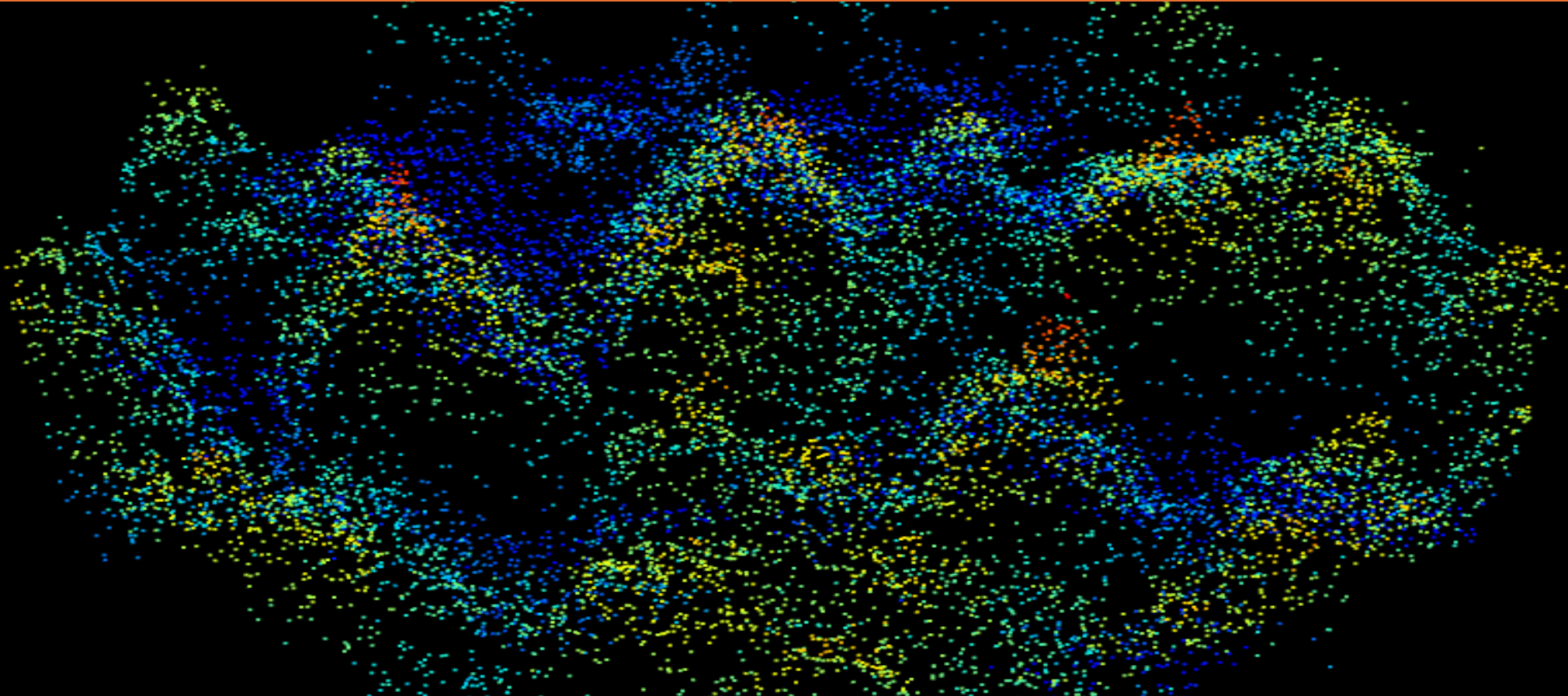


Stand density for evaluating silvicultural opportunities and future yields



Shes Bhandari, Doug Reid, Christopher Stratton, Todd Little, Muhammad Waseem Ashiq

Ontario Ministry of Natural Resources

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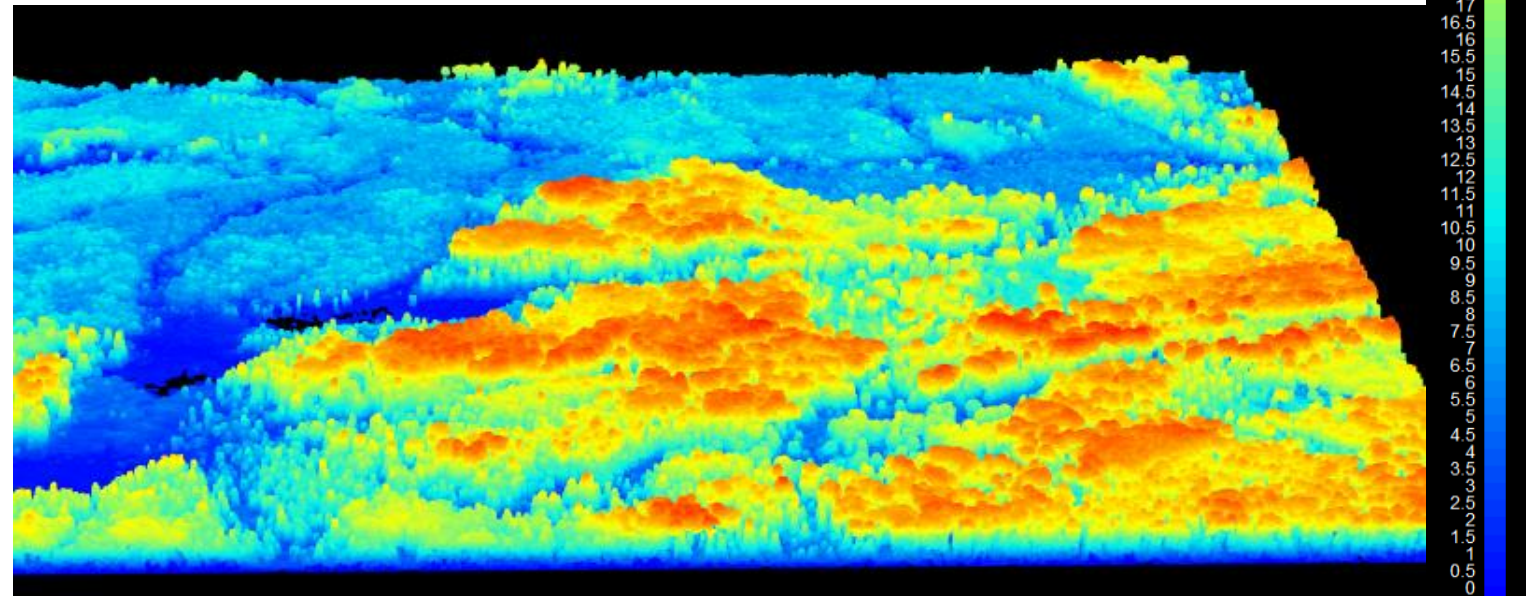
Research Rationale

- Mid rotation age forest responds better to silvicultural intervention.
- Prime candidate for commercial thinning (CT).
- Stem density estimates are important prior to density management/thinning.



Research Rationale

- Density estimates (field) is costly.
- The alternate option - lidar point cloud data (Single photon lidar) available for Ontario.
 - i. Cost effective
 - ii. Quick
- Lidar widely used in growth and yield assessment, biomass and carbon assessment etc.



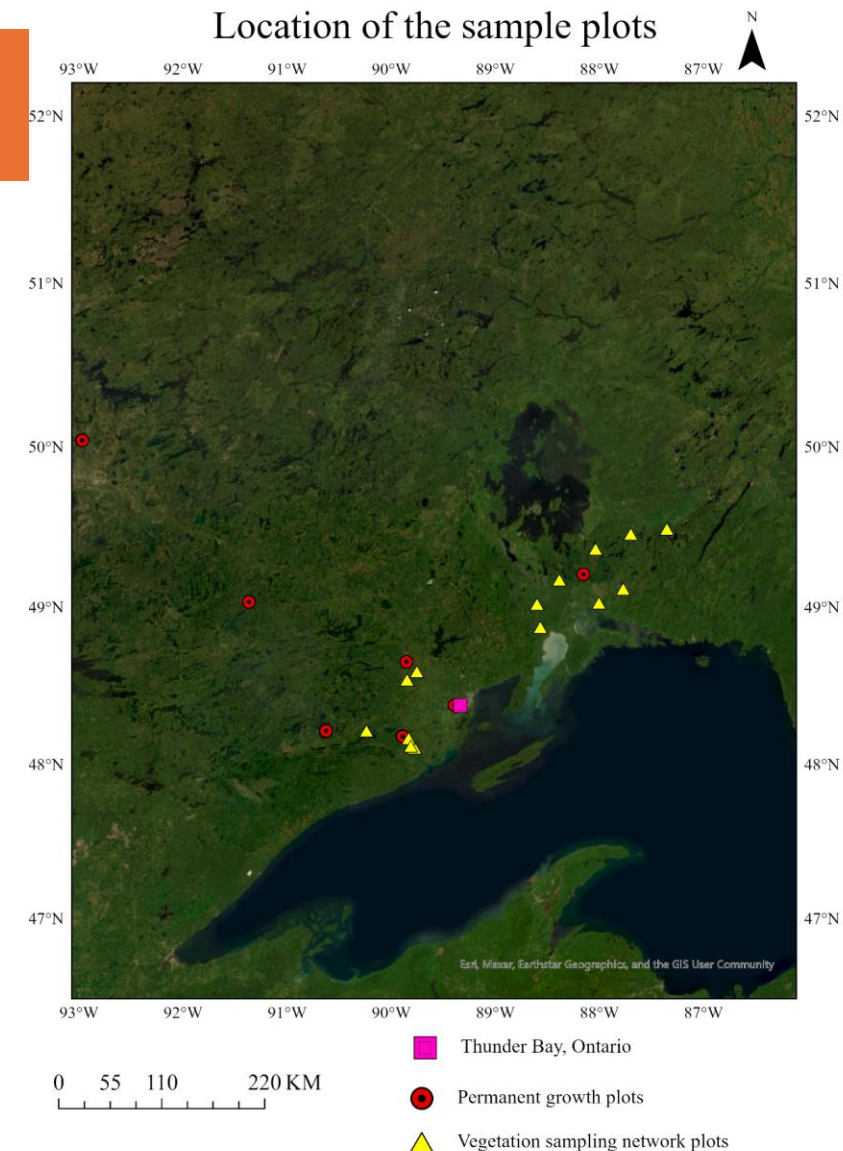
Materials and methods

Study sites

Table: Details of FMU, polygons, PGPs, VSN plots used in the study

FMU	No. of polygons	No. PGPs	No. of VSN plots	Total plots
Lakehead	5+8	11	8	19
Dryden	2	3		3
Lake Nipigon	1+4	3	4	7
Sapawe	1	3		3
Total	21	20	12	32

- Conifer dominated (Jack pine, white spruce, black spruce)



Materials and methods

Field data

- FRI Polygons of each plot was identified.
- Each PGP/VSN plot inventoried.
- 30 temporary sample plots (TSPs, area 50m²) distributed around the PGP/VSN plot in the polygon and measured
- In total more than 600 TSPs were measured.



Materials and methods

Field data analysis

Field data into three categories.

- i. All trees
- ii. Live only
- iii. All live plus dead but filtered

In **last two** categories tree density per ha was estimated for different size threshold such as

- >5cm dbh
- >6cm dbh
-
- >15 cm dbh

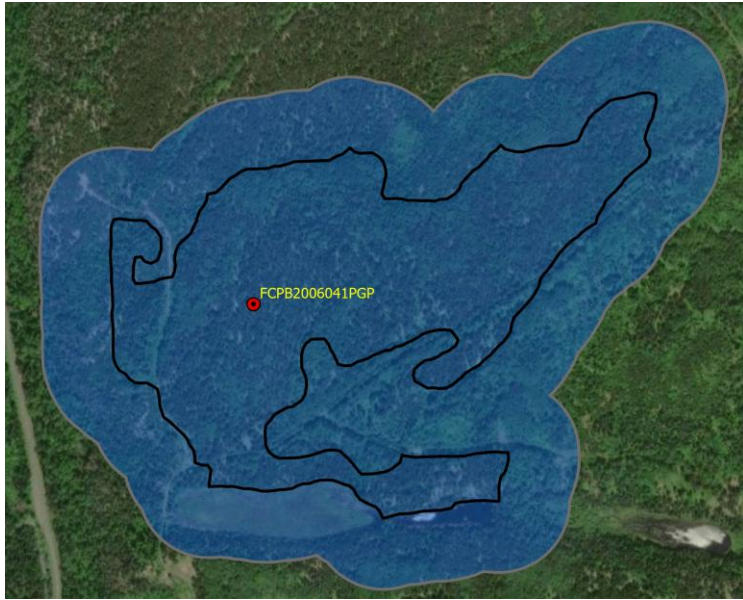
Table: Different variables/categories and their codes used in filtering field inventory data

PGPs			VSN plots		
Variables/categories	included	excluded	Variables/categories	included	excluded
Decay class	1, 2	3, 4, 5	Decay class	1, 2	3, 4, 5
Broken top	0	1	Broken top	N	Y
Crown condition code	1, 2	3, 4, 5, 6	NA		
Bark retention code	1, 2, 3, 4	5, 6, 7	Bark retention code	1, 2, 3, 4	5, 6, 7

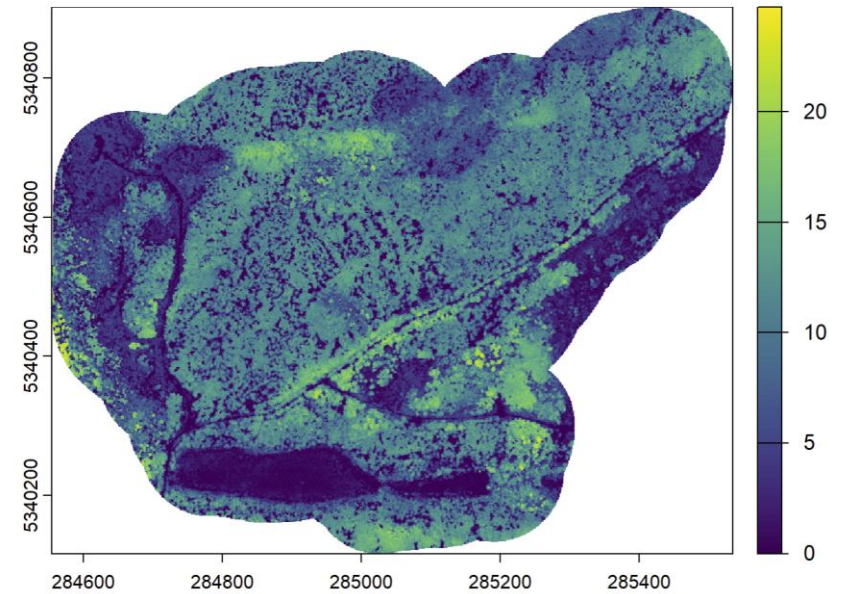
Materials and methods

Lidar data analysis

- 100 m buffer on each polygon.



CHM developed for polygon



Materials and methods

Lidar data analysis

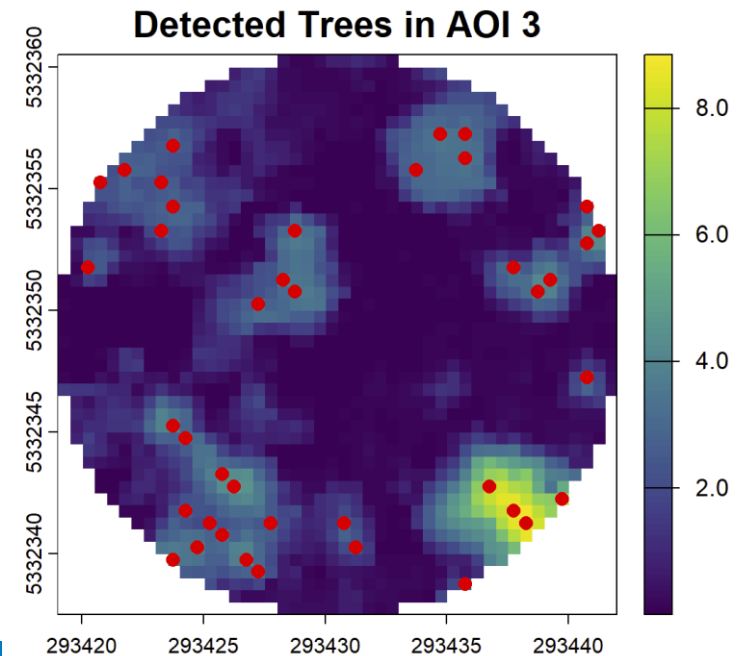
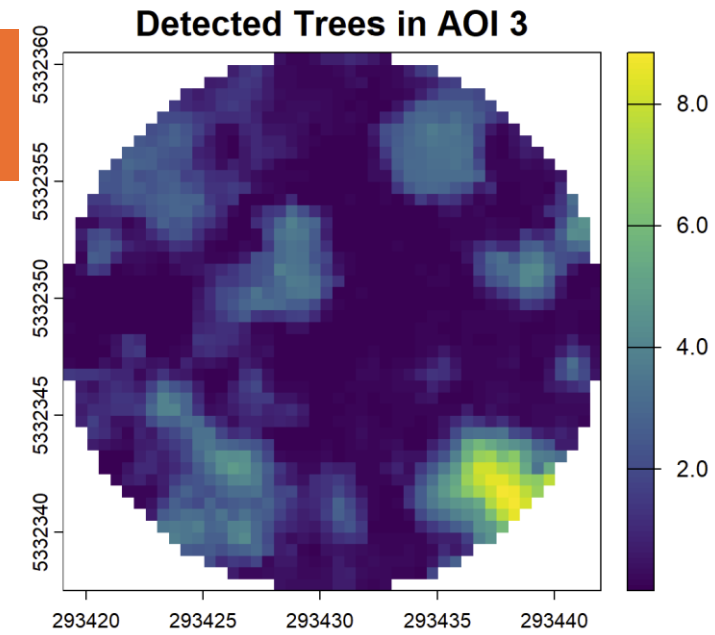
- CHM cropped and masked for each plot and tree detected by “locate_trees” function.

Treetops = locate_trees (CHM, lmf (ws, hmin))

Where,
CHM is canopy height model,

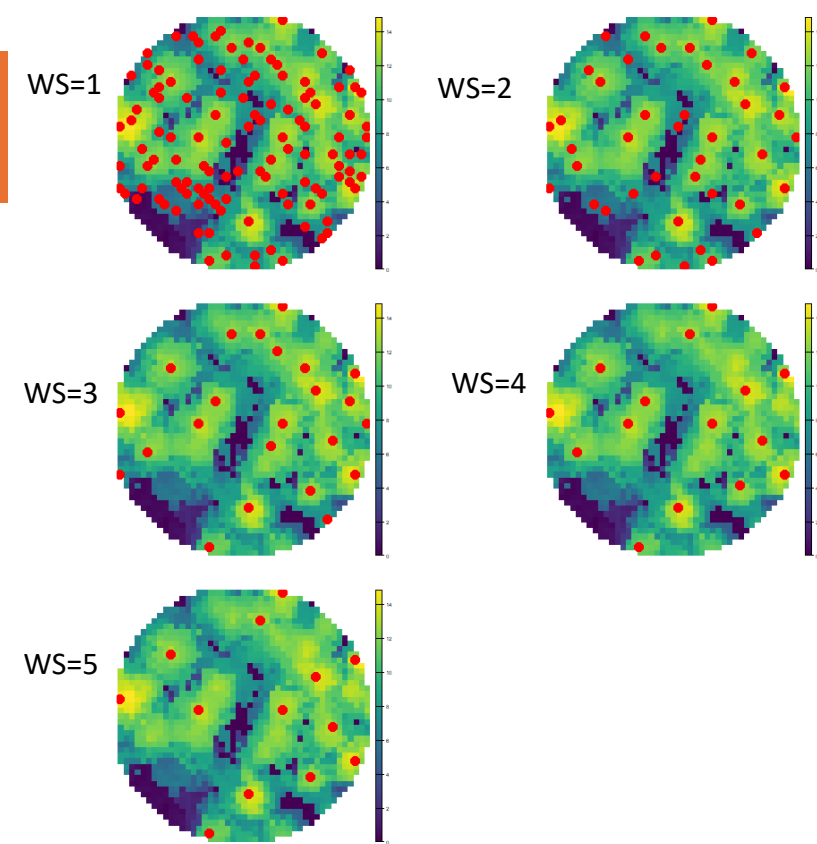
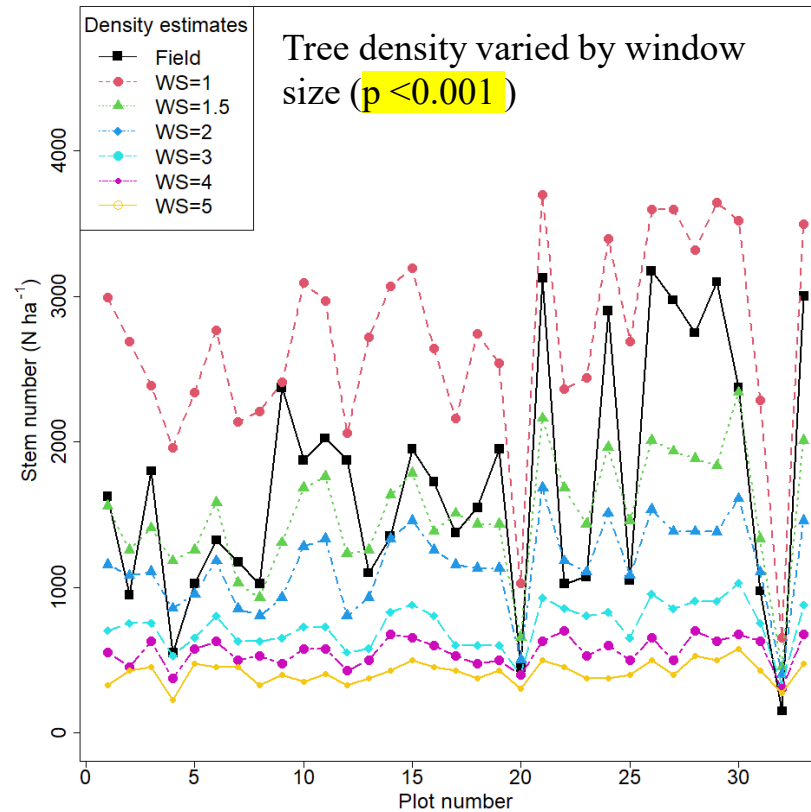
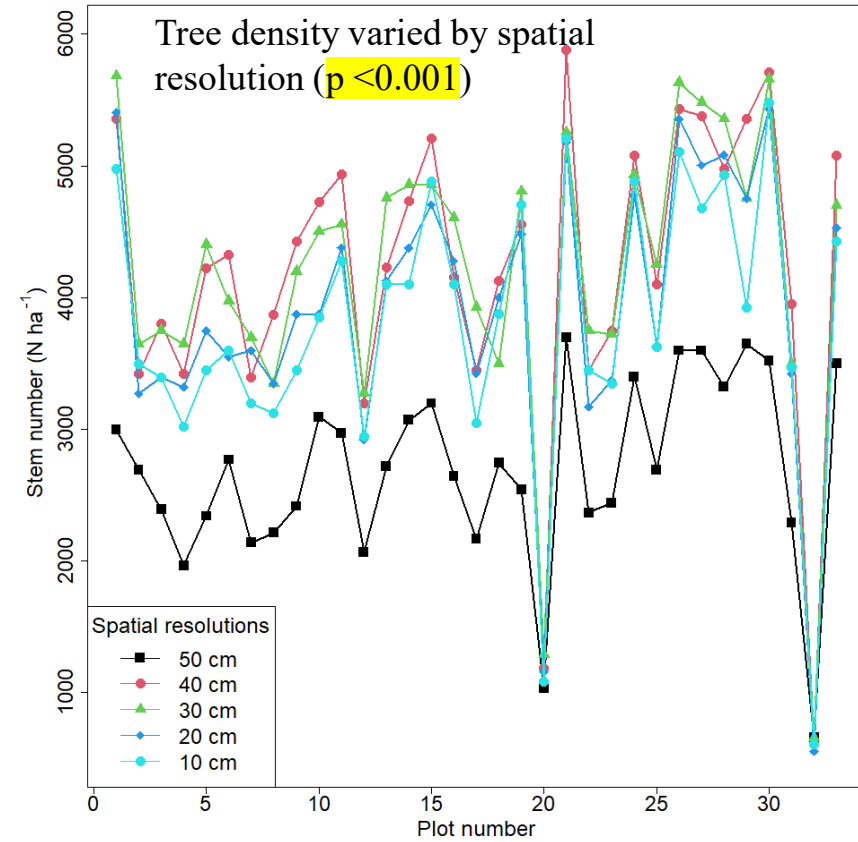
WS is the window size and its numerical value considered was 1, 1.5, 2, 3, 4, 5

hmin is minimum height of trees considered in the analysis



Materials and methods

Why different resolution and window size



Materials and methods

Comparison of Lidar vs field measured density

Paired sample t-test

Removal of significant pairs

vendor provided CHM vs. field density
Lidar derived CHM vs. field density

All live plus dead not filtered,
All live only,
All live plus dead but filtered

> 5cm dbh
>6 cm dbh,
>15 cm dbh

Table: Number of pairs that were used in paired t-test

Data source	Categories	Total pairs	Non-sig. pairs
Vendor provided CHM	All live + dead not filtered	$1*6=6$	None
	All live	$12*6=72$	8
	All live + dead filtered	$12*6=72$	8
Lidar point cloud (pitfree)	All live + dead not filtered	$1*5*6=30$	1
	All live	$12*5*6=360$	44
	All live + dead filtered	$12*5*6=360$	44
Lidar point cloud (p2r)	All live + dead not filtered	$1*5*6=30$	1
	All live	$12*5*6=360$	39
	All live + dead filtered	$12*5*6=360$	37
Total		1650	182

Materials and methods

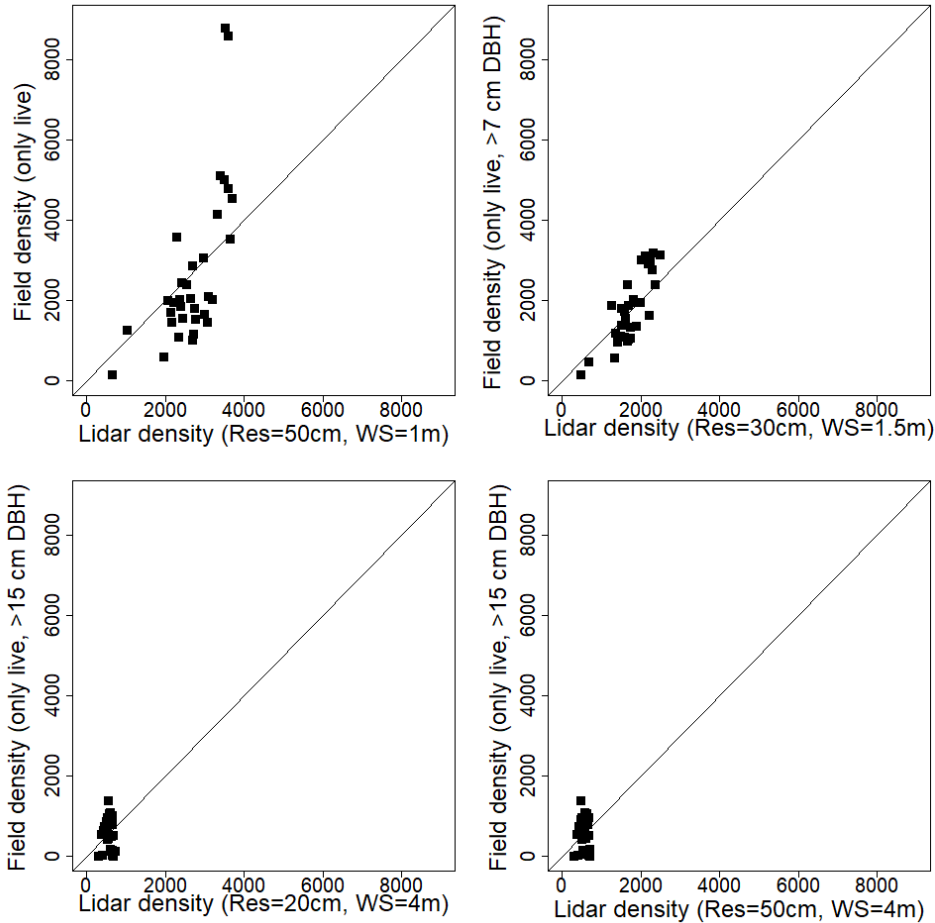
Validation

- Lidar derived density estimated for polygon in which PGPs or VSN plots are located.
- The lidar density compared with tree density measured in 30 TSPs from each polygon.

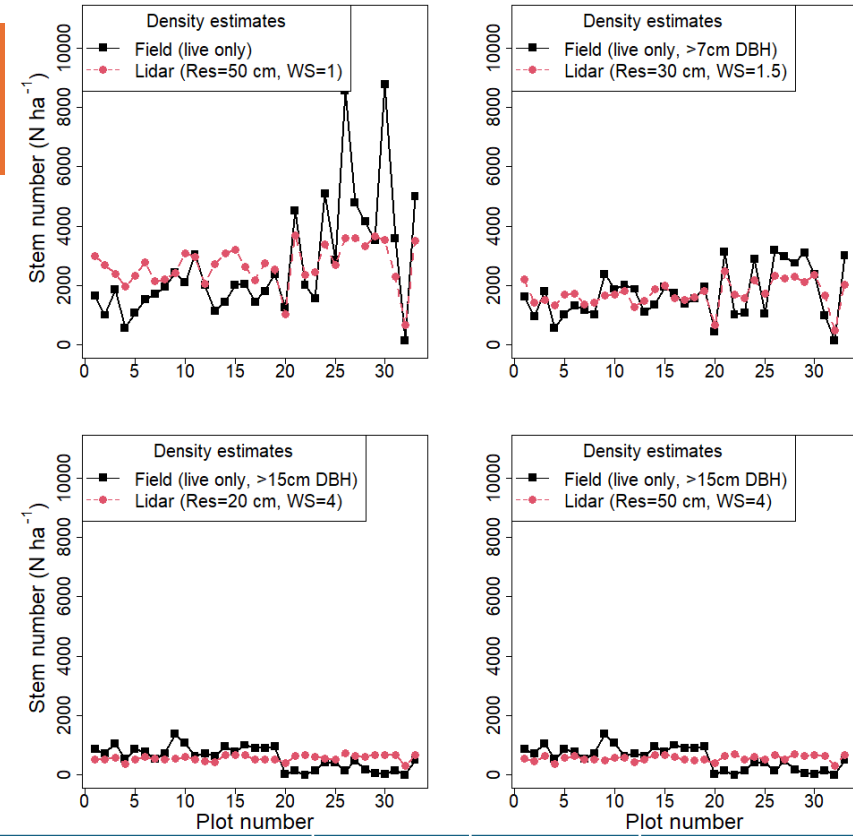


Results

Lidar derived density (pit free) vs field measured density (all live only)



12*30=360, 44 not different



Field density (stems per ha)	Lidar density (stems per ha)	t-value	p-value	Mean difference
all live only	50cm_ CHM, WS_1	0.02	0.98	6.17
>7cm dbh live only	30cm_ CHM, WS_1.5	0.00	1.00	-0.24
>15cm dbh live only	20cm_ CHM, WS_4	0.01	0.99	0.50
>15cm dbh live only	50cm_ CHM, WS_4	0.06	0.95	4.30

Results

Comparison among best of each category

CHM	Algorithm	Field density (stems per ha)	Lidar density (stems per ha)	t-value	p-value	Mean difference
Vendor provided CHM	NA	All live plus dead but not filtered	50cm CHM, WS 1	-2.06	0.05	-521.28
		>7cm DBH live only	50cm CHM, WS 1.5	-0.65	0.52	-62.74
		>7cm DBH live plus dead but filtered	50cm CHM, WS 1.5	0.67	0.51	70.60
Lidar derived CHM	Pit free	All live plus dead but not filtered	50cm CHM, WS 1	1.57	0.13	409.96
		>7cm dbh live only	30cm CHM, WS 1.5	0.00	1.00	-0.24
		>9cm dbh live plus dead but filtered	50cm CHM, WS 1.5	0.09	0.93	7.04
	P2r	All live plus dead but not filtered	50cm CHM, WS 1	-0.48	0.64	-124.22
		>6cm dbh live only	10cm CHM, WS 1.5	0.05	0.96	5.41
		>7cm dbh live plus dead but filtered	20cm CHM, WS 1.5	-0.06	0.95	-5.60

Results

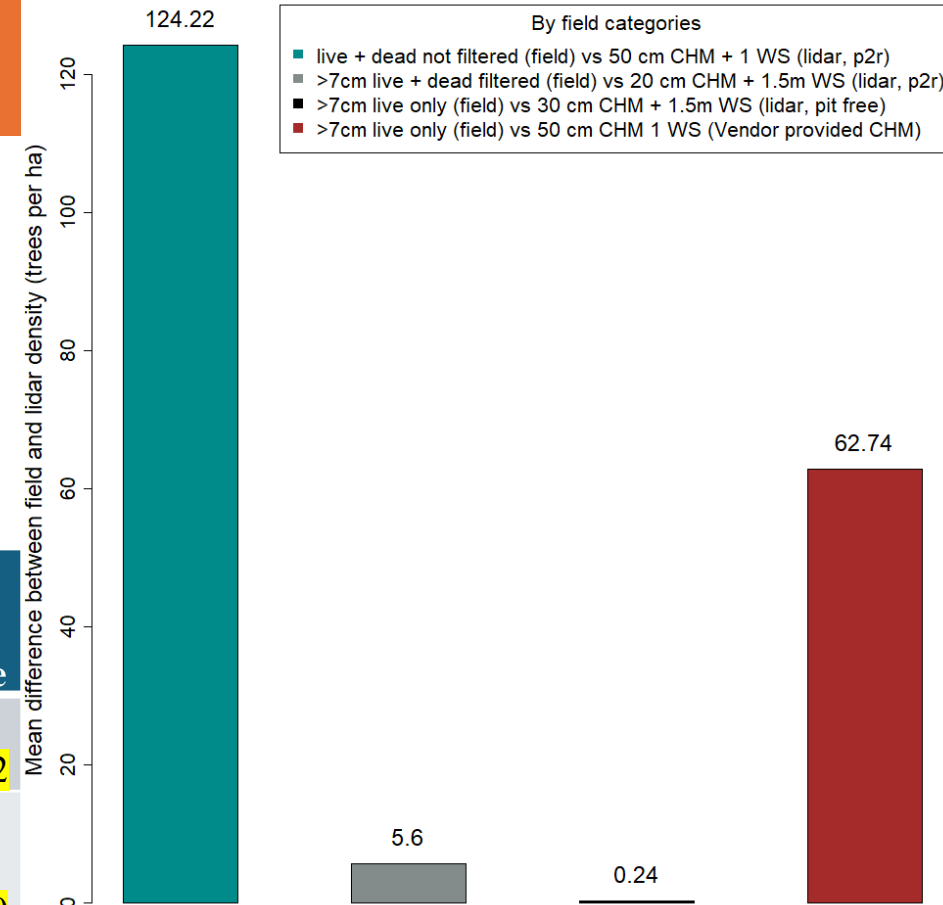
Comparison among best of each category

Field density (stems per ha)	CHM source	Algorithm	Lidar density (stems per ha)	t-value	p-value	Mean difference
All live plus dead but not filtered	Vendor provided CHM	NA	50cm CHM, WS 1	-2.06	0.05	-521.28
	Lidar derived CHM	Pit free	50cm CHM, WS 1	1.57	0.13	409.96
	Lidar derived CHM	P2r	50cm CHM, WS 1	-0.48	0.64	-124.22
>7cm DBH live only	Vendor provided CHM	NA	50cm CHM, WS 1.5	-0.65	0.52	-62.74
>7cm dbh live only	Lidar derived CHM	Pit free	30cm CHM, WS 1.5	0.00	1.00	-0.24
>6cm dbh live only	Lidar derived CHM	P2r	10cm CHM, WS 1.5	0.05	0.96	5.41
>7cm dbh live plus dead but filtered	Vendor provided CHM	NA	50cm CHM, WS 1.5	0.67	0.51	70.60
	Lidar derived CHM	Pit free	50cm CHM, WS 1.5	0.09	0.93	7.04
>7cm dbh live plus dead but filtered	Lidar derived CHM	P2r	20cm CHM, WS 1.5	-0.06	0.95	-5.60

Results

Table: Comparison among best of each category (vendor provided CHM density and lidar derived density)

CHM source	Field density (stems per ha)	Algorithm	Lidar density (stems per ha)	t-value	p-value	Mean difference
Lidar point cloud derived CHM	All live plus dead but not filtered	P2r	50cm CHM, WS 1	-0.48	0.64	-124.22
	>7cm dbh live plus dead but filtered	P2r	20cm CHM, WS 1.5	-0.06	0.95	-5.60
	>7cm dbh live only	Pit free	30cm CHM, WS 1.5	0.00	1.00	-0.24
Vendor provided CHM	>7cm DBH live only	NA	50cm CHM, WS 1.5	-0.65	0.52	-62.74



Results

Validation

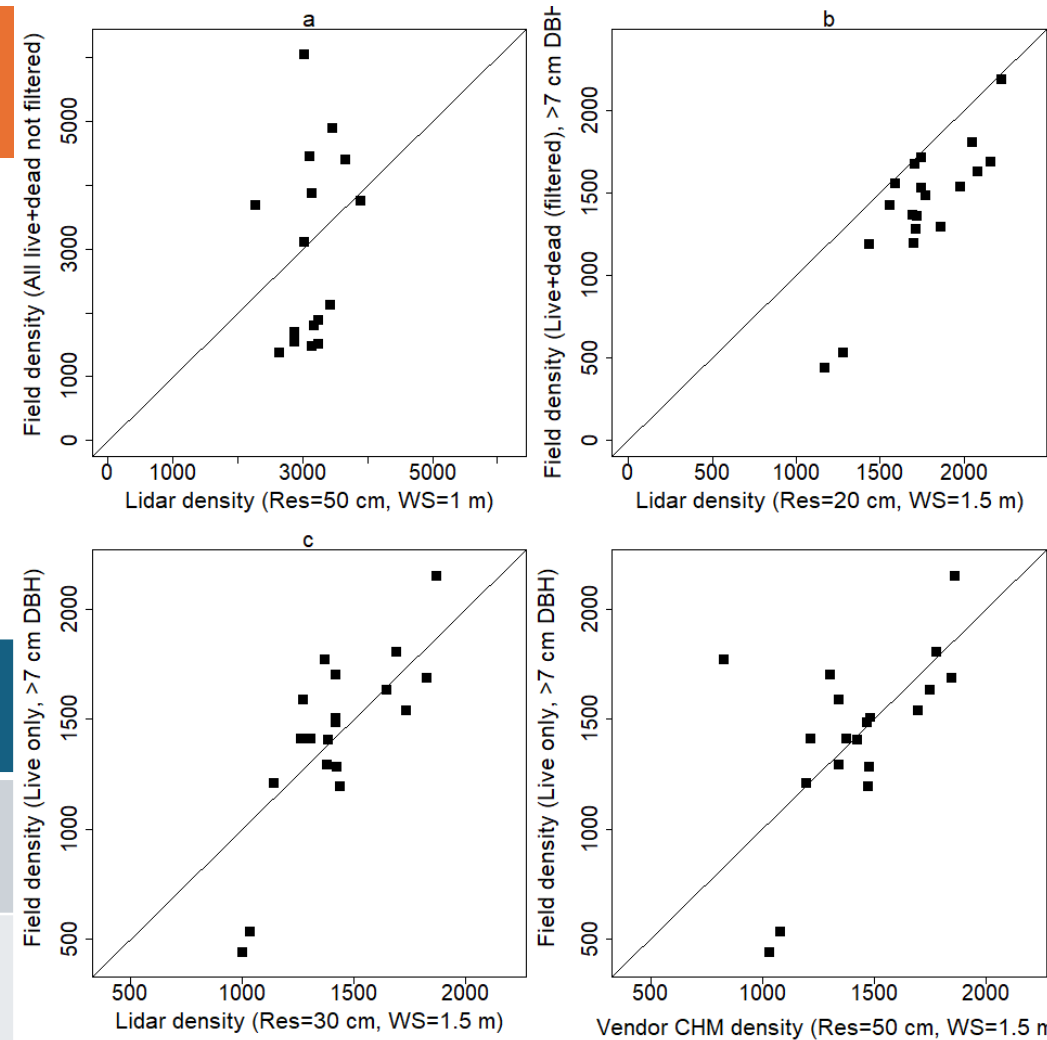


Table: Validation of lidar density with polygon level field measured density

CHM source	Field density (stems per ha)	Algorithm	Lidar density (stems per ha)	t-value	p-value	Mean difference
Lidar point cloud derived CHM	All live plus dead but not filtered	P2r	50cm CHM, WS 1	1.09	0.29	542
Lidar point cloud derived CHM	>7cm dbh live plus dead but filtered	P2r	20cm CHM, WS 1.5	-6.49	<0.001	-332
Lidar point cloud derived CHM	>7cm dbh live only	Pit free	30cm CHM, WS 1.5	0.005	1	0.32
Vendor provided CHM	>7cm DBH live only	NA	50cm CHM, WS 1.5	0.05	0.95	4.47

Conclusion

- Tree density can be estimated from lidar point cloud data with acceptable accuracy. Vendor provided CHM not as accurate – more processing required.
- Spatial resolution and window size can have influential role in density estimate.
- Accuracy of density estimate depends on the tree status (size (i.e. dbh), live, dead, top broken etc.). Live trees are more accurately detected.
- Live trees are more accurately detected.
- More sampling needed to address mixedwood conditions. Utility of density estimate could be improved by also estimating basal area ($\text{m}^2 \text{ha}^{-1}$) at the same time.