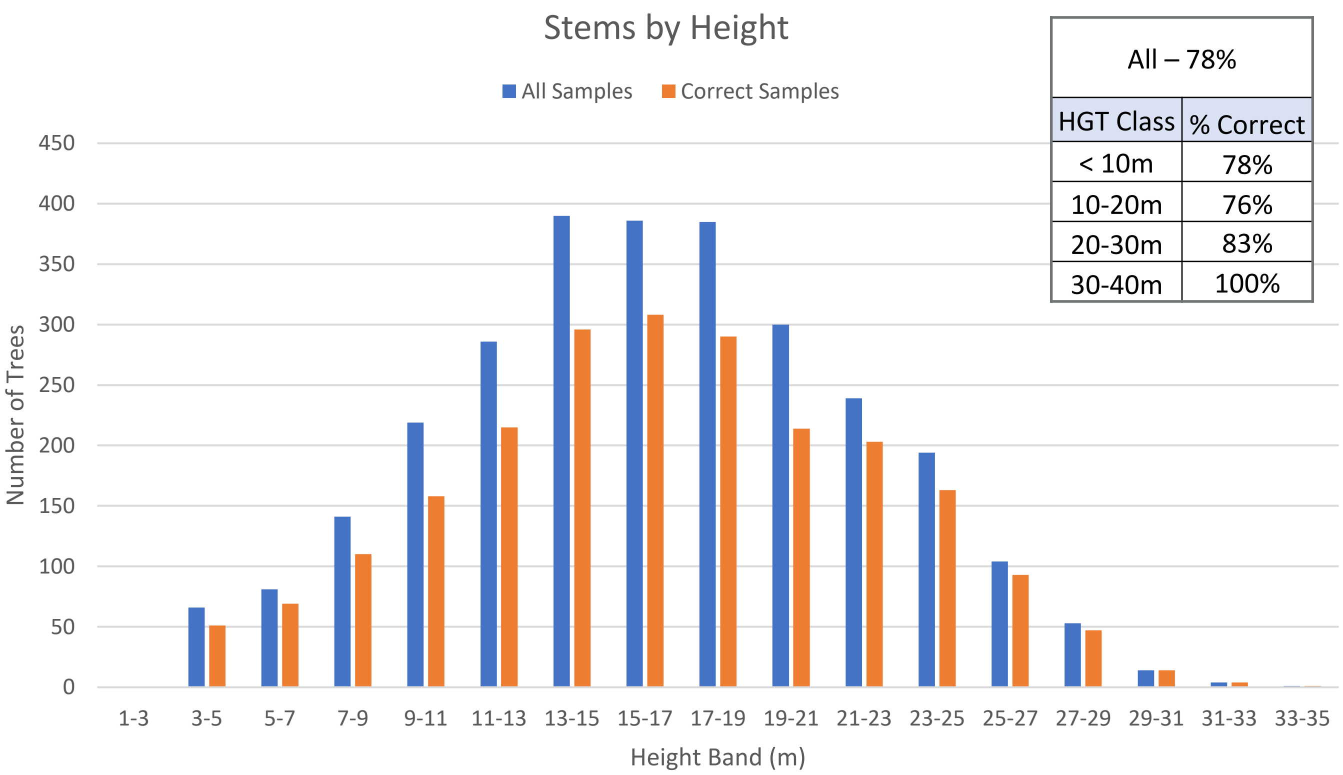
		TSI															
		BF	CW	LA	PJ	PR	PW	SB	SW	AB	BW	MR	PB	PT	SN	Total	Hit rate (Correct/ Photo Interp)
Photo Interpreter	BF	184	5	0	4	0	0	26	1	0	2	0	0	0	0	222	83%
	CW	2	162	2	1	0	0	4	2	1	11	0	0	0	0	185	88%
	LA	9	1	170	7	0	0	34	2	0	1	0	0	0	0	224	76%
	PJ	5	2	1	281	2	0	57	1	0	8	0	0	7	0	364	77%
	PR	0	0	0	8	29	1	0	2	0	1	0	0	0	0	41	71%
	PW	0	0	2	3	0	113	3	5	0	1	0	0	0	0	127	89%
	SB	24	0	9	13	0	1	410	15	0	4	0	0	0	2	478	86%
	SW	4	1	0	2	0	5	22	125	0	3	0	0	0	0	162	77%
	AB	0	0	0	0	0	0	0	0	89	12	1	0	1	0	103	86%
	BW	2	6	1	5	0	0	2	0	7	230	1	18	24	1	297	77%
	MR	2	2	0	0	0	0	0	0	4	22	22	0	5	0	57	39%
	PB	0	2	0	1	0	0	2	0	1	35	1	62	80	0	184	34%
	PT	0	0	0	3	0	0	2	1	1	22	0	13	227	0	269	84%
	SN	0	2	0	5	0	0	4	0	0	1	0	0	6	132	150	88%
Total		232	183	185	333	31	120	566	154	103	353	25	93	350	135	**2863**	**78%**
Precision (Correct/ TSI)		79%	89%	92%	84%	94%	94%	72%	81%	86%	65%	88%	67%	65%	98%		
Weighted Avg (Hit rate & Precision)		**81%**	**88%**	**83%**	**81%**	**81%**	**91%**	**79%**	**79%**	**86%**	**71%**	**54%**	**45%**	**73%**	**93%**		

The ground truth stem test is the most comprehensive stem test conducted and includes 2,863 trees. It includes all samples > 5m in height and the mix of species samples was designed to assist with model creation. As a result, the mix does not represent the species mix found in the land base.

Strengths here include good separation of conifer from deciduous species (97%) and good separation of live trees from dead trees (99%).

Issues include some overcalling of BW as well as overcalling of SB, although SB has a good weighted average score.

Stem Test (By Height)

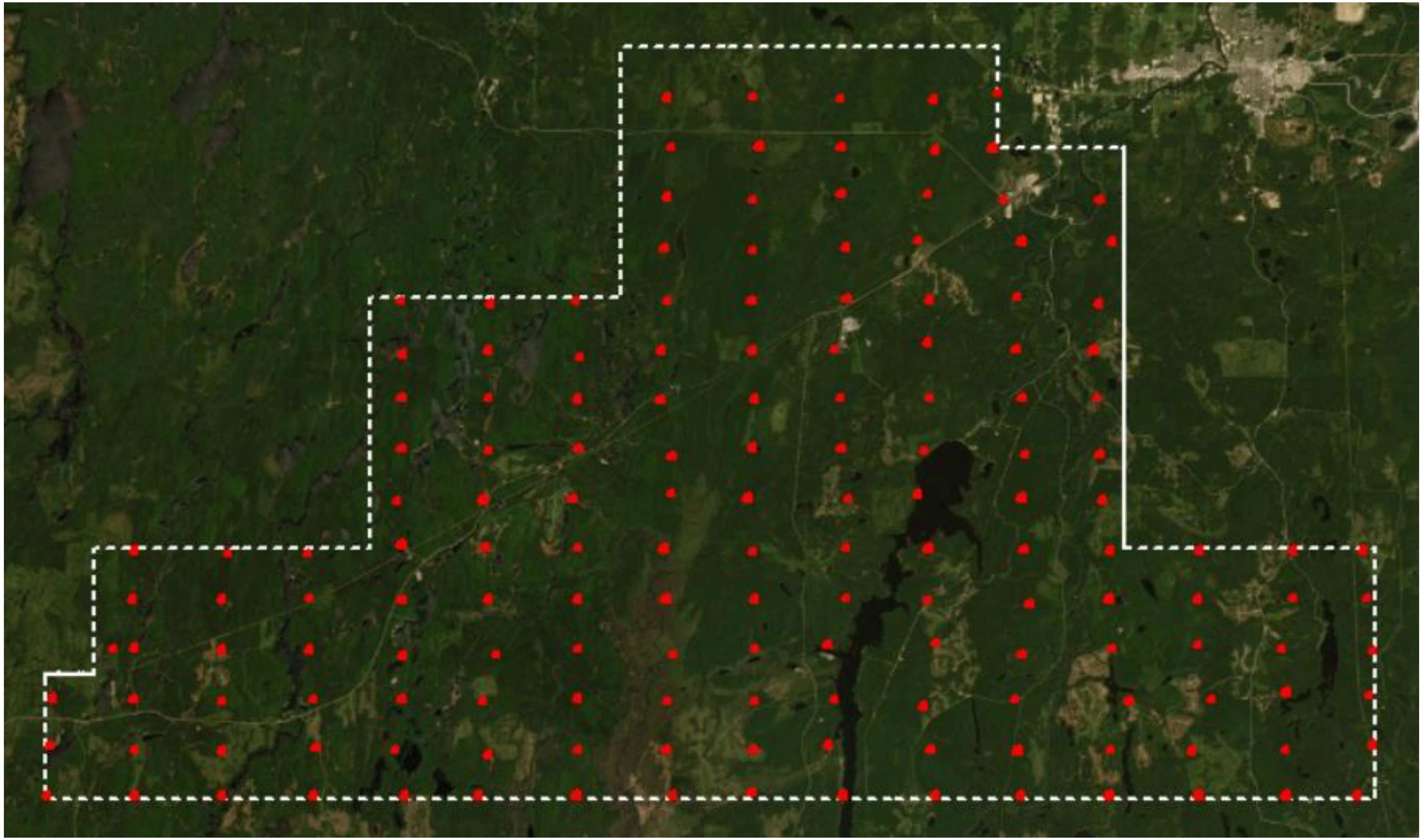


All – 78%	
HGT Class	% Correct
< 10m	78%
10-20m	76%
20-30m	83%
30-40m	100%

As expected, overall accuracies are highest for the largest trees. The <10m accuracy is above expectations primarily due to the lack of diversity in that height group.

Forestry Futures Trust – Romeo Mallette Production Area and Validation Data

FORSITE



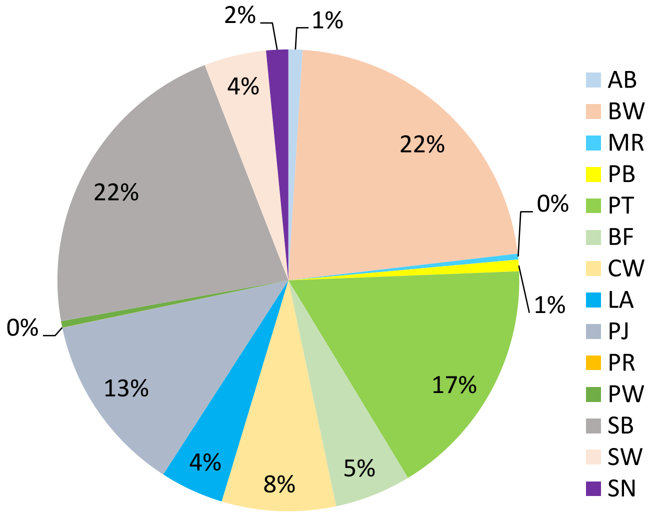
Validation areas used to create the species identification model were selected across the production area. These 162 validation areas represent a mixture of species and natural sub-regions.

AOI

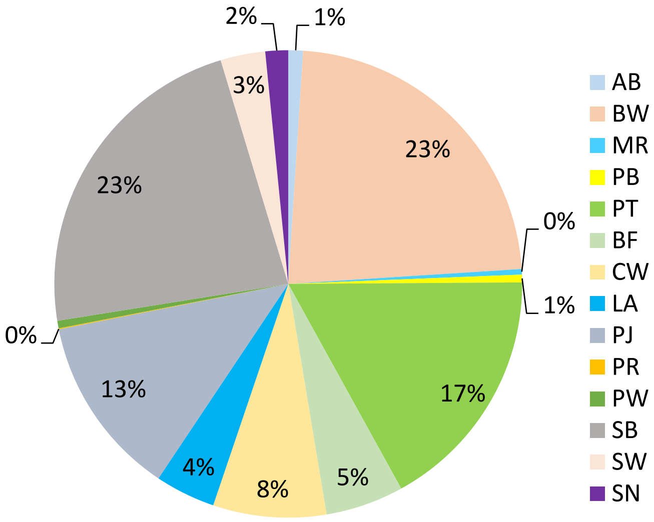
Validation Areas

Comparison to Photo Interp

Validation Area Stereo Canopy Cover



Validation Area TSI Canopy Cover



Overall, TSI is finding a very similar species breakdown by canopy cover to what was stereo interpreted in the validation areas. The pie charts on the left reflect the aggregate total for 162 areas. Detailed breakdowns follow in later slides.

Species	AB	BW	MR	PB	PT	BF	CW	LA	PJ	PR	PW	SB	SW	SN
R Square	0.972	0.956	0.172	0.347	0.967	0.909	0.987	0.983	0.977	0.002	0.934	0.970	0.856	0.993
Standard Error	0.010	0.050	0.012	0.008	0.046	0.028	0.022	0.019	0.036	0.002	0.007	0.060	0.024	0.015
Observations	162	162	162	162	162	162	162	162	162	162	162	162	162	162

	CN	DC	DE
R Square	0.988	0.986	0.993
Standard Error	0.043	0.044	0.015
Observations	162	162	162

Individual Tree Inventory - Example

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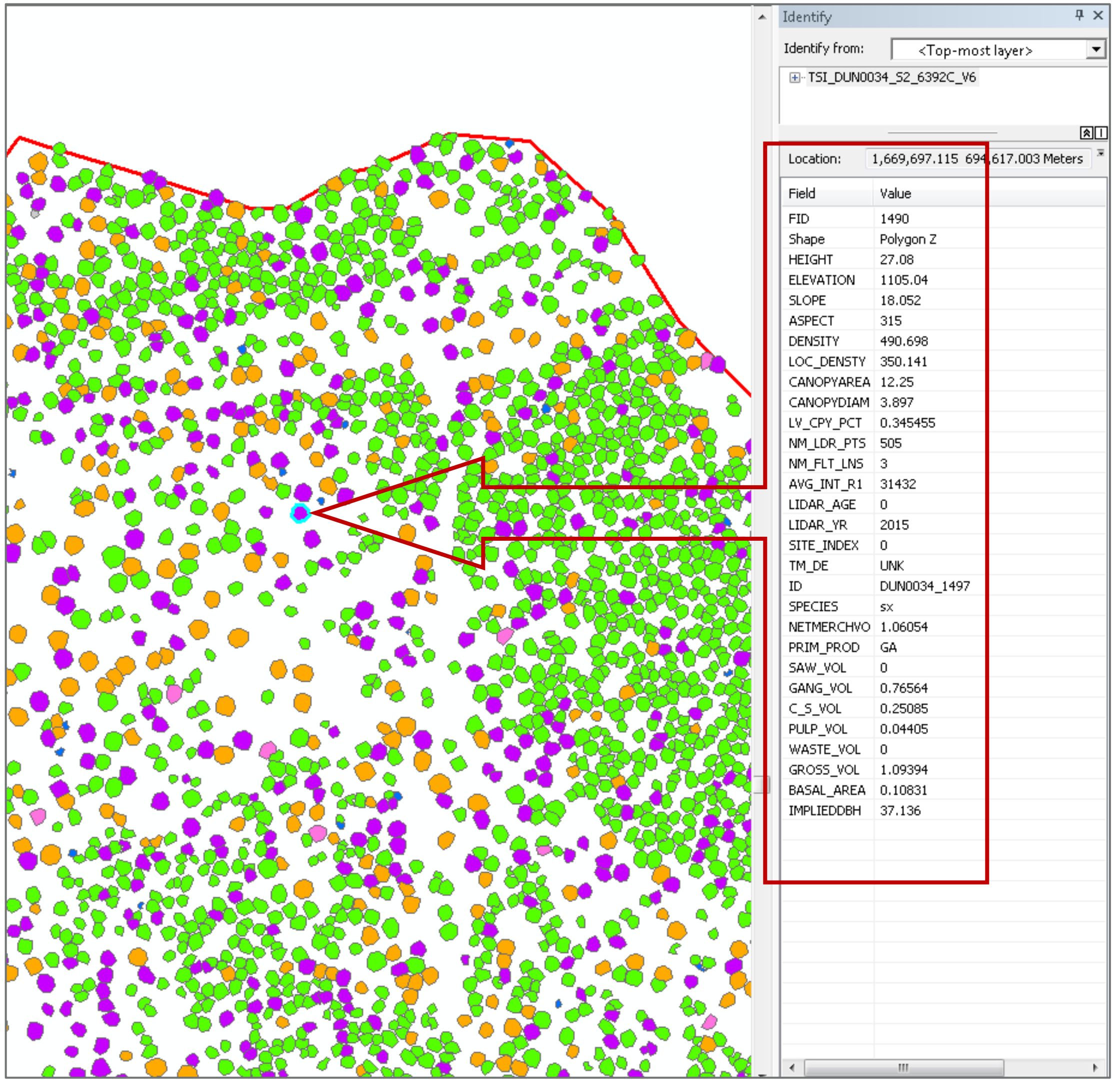
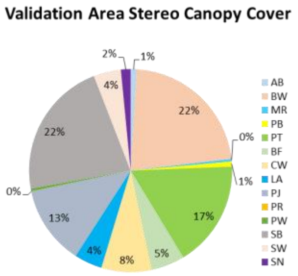
- Each tree has a unique id and associated list of attributes
- Highlighted example shows a Sw tree:
  - 27.1m Ht
  - 37.1cm DBH
  - 1.09 m3
- Can produce stand and stocking tables similar to cruise, based on almost **complete census** within any user defined polygon.

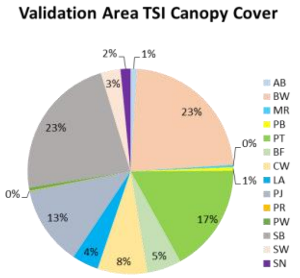


Tree Species Accuracy

Contract Standards

- Tree Species 5-10m tall >=60%: **Achieved 78%**
- Tree Species >10m tall >70%: **Achieved 78%**
- Conifer Deciduous > 90%: **Achieved 97%**
- Model matches land base species mix well
  (not over-fit to individual tree samples)





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Hex Inventory

Lidar + ITI Results + Plot Data

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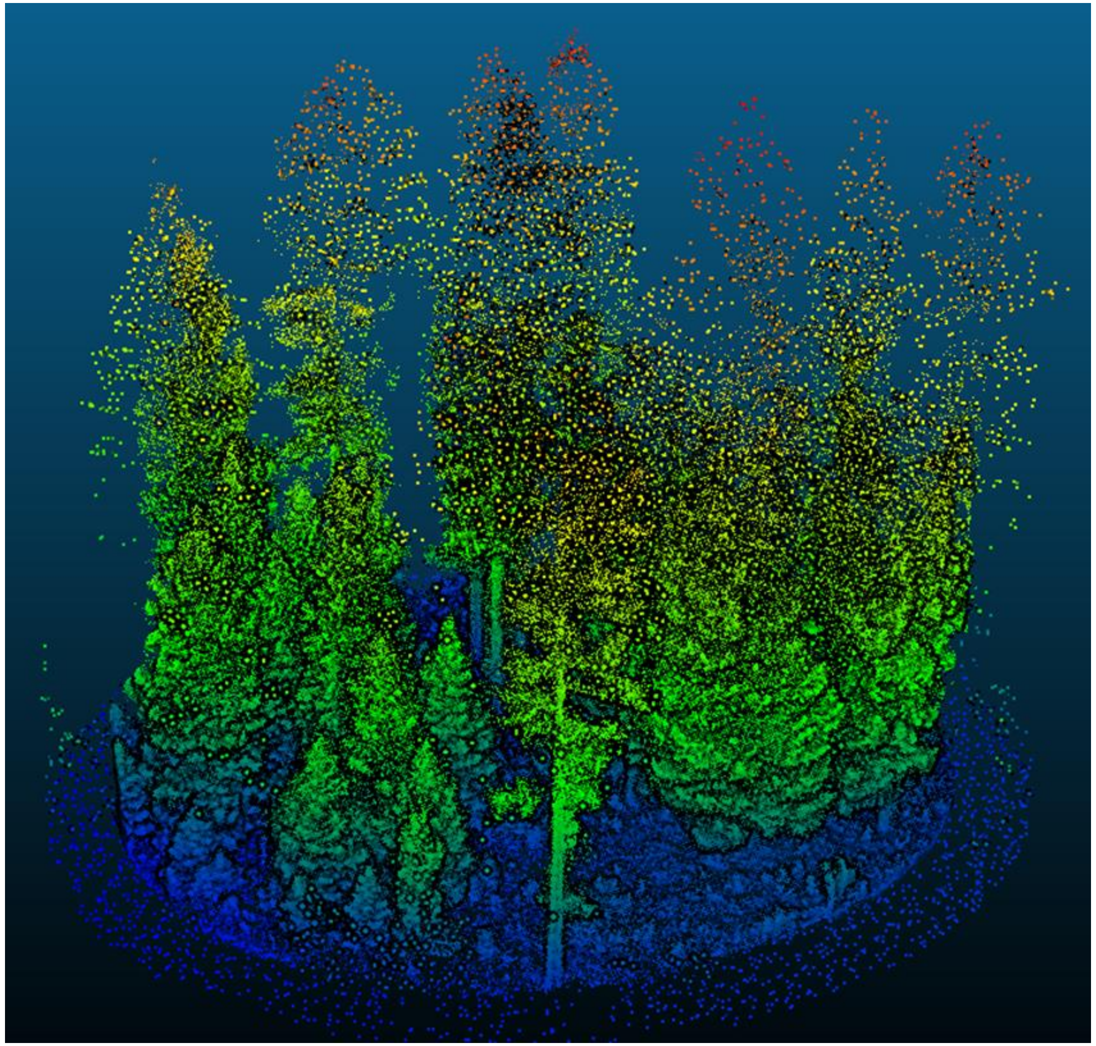
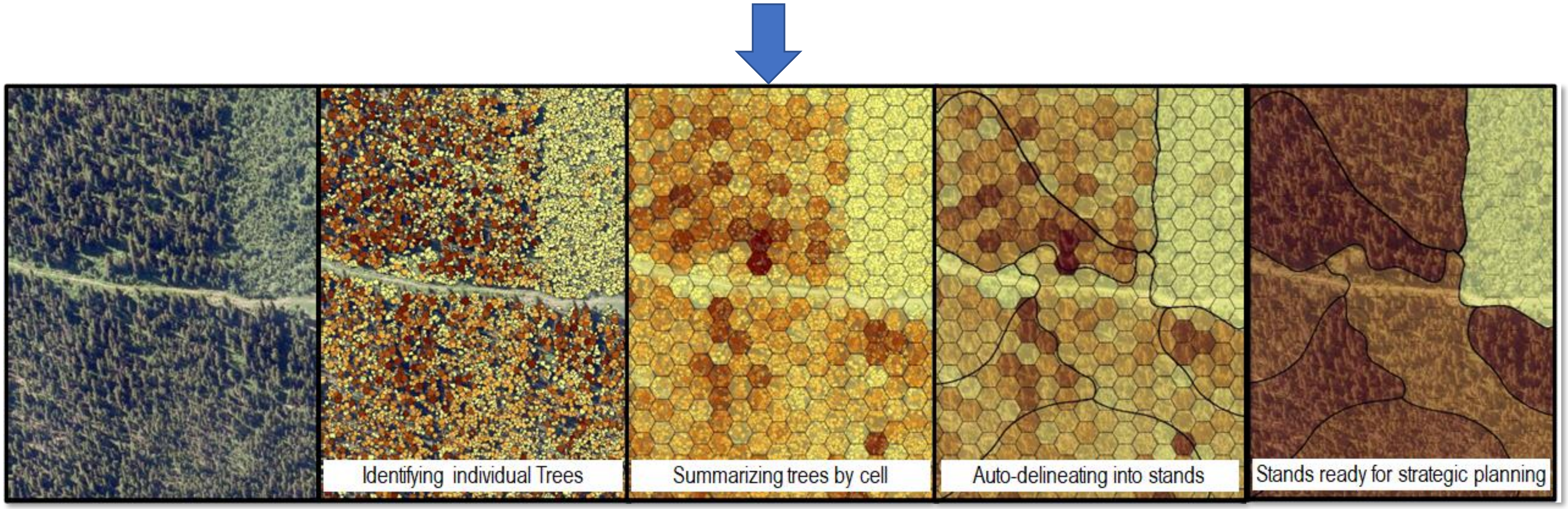
- Used at landscape scale....
- Collect Plot data (400m^2 fixed area)
- Aggregate ITI data for Plots
- Calculate ABA metrics for Plots
- Create Predictive Models (ITI + ABA)
  - Vol, SPH, BA, Tree Lists, etc
- Fill in Species and Heights from ITI



Operational to Strategic

Linked Inventories – Different Uses, Same Data

Attributes predicted using
ground plot data



Hex Attributes

Net Merch Volume

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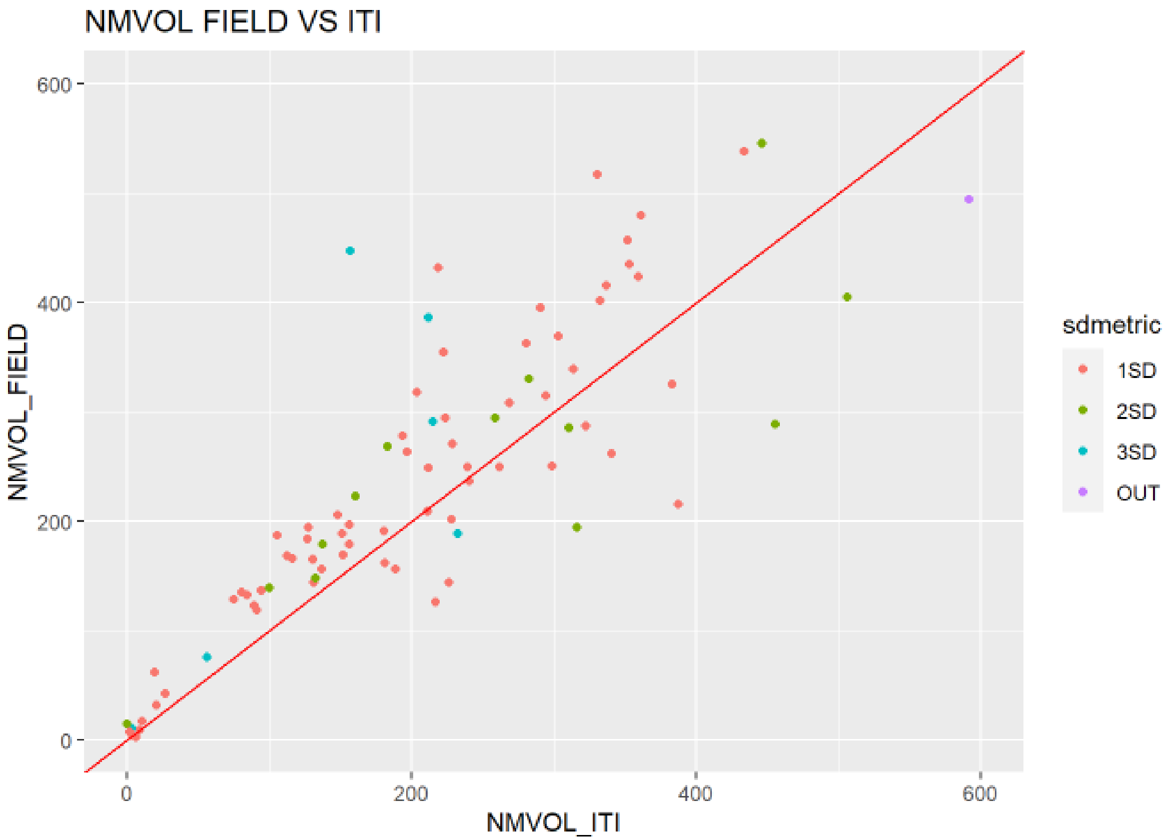
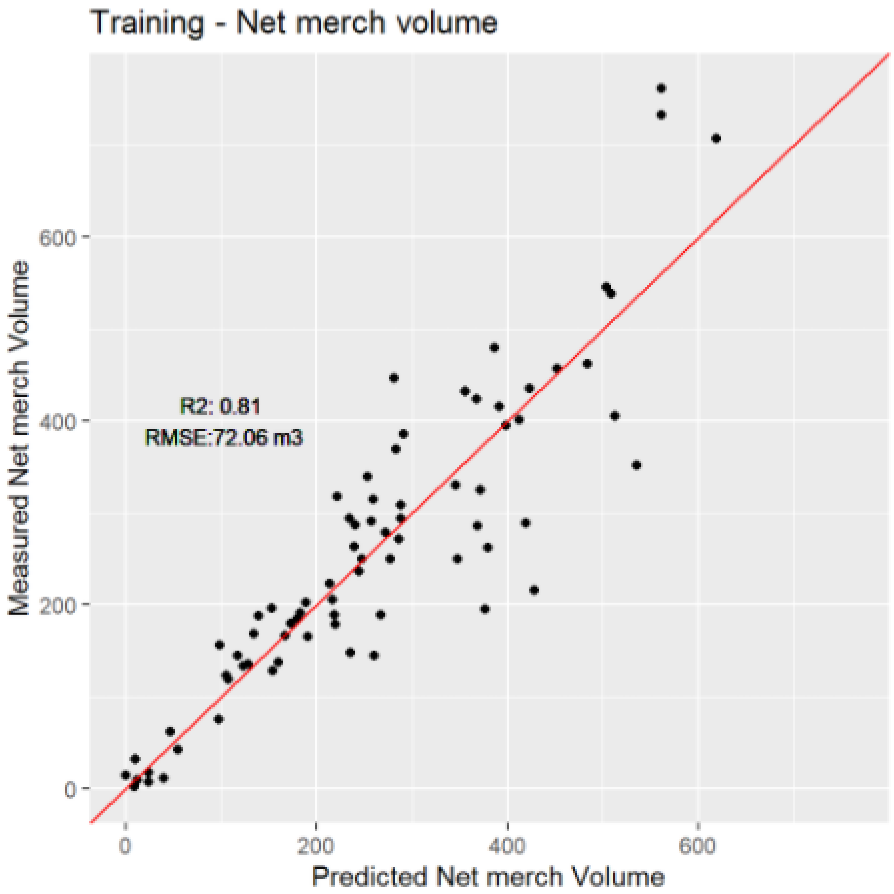
ITI



Hex Prediction



Hybrid (Hex) EFI Product

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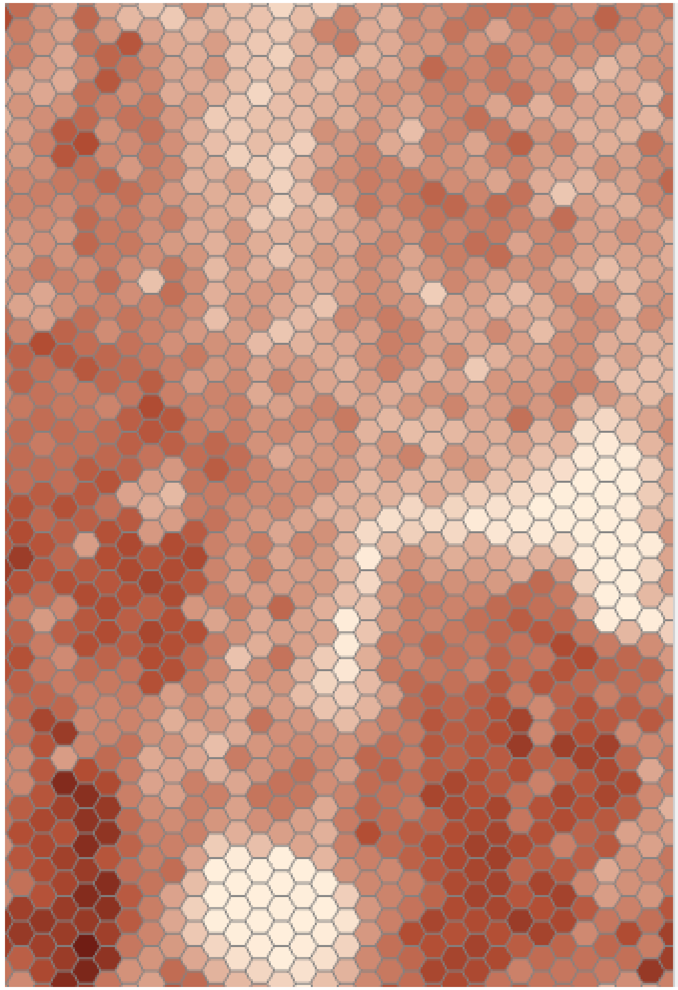
Hexs with Final Attributes

- Species %'s
- Max ht, Top Ht, Lorey Ht
- Basal Area
- SPH
- Avg DBH, QMD
- Crown Cover
- Tree list
- Vol/ha by species
- Dead percentage



HEX_INVENTORY - FN-979

PRODGRIDID	N85
EXPTGRIDID	A6
Shape_Length	74.448397
Shape_Area	400.000086
LEADING_SPP	pt
CROWN_CLOSURE	97
GROSS_VOL_PRED_HA	332.78
GROSS_MVOL_PRED_HA	250.13
NET_MVOL_PRED_HA	188.94
DWB_FACTOR	0.244633
SPH_GT_5m	1746
SPH_MERCH	1436
BASAL_AREA_HA	38.88
MERCH_BASAL_AREA_HA	36.08
LIVE_MERCH_STEMS_PER_HA	1436
DEAD_MERCH_STEMS_PER_HA	0
STAND_PERCENTAGE_DEAD	0
GROSS_MERCH_VOL_LIVE	250.13
GROSS_MERCH_VOL_DEAD	0

Creating A Polygon Inventory

FORSITE

Project Goal

- Produce homogenous polygons with FRI-like inventory attributes suitable for strategic planning purposes (timber supply analysis)
- Proof of concept for how a new polygon inventory could be created from LiDAR without the need for wall-to-wall photo interpretation

Creating A Polygon Inventory

A new approach

- Traditionally photo interp. polygons are delineated based on similar characteristics in:
  - Ecosite, tree species, landforms
  - Interpreter skill / experience.
- Auto delineated polygons are created using an eCognition segmentation algorithm that looks to grow regions (stands) with similar values for leading species, stand height, and crown closure

Polygon Delineation

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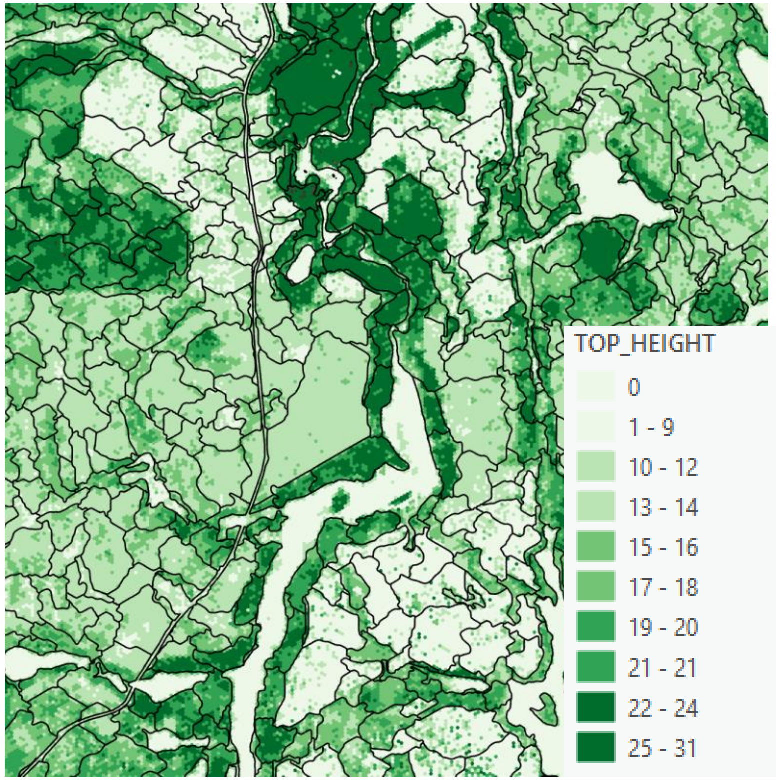
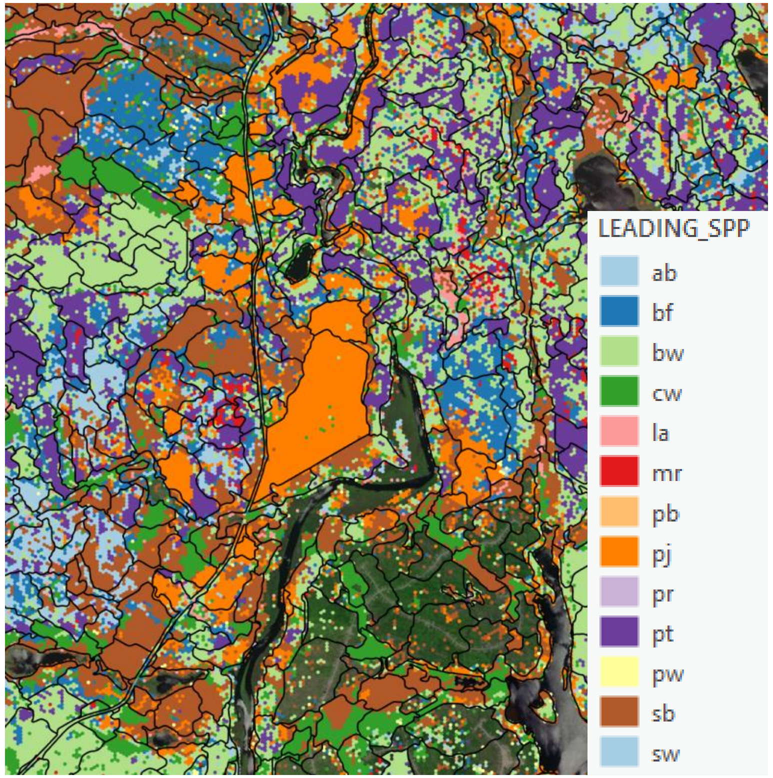
Input Datasets and Final Polygons

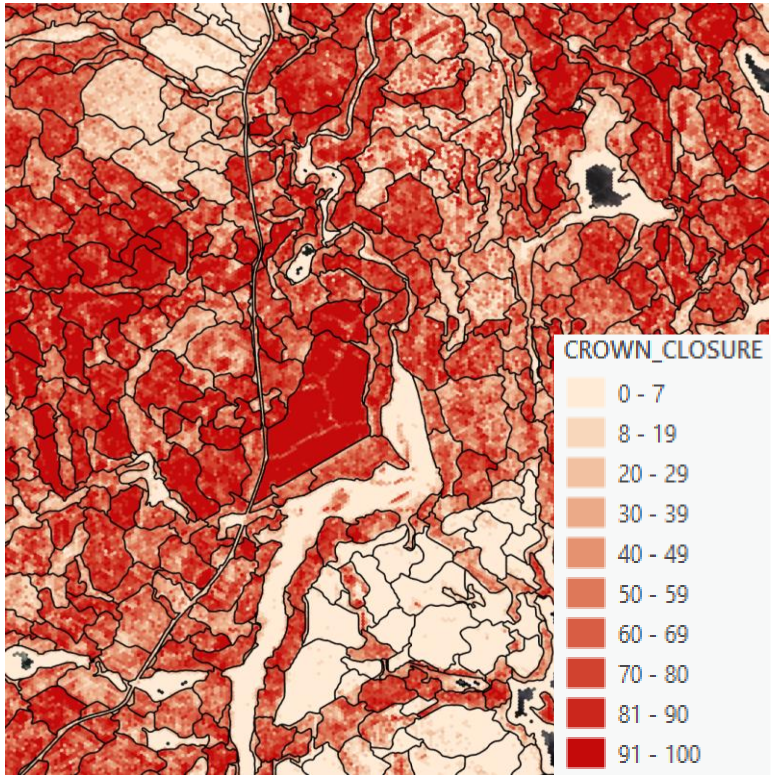
Top Height



Lead Species



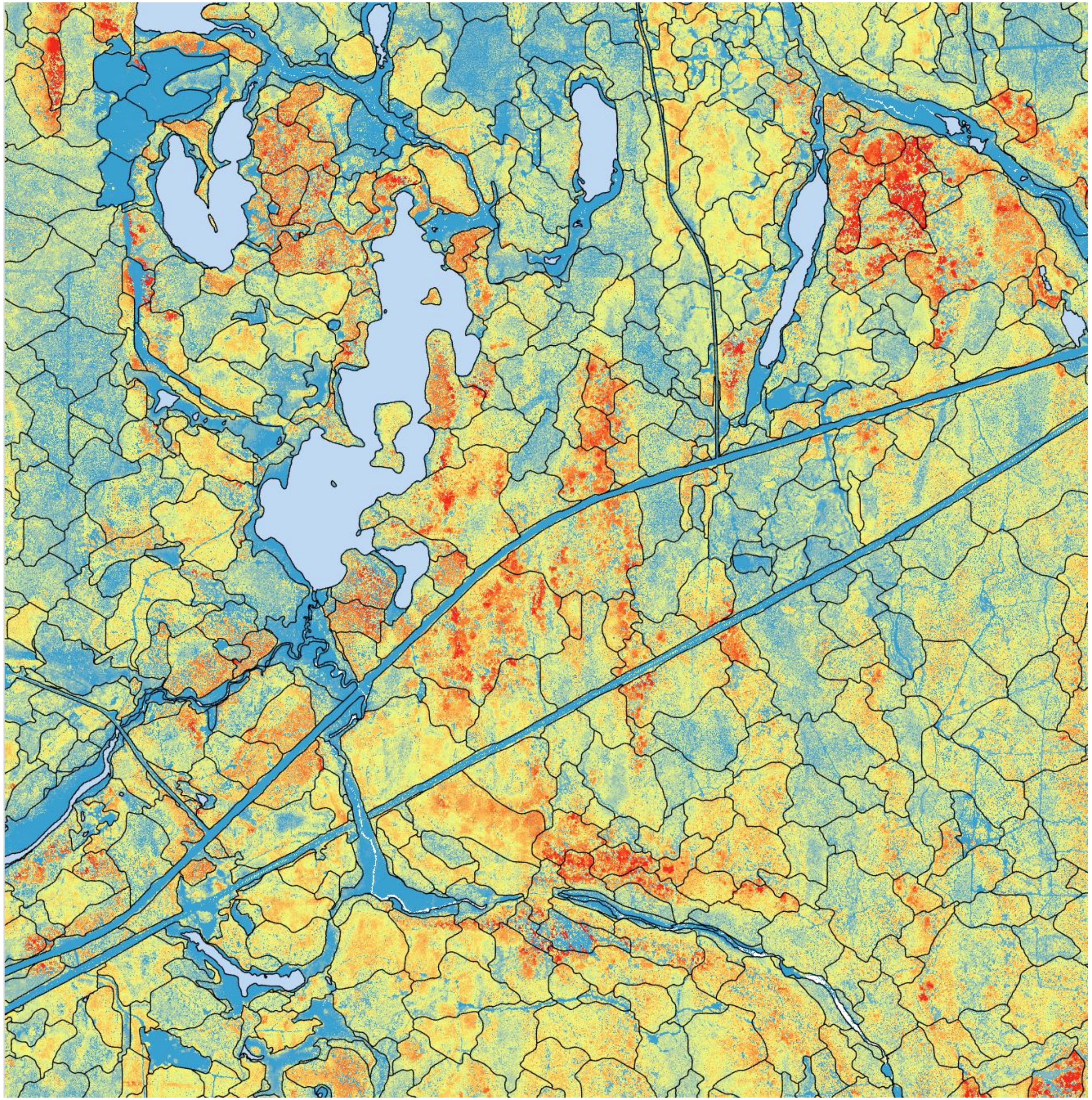
Crown Cover



Creating Inventory Polygons

A Fusion of Data Sources

- Non-forest from ‘05 FRI
- LiDAR water
- Automated polygons for remaining forest
- Silviculture Records / Openings / New Interp



Creating A Polygon Inventory

FORSITE

Polygon Attribution

The finalized polygons were attributed using the HEX and ITI data as follows:

1. Species Proportions	Summary of ITI Species weighted by BA
2. Basal Area (total, merch)	Area Weighted Avg of Hex Values
3. Volumes (gross, gross merch, net merch)	Area Weighted Avg of Hex Values
4. Stems per Hectare:	Area Weighted Avg of Hex Values
5. Heights (top, Lorey)	Area Weighted Avg of Hex / ITI Values / LEFI (Top Height)
6. Quadratic Mean Diameter (merch)	Area Weighted Avg of Hex Values

Accuracy of the 6 categories of attributes above were the main focus of this project. Attributes that were the focus of other FFT-KTTD projects were not considered including: vertical structure and site index.

Comparison of Polygon Size

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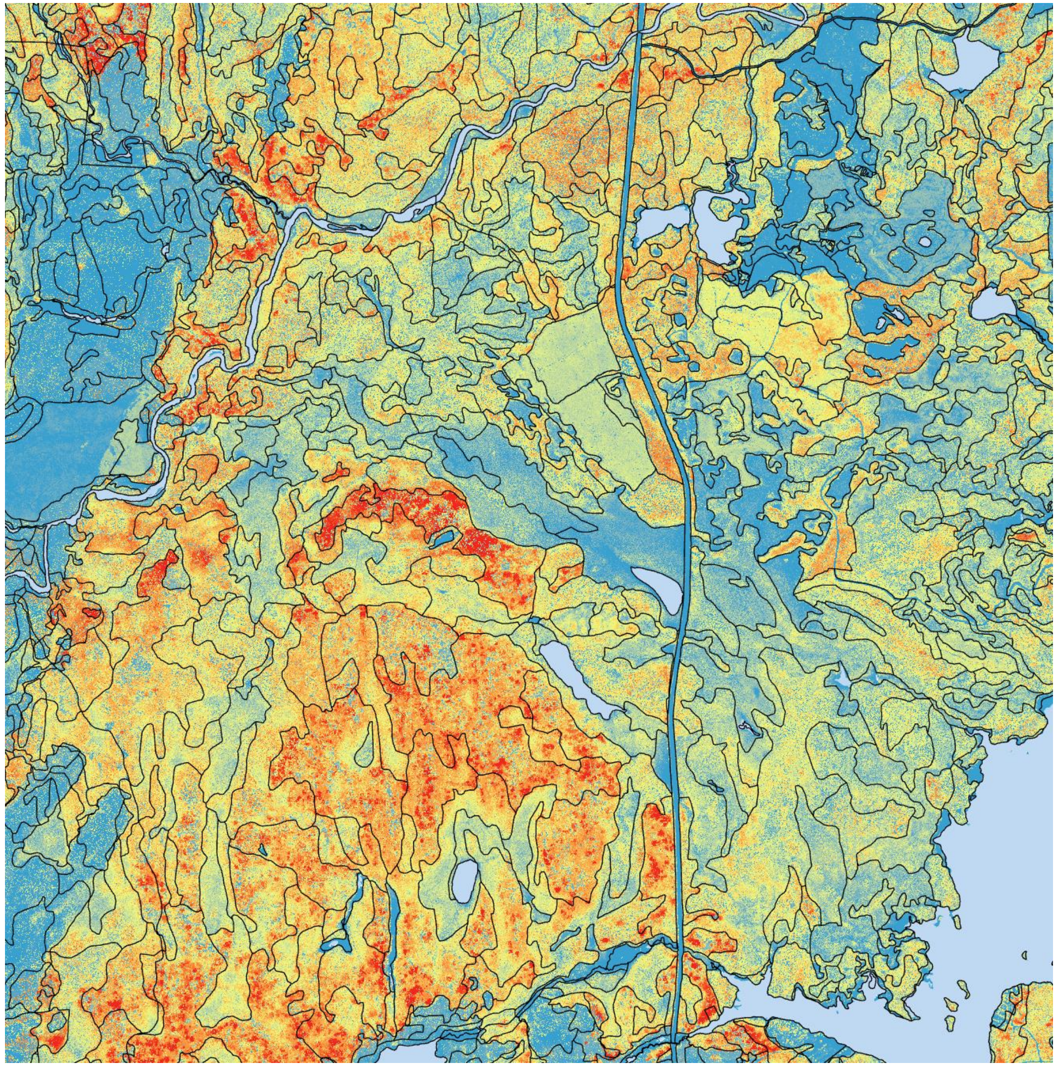
'05 FRI – '18 Segmentation

- Auto delineated polygons result in:
  - More, smaller polygons
  - Less variation in size

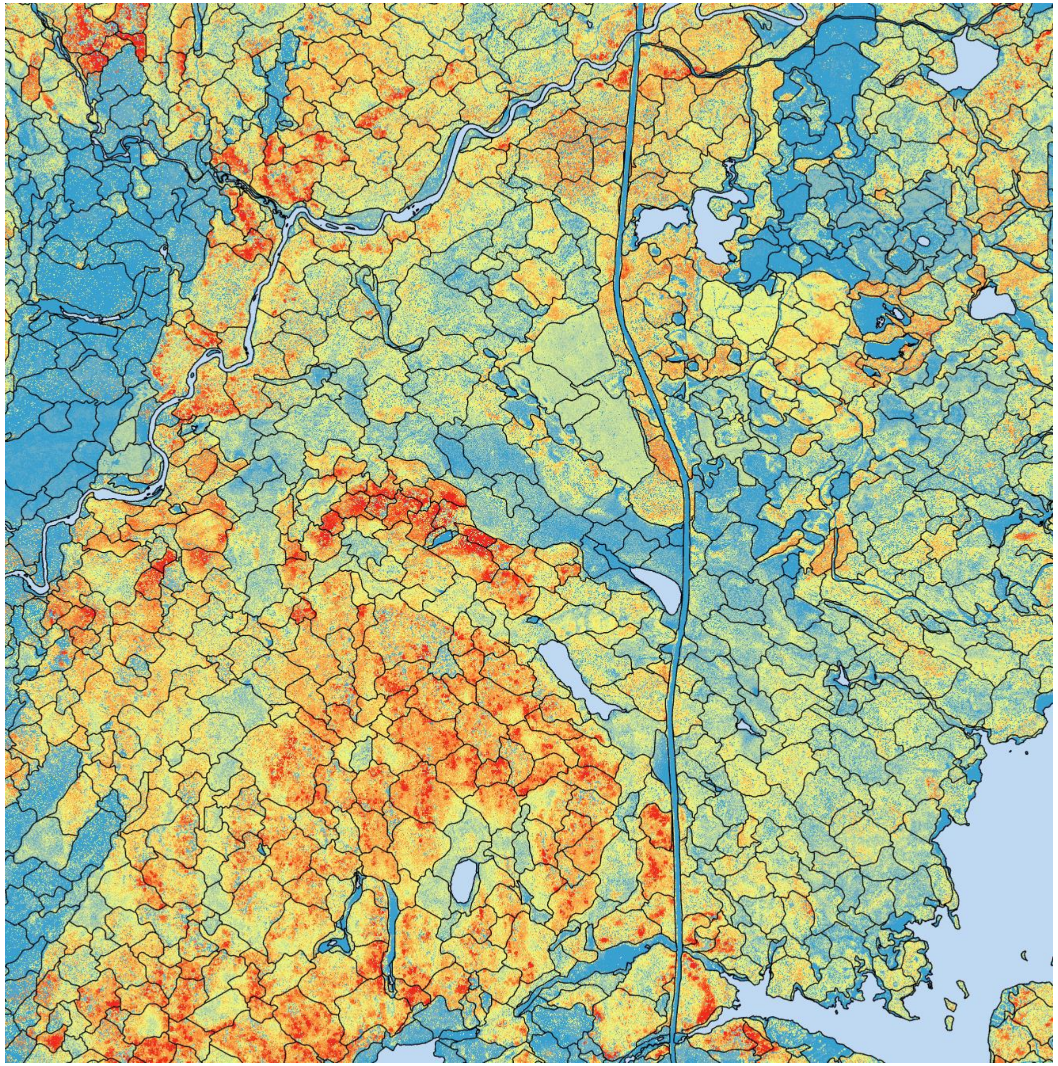
	2005 FRI	2023 Polygon Segmentation	Difference
Number of polygons (FOR)	12,095	20,757	8,662
Minimum (Ha)	0	0	(0)
Maximum (Ha)	145	40	(104)
Mean (Ha)	7	4	(3)
Median (Ha)	4	3	(1)
Standard Deviation (Ha)	10	4	(7)
Variance (Ha)	106	13	(93)

Polygon Comparison

FRI (7 Ha avg)



Automated (4 Ha avg)

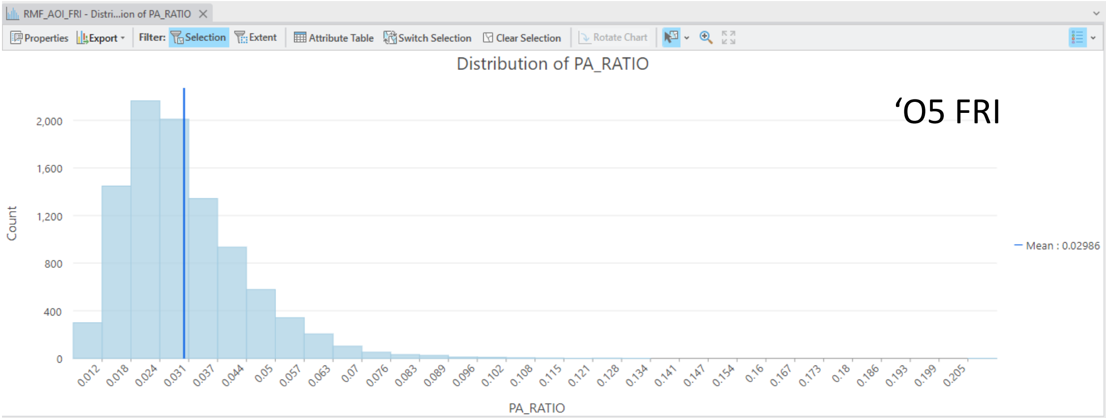


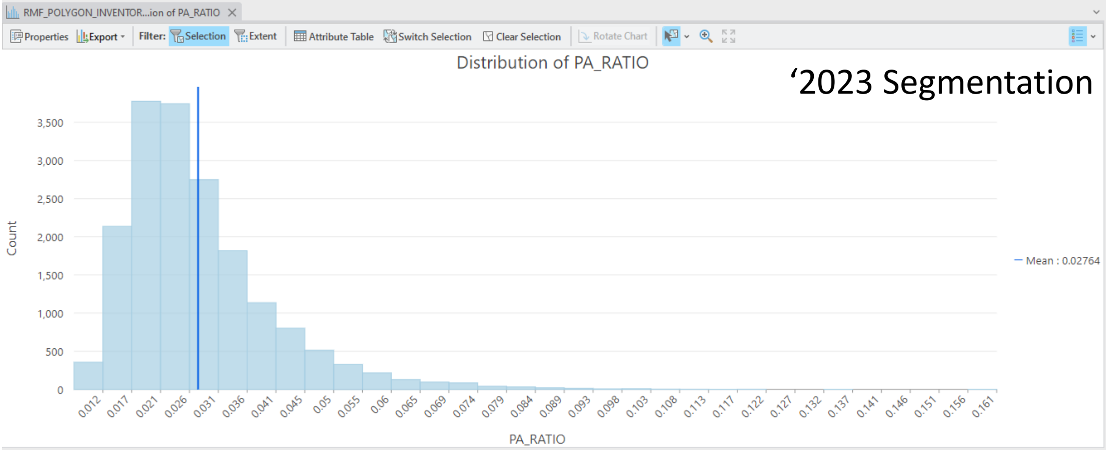
1 : 20,000

Comparison of Polygon Shape

Perimeter / Area (Edge) Ratio

- The perimeter-area ratio is an indicator of polygon shape complexity.



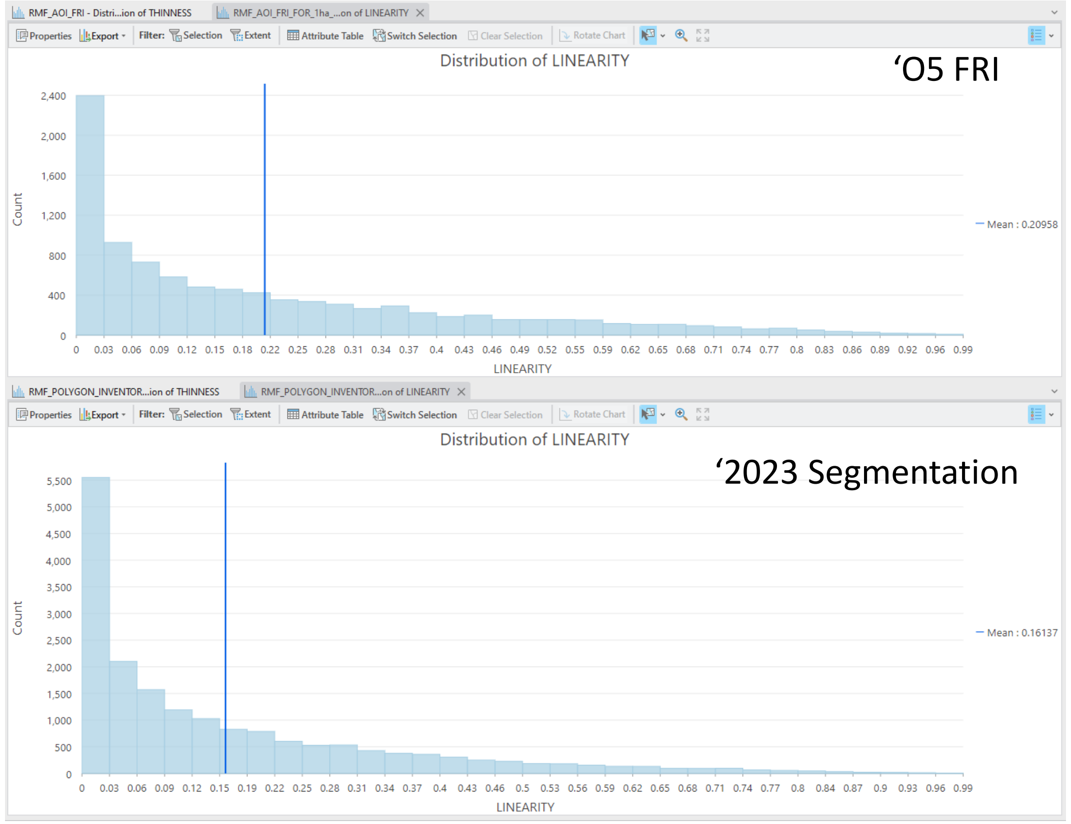


Perimeter / Area (Edge) Ratio Polygons > 1 ha	2005 FRI	2023 Polygon Segmentation
Number of polygons (FOR)	9,569	18,018
Minimum	0.005	0.007
Maximum	0.212	0.161
Mean	0.030	0.028
Median	0.027	0.025
Standard Deviation	0.014	0.012

Comparison of Polygon Shape

Linearity Index

- Linearity index is a measure of how well a polygon can be described by a straight line.

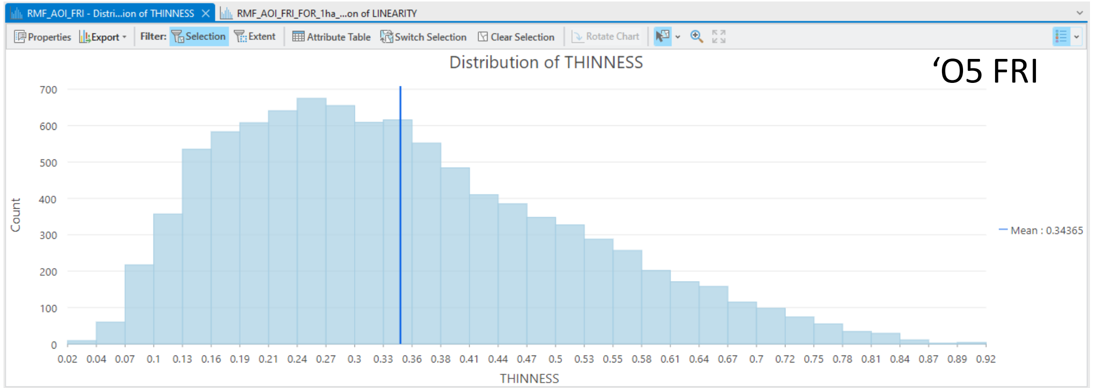


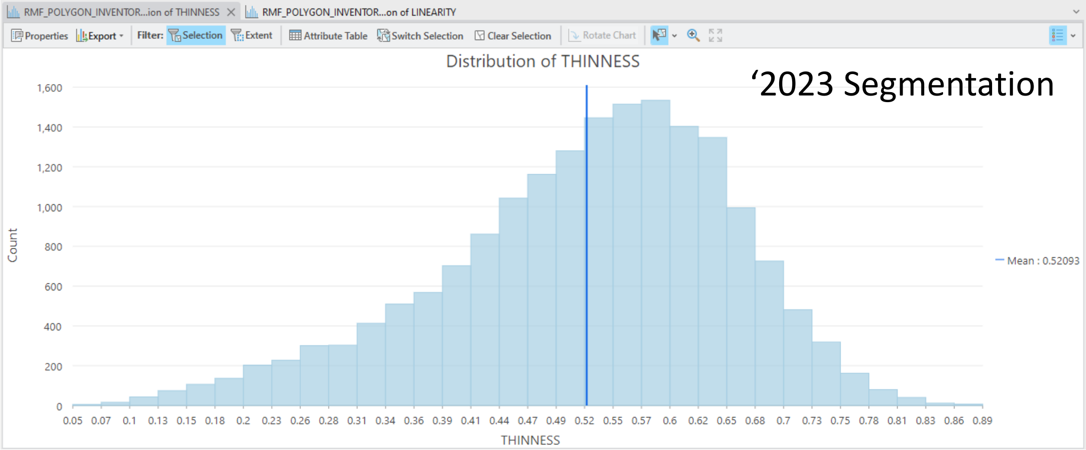
Linearity Index Polygons > 1 ha	2005 FRI	2023 Polygon Segmentation
Number of polygons (FOR)	9,569	18,018
Minimum	0.000	0.000
Maximum	0.986	0.991
Mean	0.210	0.161
Median	0.132	0.089
Standard Deviation	0.218	0.187

Comparison of Polygon Shape

Thinness Ratio

- The Thinness Ratio describes the relation between a polygons perimeter to its area using geometric attributes of a circle as a basis for comparison.



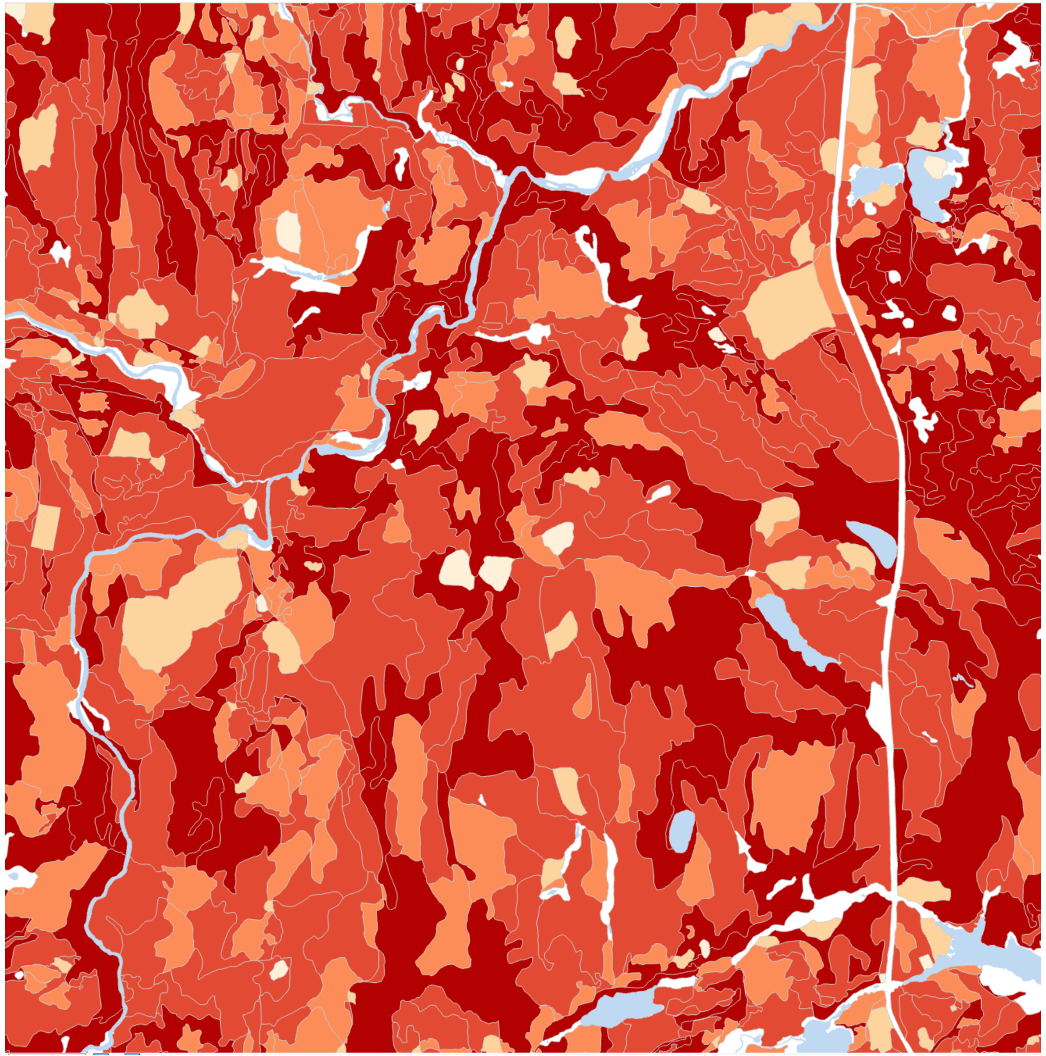


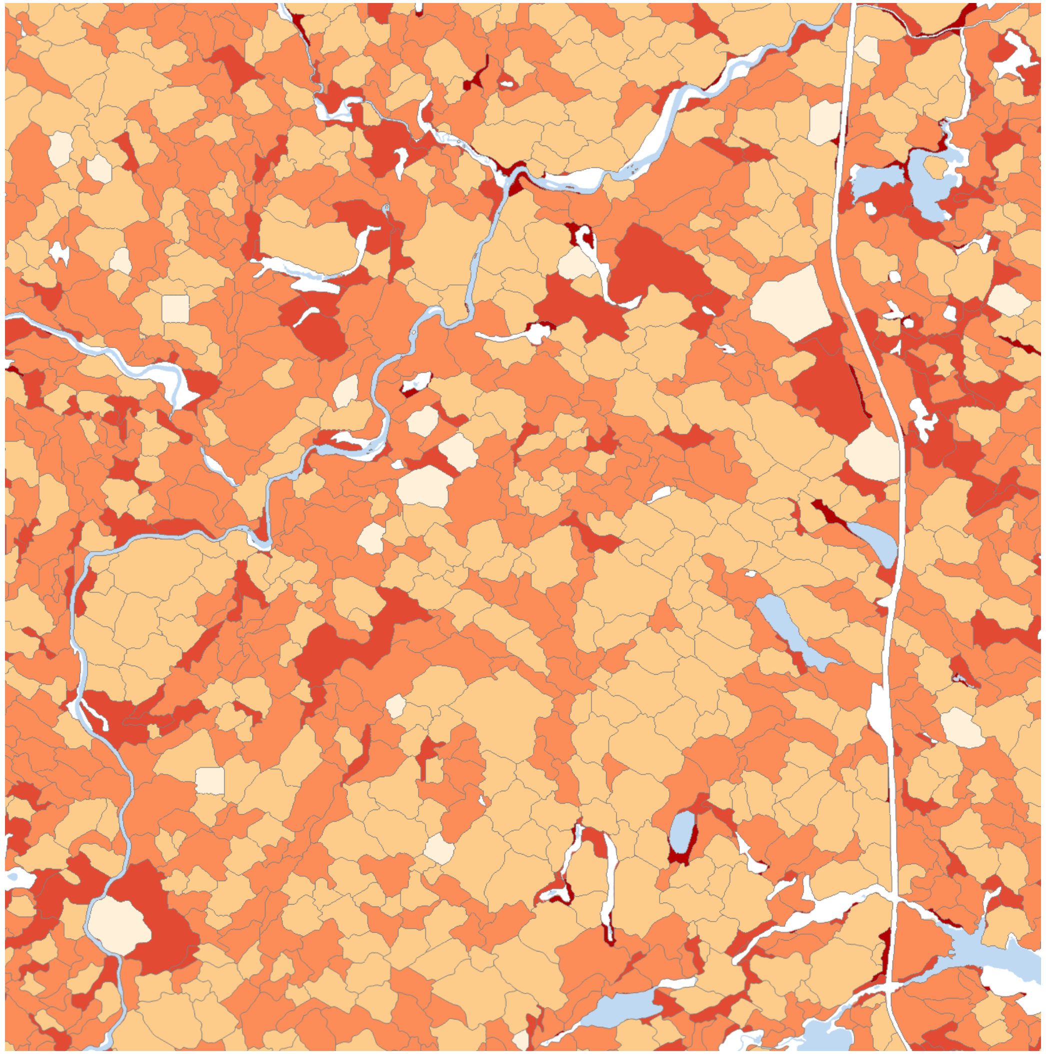
Thinness Ratio Polygons > 1 ha	2005 FRI	2023 Polygon Segmentation
Number of polygons (FOR)	9,569	18,018
Minimum	0.015	0.047
Maximum	0.922	0.886
Mean	0.344	0.521
Median	0.319	0.539
Standard Deviation	0.166	0.134

Polygon Comparison

Forest Management Specialists

Thinness Ratio FRI (avg .344) vs Automated (avg.521)





Polygon Quality Assessment

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SUMAC Photo Interpretation

- Quality assessment of 2,500 hectare area for:
  - LiDAR derived species composition,
  - Auto stand delineation

- Photo Interpreter Detailed Review

Polygon Quality Assessment

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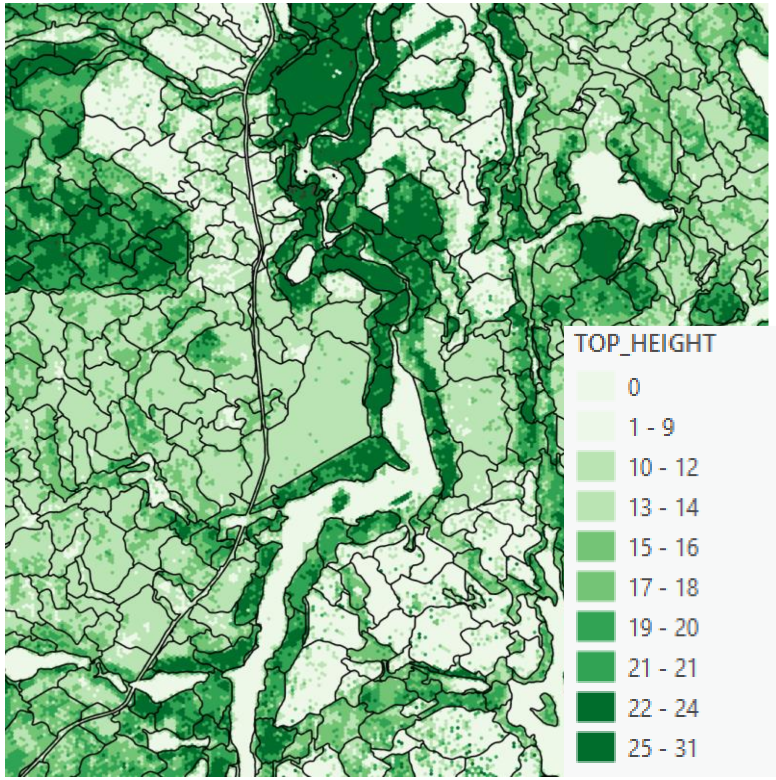
Stand Delineation

- Sometimes missed hard breaks between age classes, depletions and mature forests, upland and lowland, species composition
  - A function of raster stand delineation and required smoothing
- Grouped parts of different strata
- Polygons seldom encompassed the full extent of a particular strata
- Polygons did not represent ecosites well

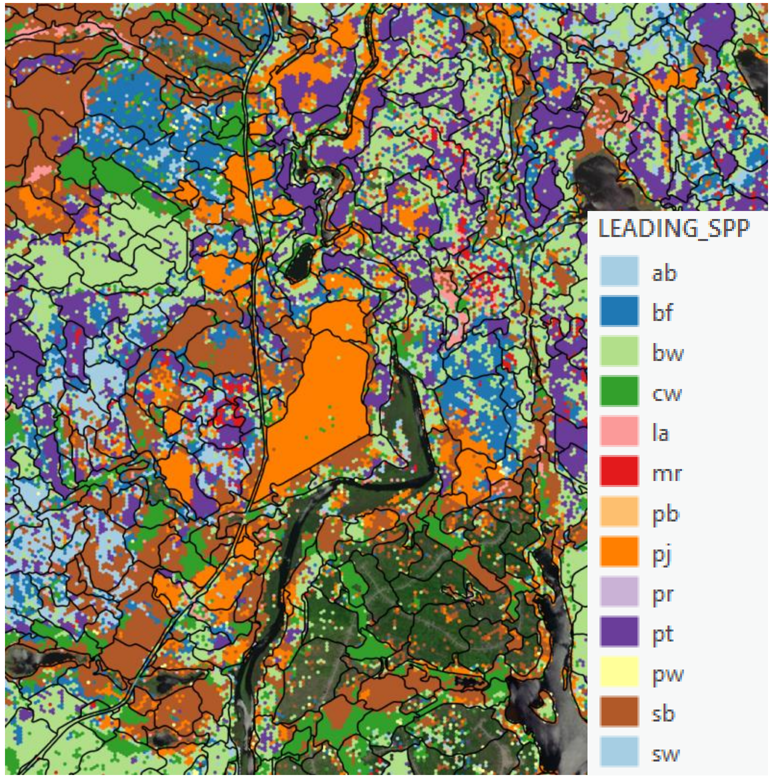
Polygon Delineation

Input Datasets and Final Polygons

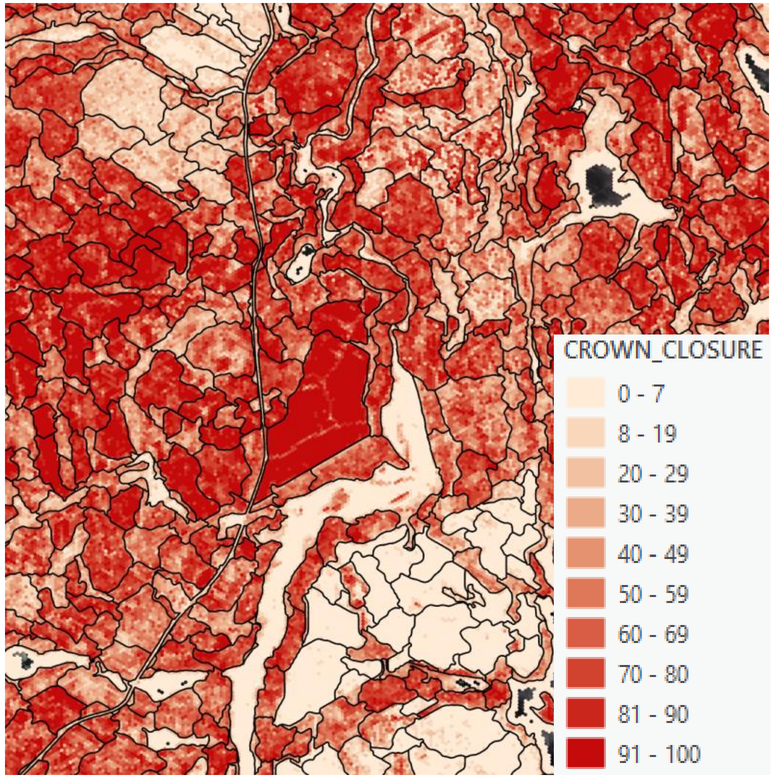
Top Height



Lead Species



Crown Cover



Polygon Quality Assessment

Species Composition

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- **Species accuracy as good or better than the average interpreter**
- Shortcomings in delineation led to complex species compositions within mixed strata stands e.g. Sb 34Pj 26Pt 20Bw 8Bf 5Sw 4Pb 2Pw 1
- Some species confusion
  - Mature Pw vs Sw vs La vs Pr presumably because similar large limby appearance of their crowns,
  - Pb vs Pt vs Bw miss ID was more prevalent in younger stand,
  - Ab vs Bw – Ab often underestimated,
  - A bit of confusion between Sb vs Sw vs Bf,
  - Bf often overlooked when young,

Recent Improvements

FORSITE

- Separate conifer and deciduous models
- Age /site index prediction in AB
- Two tiered predictions in AB
- GIS polygon approach

ITI/Hex Time Frames and Budget

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Advantage

- Produced in a much shorter timeframe
- Most time restrictive element is the plots
- Millions of hectares can be done in 6-10 months

Disadvantage

- Small landbases don’t benefit from economies of scale

ITI/Hex Products and Attributes

FORSITE

Advantage

- Operational to Strategic Inventory products that are linked (ITI/Hex/Poly)
- Less subjective attribution
- Plot driven corrections in the hexagon EFI
- Volume/BA/Stems information created

Disadvantage

- Harder to capture ‘intangibles’ like a photo interpreter (understorey)
- Room for improvement on stand polygon delineation leveraging new data sources (digital soils mapping)

Consistency

FORSITE

Advantage

- More consistent data driven attribution
- Eliminates potential data entry errors
- Will allow users to compensate for any bias over time

Disadvantage

- Less able to address unique or special conditions where human judgement is necessary

Polygon Homogeneity

Advantage

- Smaller polygons can be created for no additional cost
- These smaller polygons are more homogeneous
- Better growth and yield estimates due to less within polygon variability
- Population level growing stock check with volume estimates

Disadvantage

- Do not always capture landforms as well as human delineated polygons
- Does not look like traditional FRI polygons

Conclusions

Some Clear Wins with Room for Improvement

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- Results clearly show there is big opportunity to leverage ITI
  - LiDAR derived species at an individual tree level
- The question becomes about trade-offs (data driven vs manual interp)
  - Cost similar at large scales (~ 1 million hectare), ITI/Hex cheaper if ground plots already available.
  - ITI/EFI much faster and more consistent across large areas (less subjectivity)
  - ITI/EFI have huge benefits to operational planning
    - Within-stand wall-to-wall tree attributes
    - Tree size for determining product sort estimates
  - Automated polygons can be smaller without adding cost – goal is to increase homogeneity and support better yield curve predictions
- Potential opportunity to blend both methodologies (non forest, eco types)

Project deliverables

FORSITE

- Individual Tree Inventory
  - Point geodatabase
  - Polygon geodatabase
- Hexagon Inventory geodatabase
- Polygon Inventory geodatabase
- ArcGIS Forsite LiDAR Add-In
- Final Report

Using the hex and iti

Forsite LiDAR Add-In Demo

Future Research

FORSITE

- Improve understory identification
- Define Stand structure types across the landbase prior—single story, two story or complex. (Woods and Penner Petawawa research forest – CWFC 2023 presentation)
- Continue improving the Age and Site Index methodology
- Continue refining polygon delineation methodology

Thank You Project Partners

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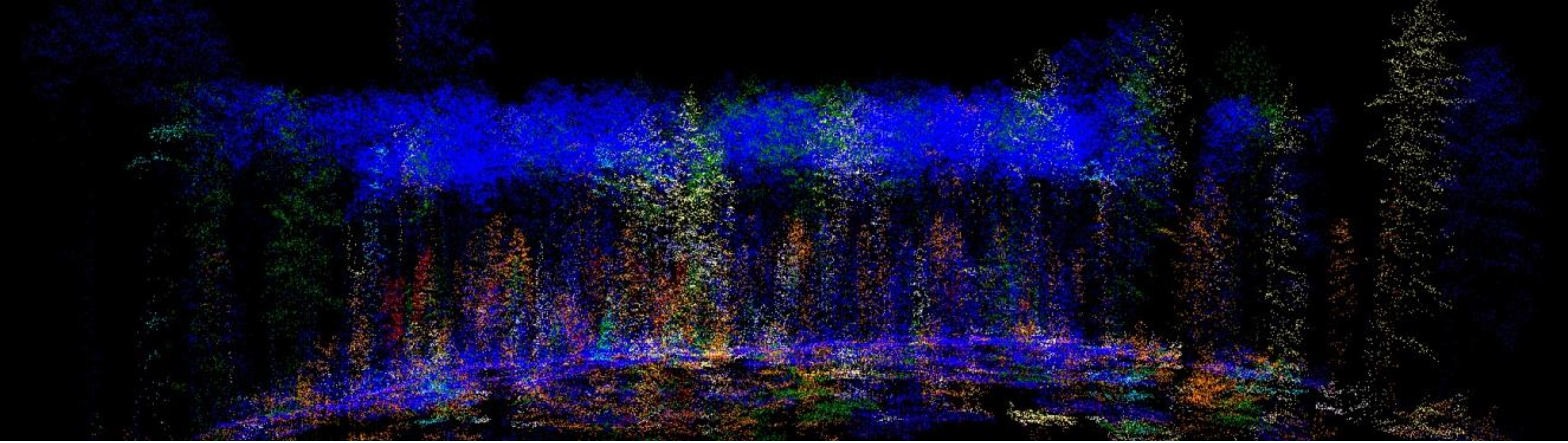

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