

# APF LiDAR Model Calibration Results

Accelerating the implementation of enhanced forest inventories in Ontario  
KTTD 20B-2021

Margaret Penner & Murray Woods

July 19, 2022




# LiDAR Data Delivered to SFLs/ROD

- **DTM = Bare Earth derivative**
- **CHM = Canopy Height Model derivative**
- **LAS\_Classified\_Point\_Clouds = classified LiDAR point clouds**
- **Hydro Break lines = Predicted water polys**
- **Stream Network = Predicted Lidar derived stream network**
- **Canopy Metrics = Height percentiles, cover , density metrics**
- **DSM = Digital Surface Model derivative**
- **Intensity Raster = a measure of signal width upon return of signal**
- **Reports – Calibration, Control, Flight Mission**

Calibration_Reports	03/08/2021 1:51 PM	File folder
Canopy_Metrics	03/08/2021 1:52 PM	File folder
CHM	03/08/2021 2:13 PM	File folder
Control_Report	03/08/2021 2:13 PM	File folder
DEM	03/08/2021 2:31 PM	File folder
DSM	03/08/2021 2:49 PM	File folder
Flight_Mission_Reports	03/08/2021 2:49 PM	File folder
Hydro_Breaklines	03/08/2021 2:49 PM	File folder
Intensity_Raster	03/08/2021 3:01 PM	File folder
LAS_Classified_Point_Clouds	03/08/2021 7:29 PM	File folder
LAS_Tile_Index	03/08/2021 7:29 PM	File folder
QC_Index	03/10/2021 5:44 PM	File folder
Stream_Networks	03/08/2021 7:29 PM	File folder

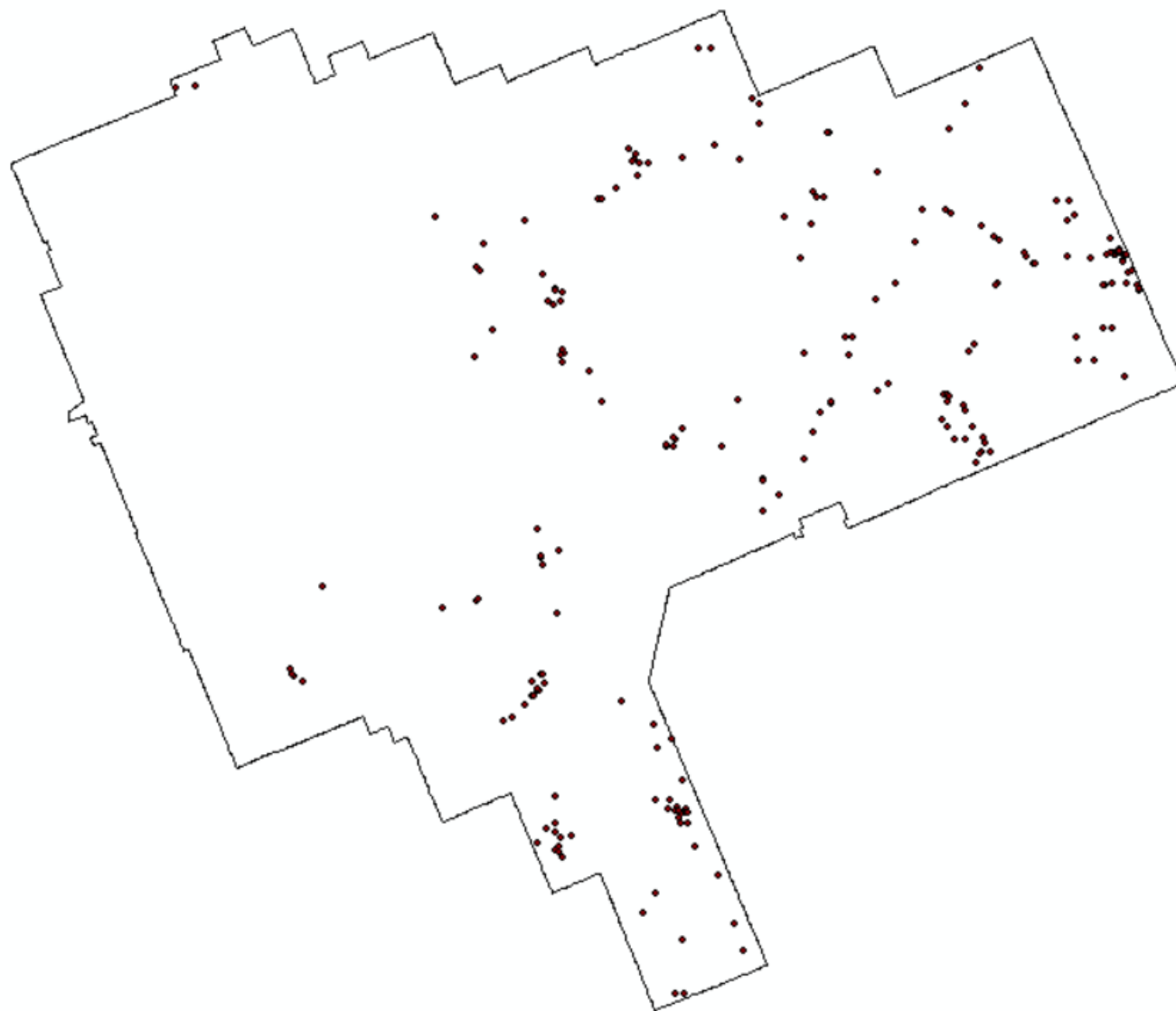
# Focus – T2 LiDAR Inventory Products

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- Calibration Plot Overview
  - Calibration Plot Quality
  - Modeling Approach & Results
  - Plot level & Stand Level Validation
  - T2 outputs
  - Next Steps – Current Research Focus
  - Questions & Discussion

# APF Calibration Plot Distribution

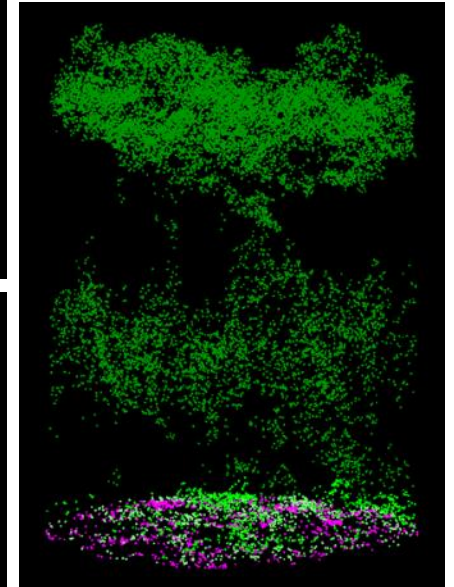
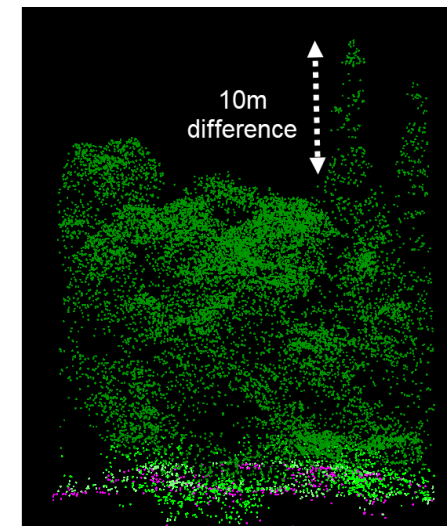
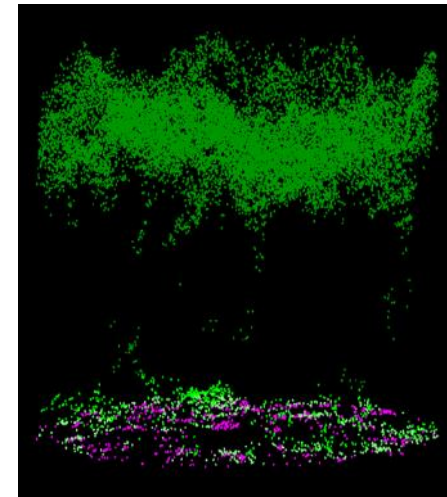
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- 225 plots established
- July 7 – Sept 24, 2020
- Sampling used a LiDAR “Structurally Guided” approach
- 2 plots excluded from modeling as there were no live trees > 7cm
- 223 plots used



# LiDAR Derived ABA Inventory – Phase 1

- Area-Based-Approach (ABA)-20m raster inventory product
- All raster cell vertical structures are treated the same way
- Calibration plot summary considers ALL live trees and sums their contribution to total per ha values
- This has been the default prediction method for Ontario (and other jurisdictions)
- Ongoing research to predict structure classes & inventory attributes by layer (FFT – KTTD project) – Phase 2

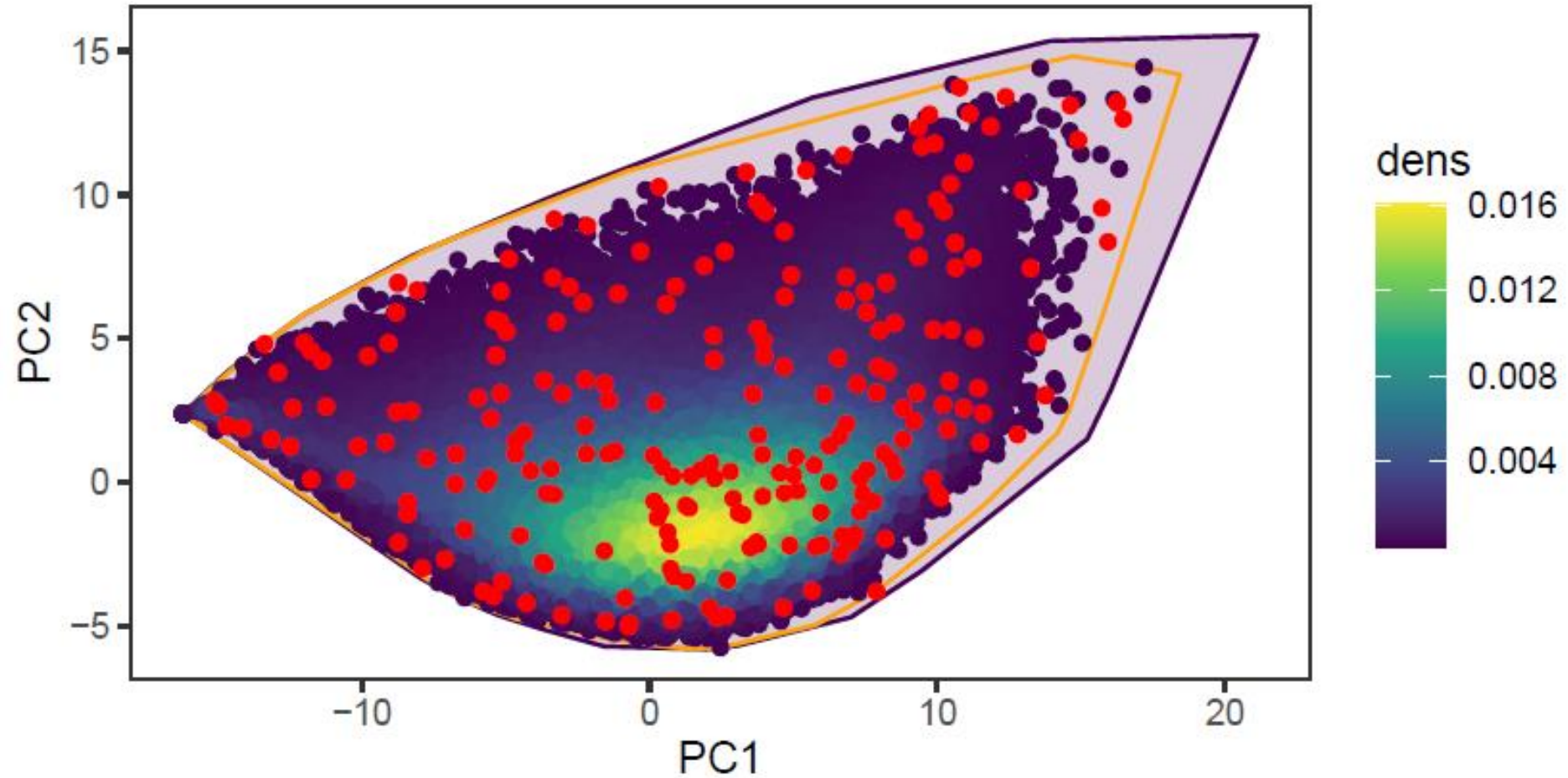


# APF Calibration Data Summary

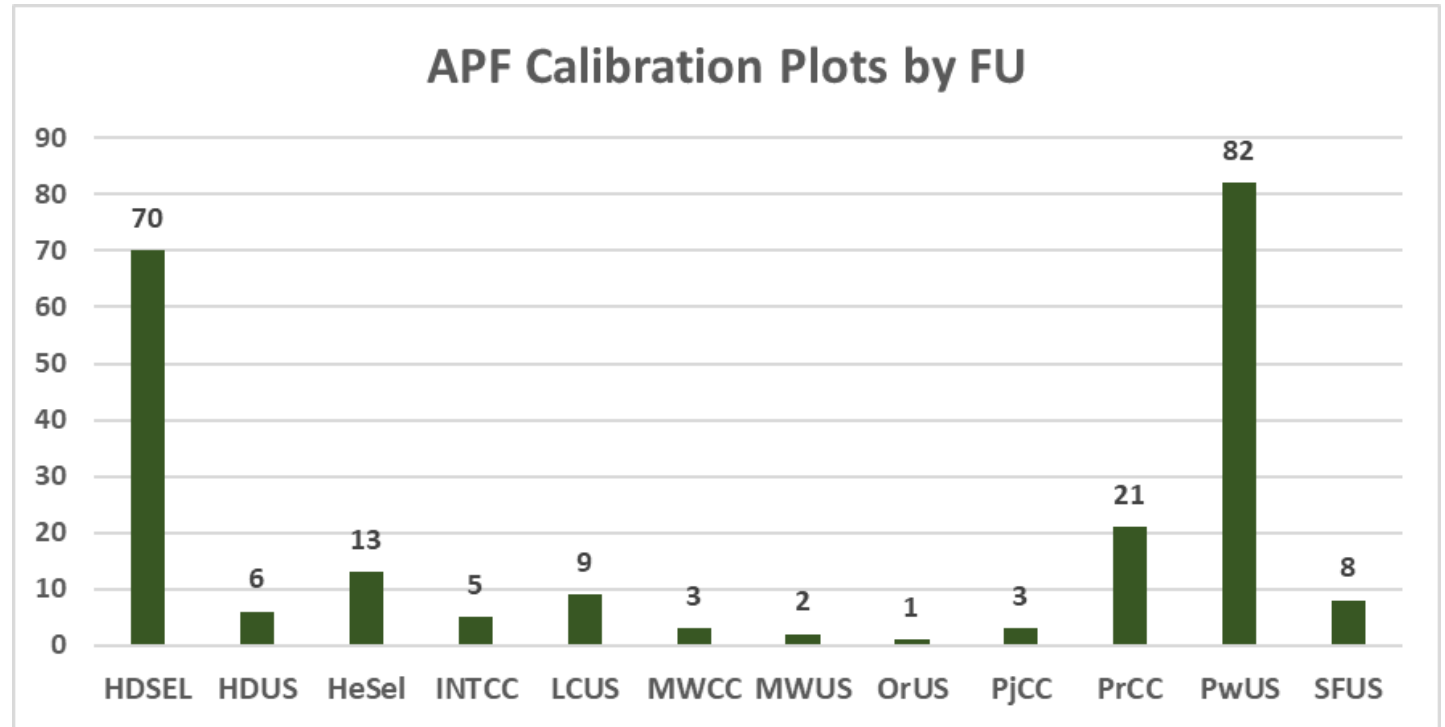
APF- Forest Unit	No Plots	Breast Height Age (yrs)[1]	CDHT (m)	Basal Area (m <sup>2</sup> ha <sup>-1</sup> )	GTV (m <sup>3</sup> ha <sup>-1</sup> )	GMV (m <sup>3</sup> ha <sup>-1</sup> )
HDSEL	70	73 (N=61) (25 - 145)	19.1 (10.5 - 25.6)	24.9 (4.4 - 46.2)	193 (24.2 - 409.5)	140 (0 - 343)
HDUS	6	66 (N=5) (39 - 91)	17.7 (14.8 - 23.1)	25.8 (14.6 - 30.6)	186 (90.3 - 263)	127 (48 - 236)
HeSel	13	111 (N=12) (46 - 176)	20.2 (14.2 - 25)	33.4 (21.4 - 51.5)	247 (131 - 395)	206 (99 - 365)
INTCC	5	94 (55 - 120)	25.1 (20 - 30.9)	45.4 (34.7 - 64.8)	491 (313 - 708)	442 (260 - 643)
LCUS	9	74 (38 - 102)	11.4 (N=8) (8.1 - 16.2)	17.3 (0.1 - 37.2)	92 (0 - 236)	66 (0 - 206)
MWCC	3	69 (54 - 87)	22.6 (16.7 - 27)	32.3 (14.6 - 43.5)	326 (101 - 495)	266 (59 - 432)
MWUS	2	76 (58 - 94)	19.1 (17.2 - 21)	27.3 (24.3 - 30.4)	227 (213 - 241)	180 (159 - 201)
OrUS	1	56 (56 - 56)	14.9 (14.9 - 14.9)	23.7 (23.7 - 23.7)	147 (147 - 147)	102 (102 - 102)
PjCC	3	46 (16 - 74)	13.2 (4 - 19.7)	11.7 (5.2 - 18.3)	81 (8 - 165)	72 (0 - 155)
PrCC	21	110 (N=20) (46 - 136)	26.5 (11.9 - 33.6)	24.6 (2.9 - 58.2)	293 (32 - 843)	270 (30 - 788)
PwUS	82	90 (N=68) (9 - 155)	24.7 (6.3 - 35.4)	27 (3.0 - 66.5)	283 (16 - 881)	252 (6 - 825)
SFUS	8	70 (34 - 115)	16.9 (11.1 - 23.6)	31.1 (12.4 - 50.5)	225 (65 - 450)	173 (46 - 412)
<b>All</b>	<b>223</b>	<b>85</b> <b>(N=197)</b> <b>(9 - 176)</b>	<b>21.6</b> <b>(N=222)</b> <b>(4.0 - 35.4)</b>	<b>26.5</b> <b>(0.1 - 66.5)</b>	<b>243</b> <b>(0 - 881)</b>	<b>203</b> <b>(0 - 825)</b>

[1] Breast height age is the average breast height age of dominant/codominant trees with measured ages. Trees were not measured for age on all plots and the sample sizes for age are less than the number of plots.

# Structurally Guided Sampling - APF

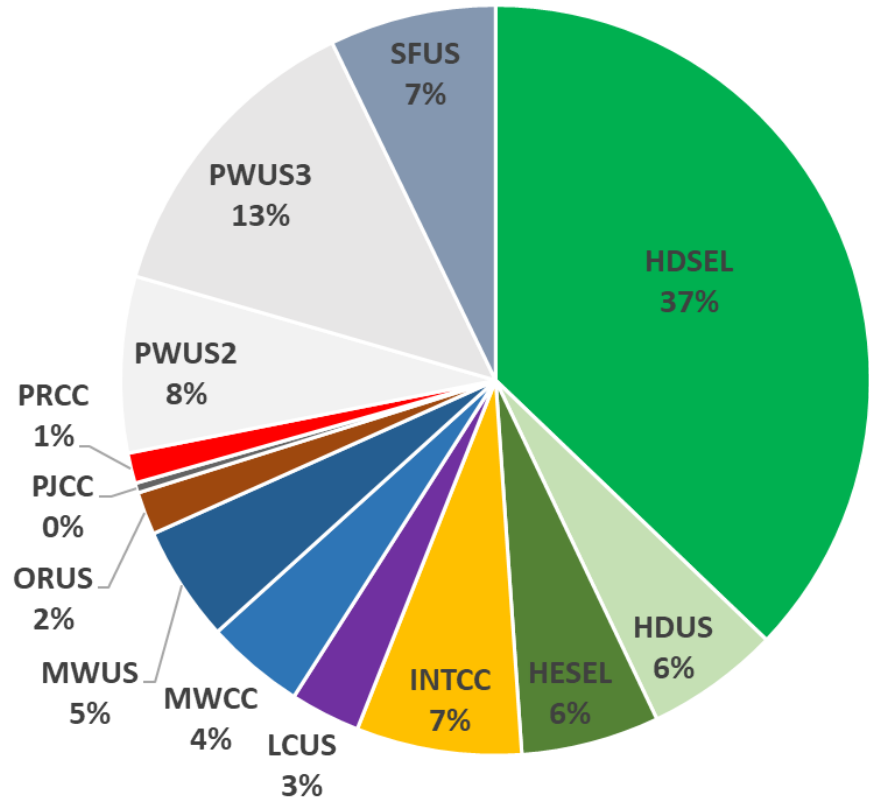


# APF Calibration Data Summary

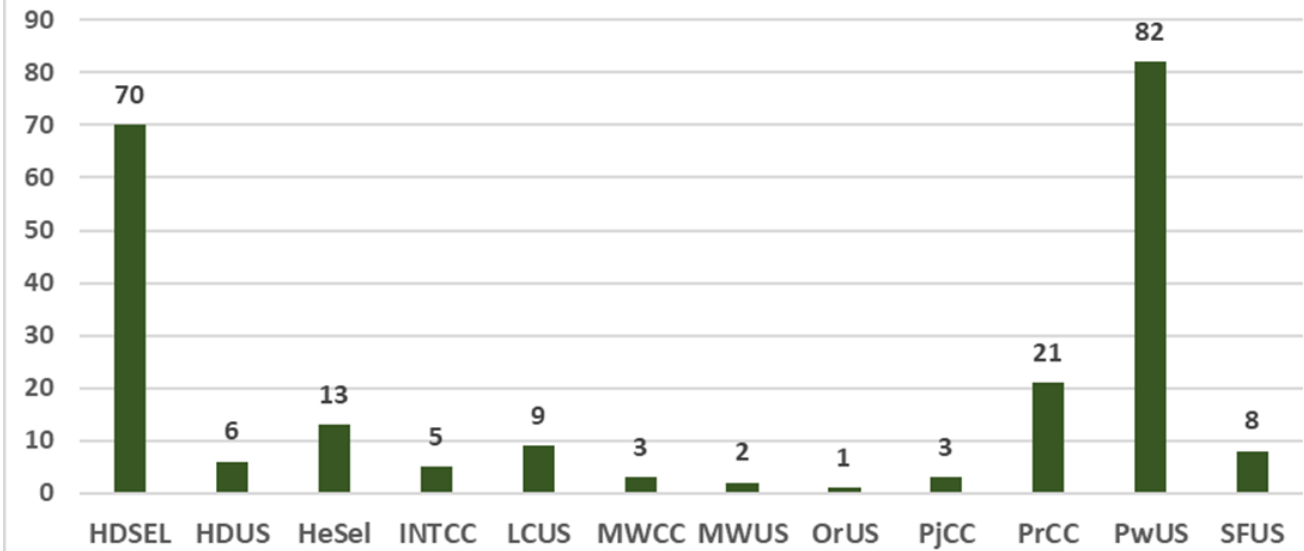




**APF Mangement Plan Forest Unit % by Area**



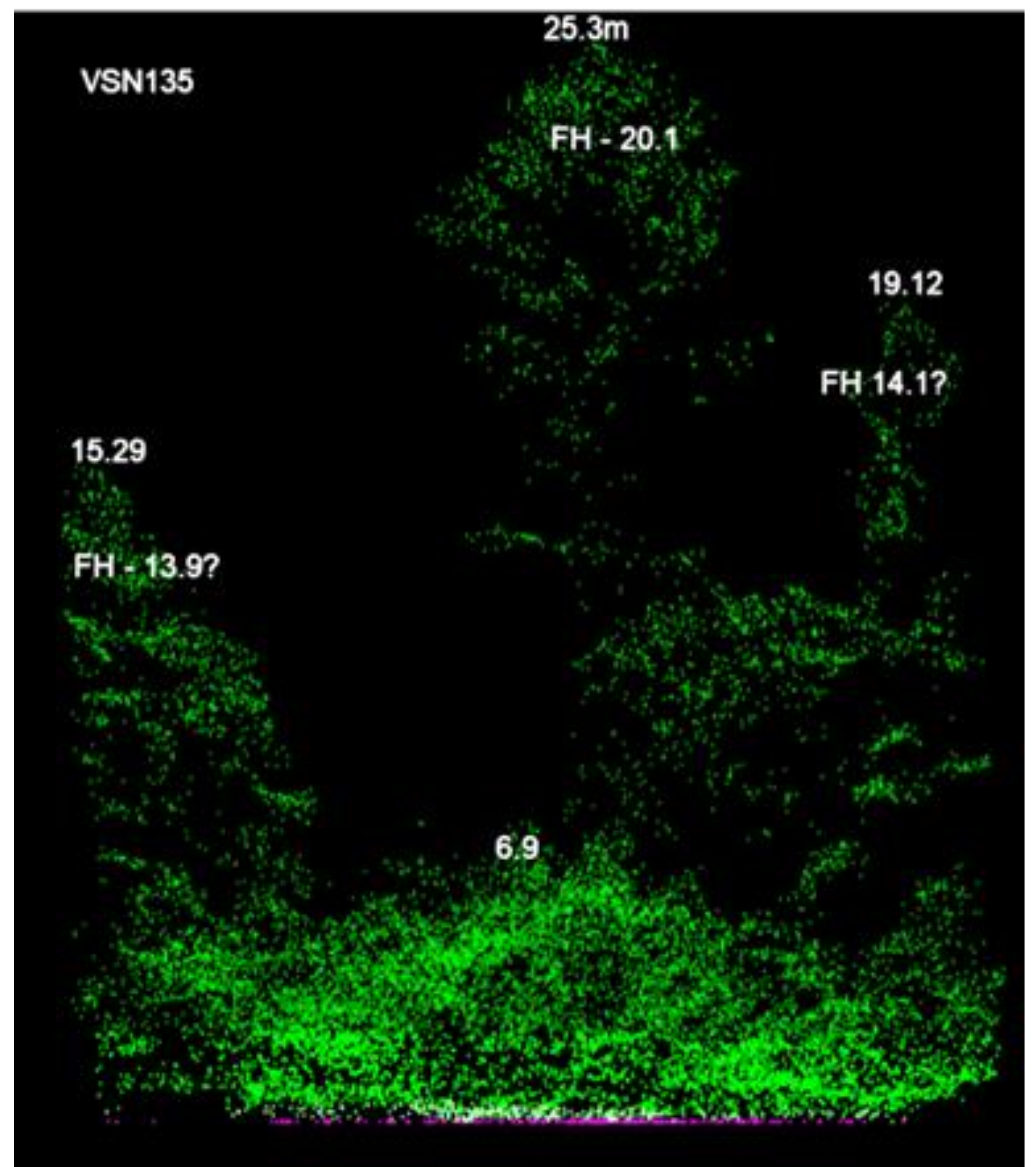
**APF Calibration Plots by FU**



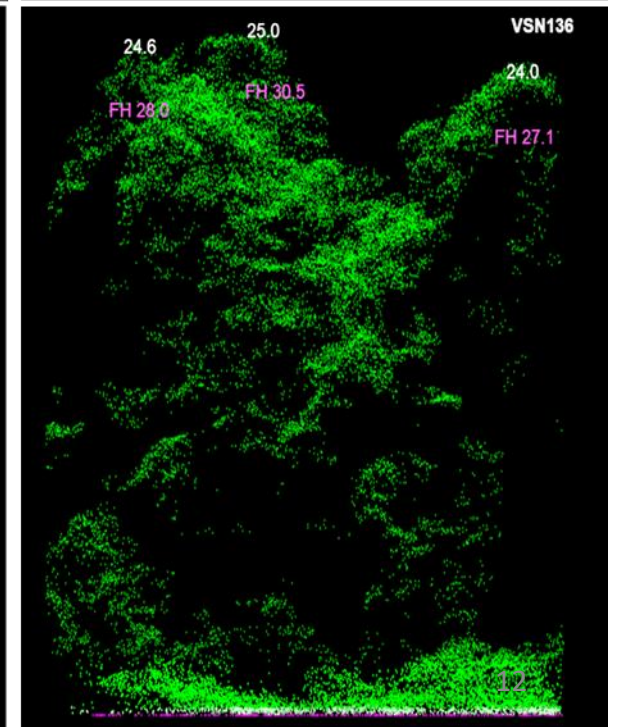
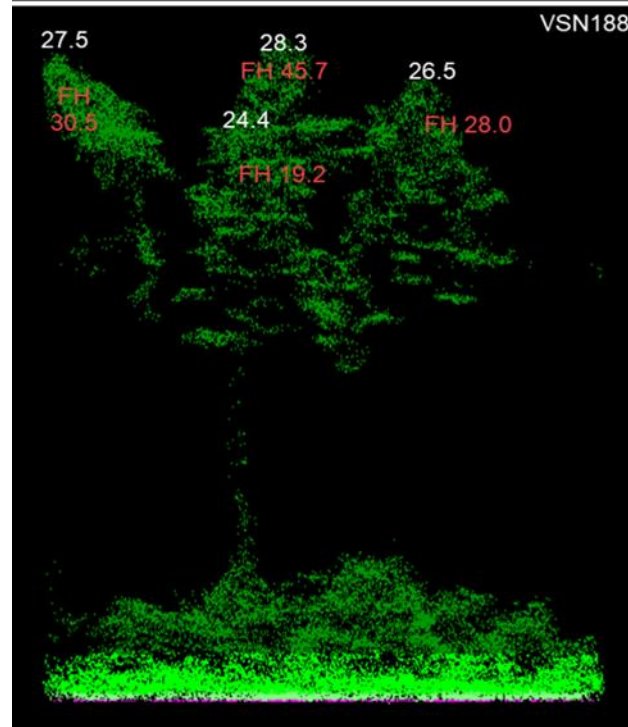
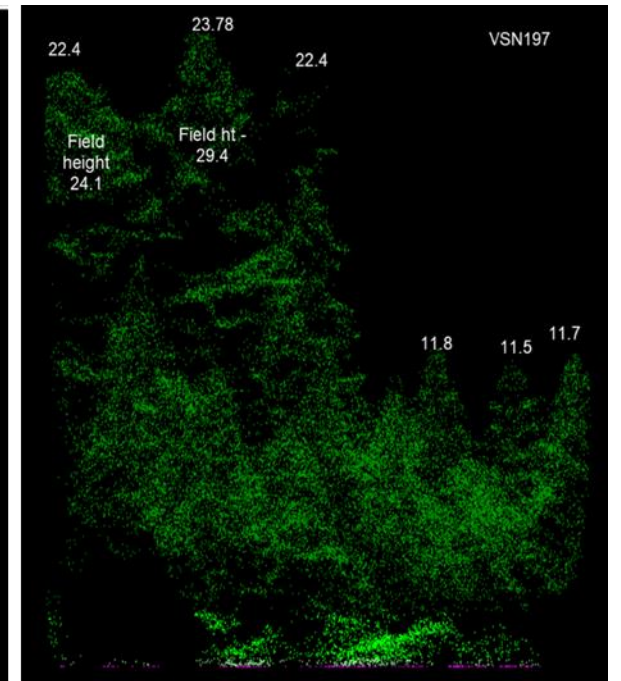
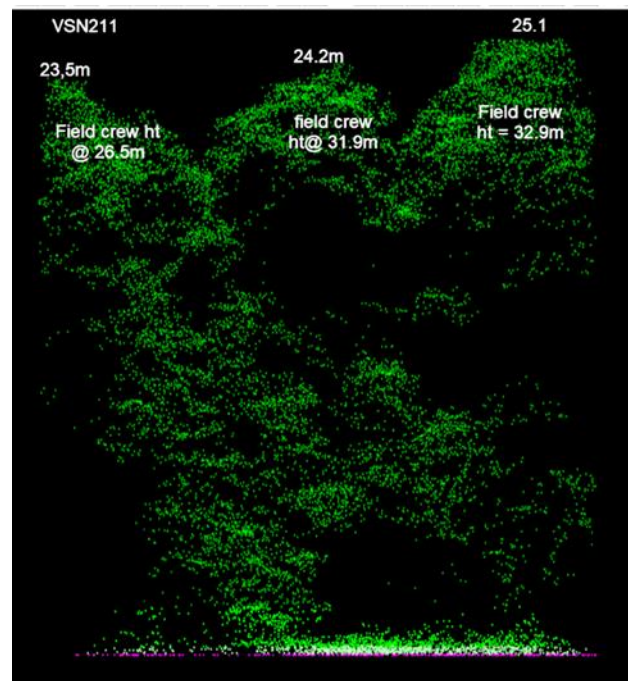
# Calibration Plot Data Quality

- High-quality ground measured calibration plot data is a necessity
- APF calibration plot data quality “questionable” ????
- Evidence of poor field height measurements found
- Unknown quality of Dbh measurements or trees in/out of plot ??

# Examples of Poor Height Measurements - too low

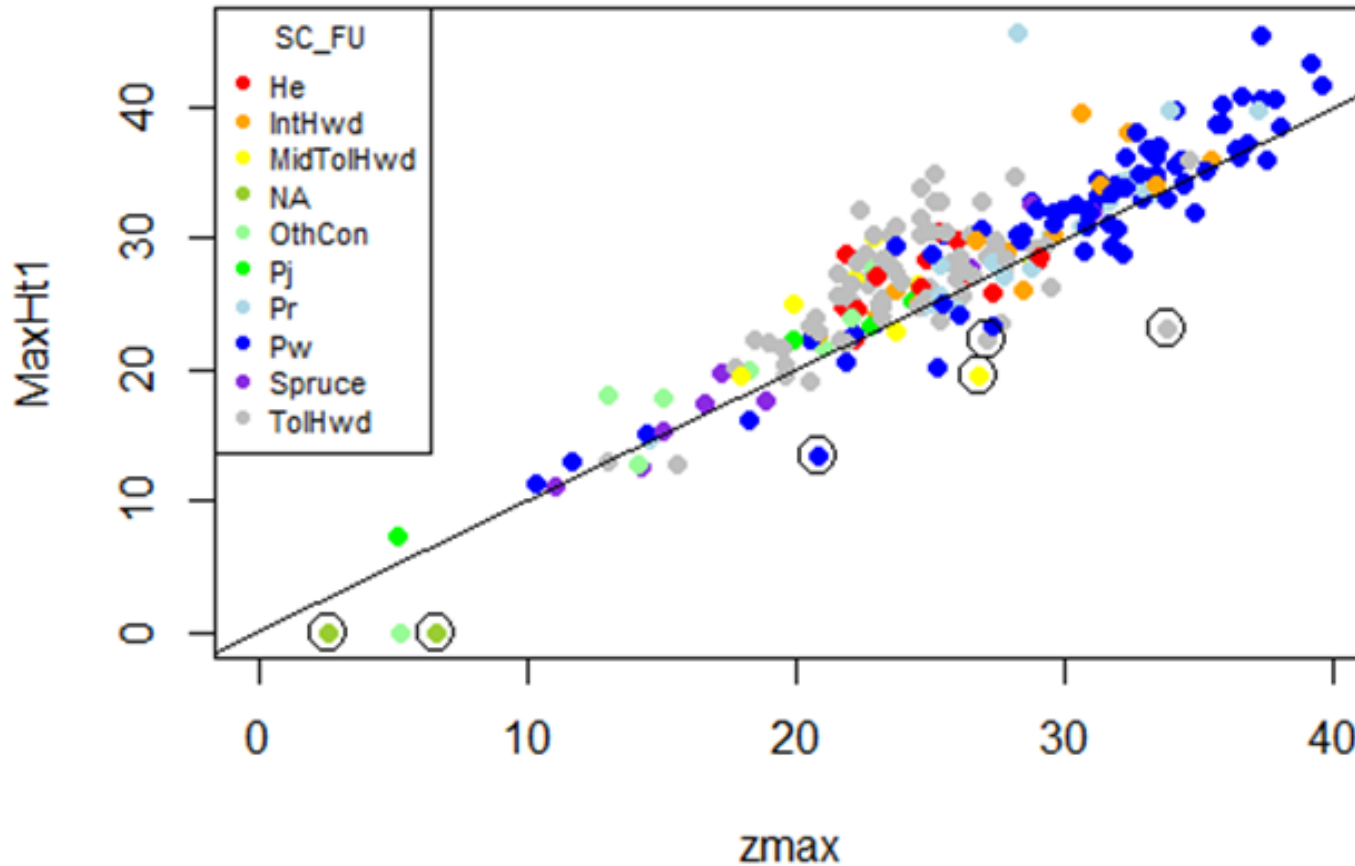


# Examples of Poor Height Measurements - too high

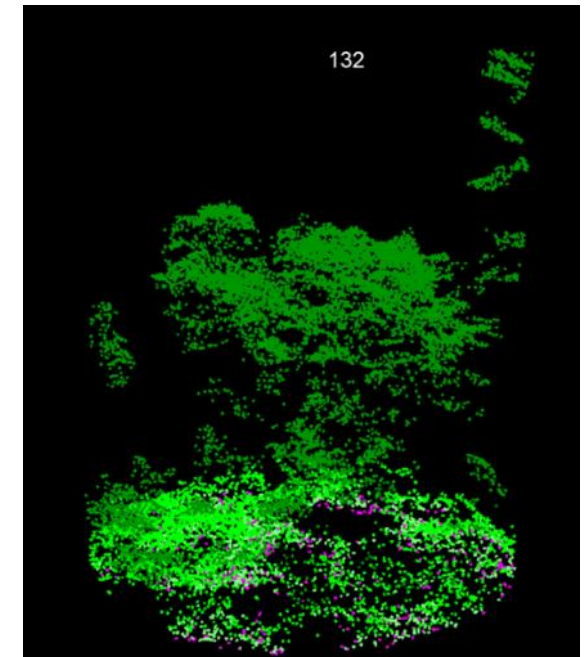


# Comparison of Plot Max LiDAR Ht and Field Ht

Original Data



○ Plot heights impacted by crowns outside measured plot

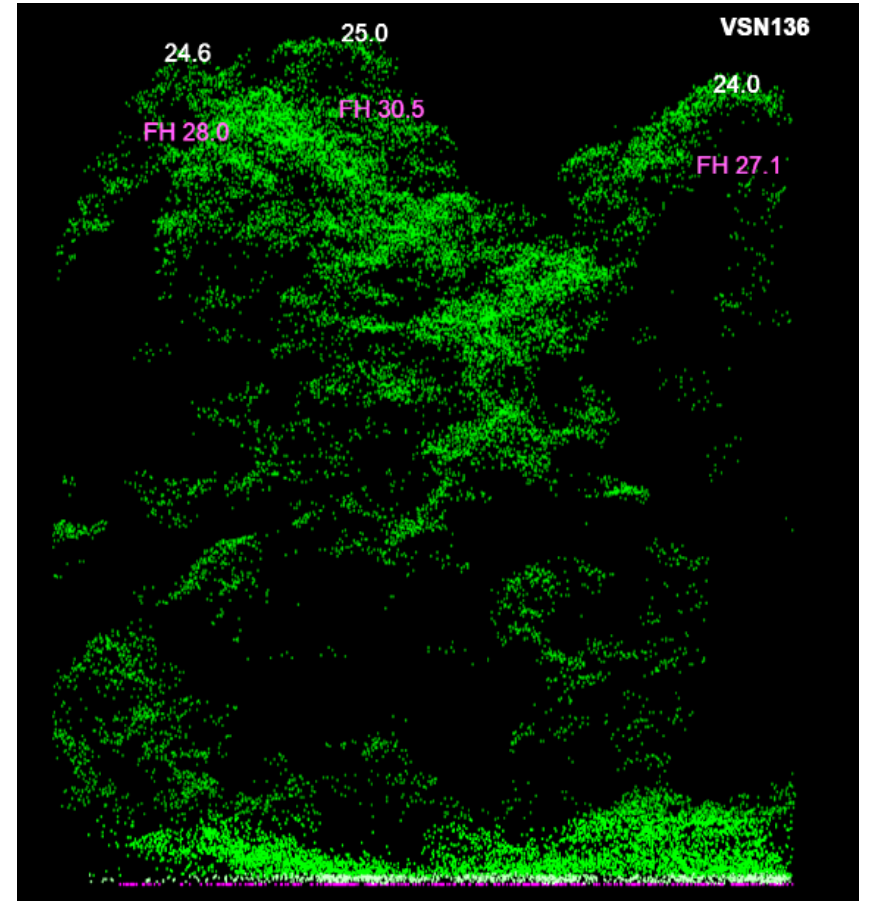
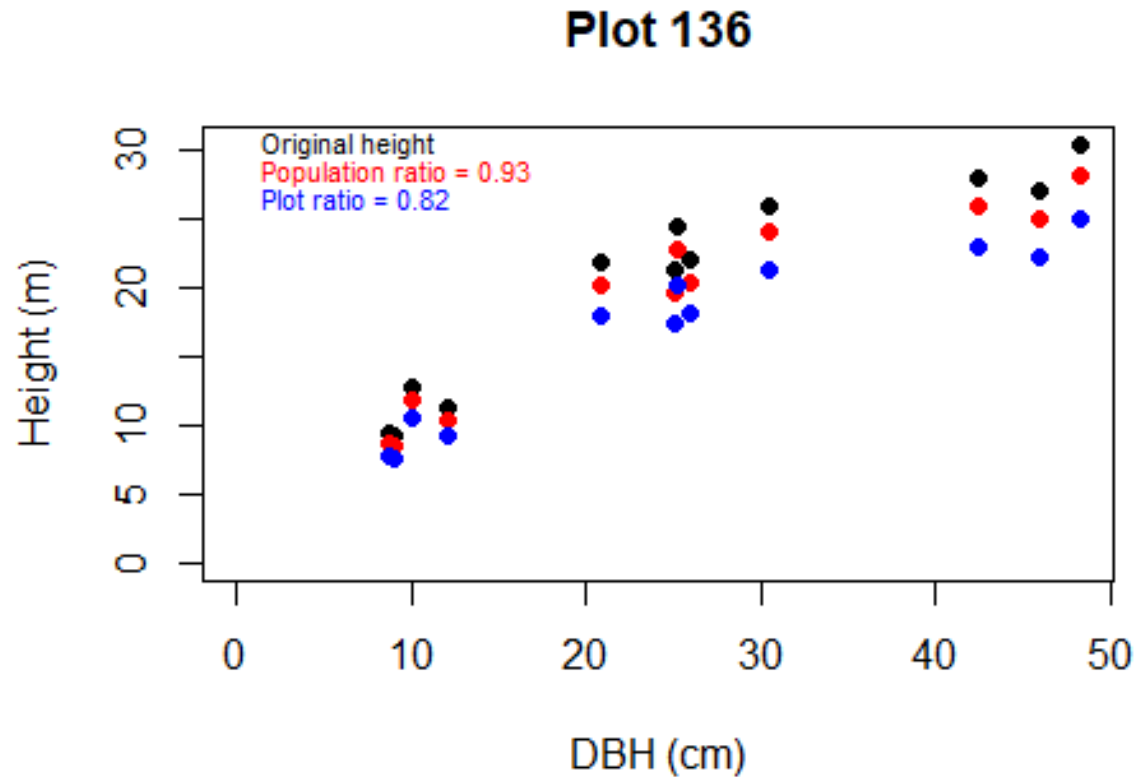


# Calibration Plot Data Adjustment - Height



- **Adjustments to field data measurements is something that should never be required!!**
- A decision to adjust the field heights using the relationship between the height of the tallest tree on the plot (MaxHt) and the maximum LiDAR return (zmax)
- A "plot level ratio" adjustment was made to each plot for the APF
- Where no suitable height trees were available to make a plot level ratio adjustment, the population level adjustment was be used

# Calibration Plot Data Adjustment - Height



For plot 136, both the population and plot adjustments are downward.

Unadjusted GTV 193.5 m<sup>3</sup>/ha, adjusted GTV = 164.3 m<sup>3</sup>/ha

# Plot Compilation – grid cell /plot attributes

**Unless otherwise noted, the following summaries are for live trees with Dbh  $\geq$  7.1 cm**

## Tree level

- Height – top height, dom/codom height, Lorey's height
- Quadratic mean Dbh

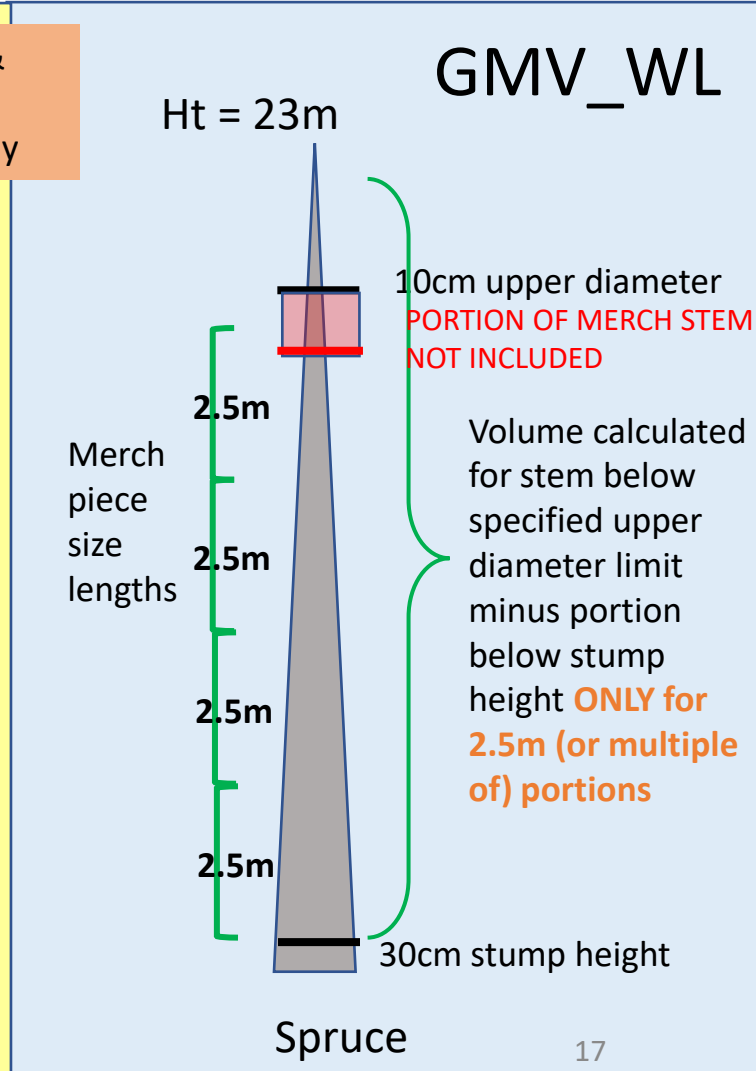
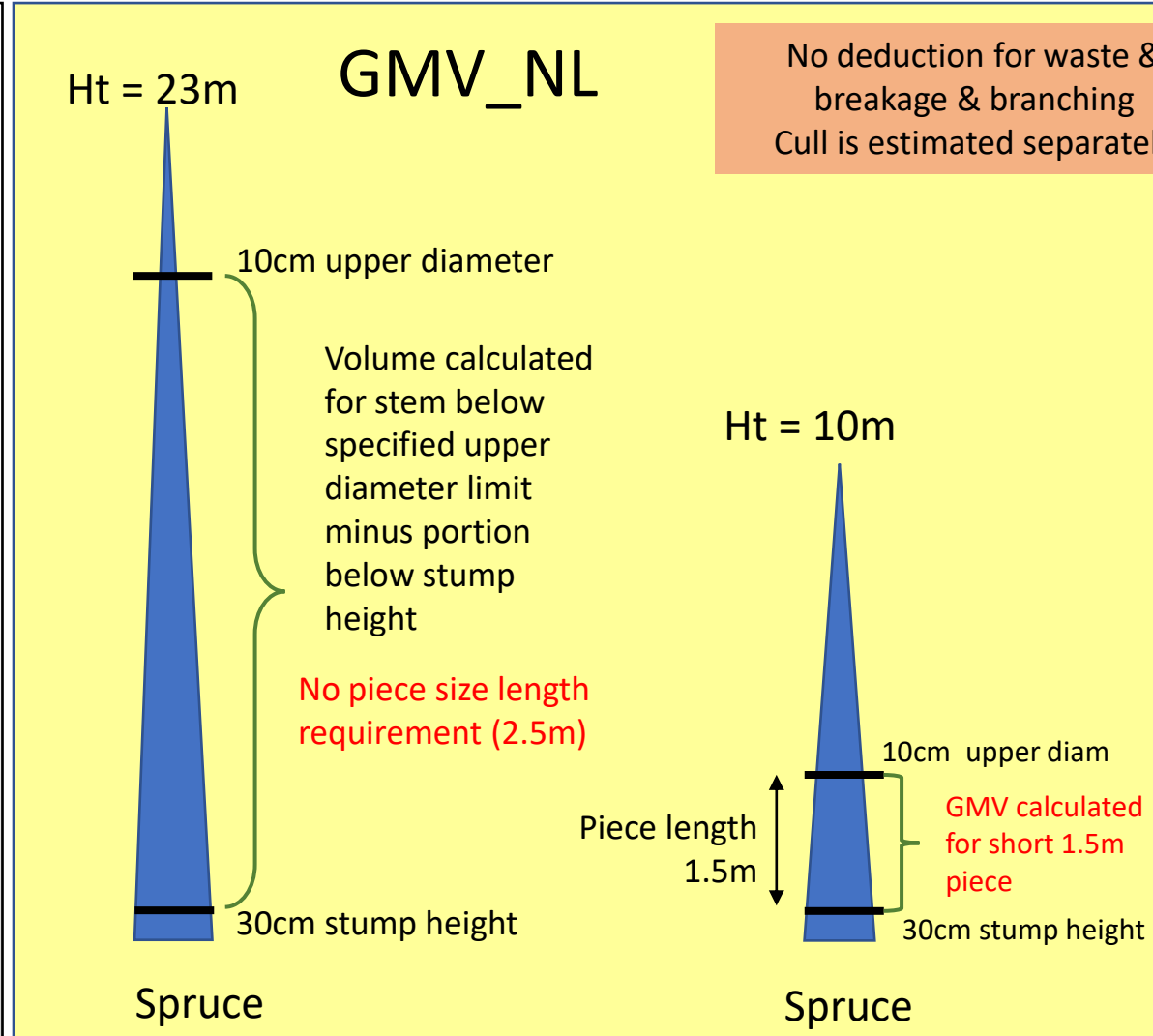
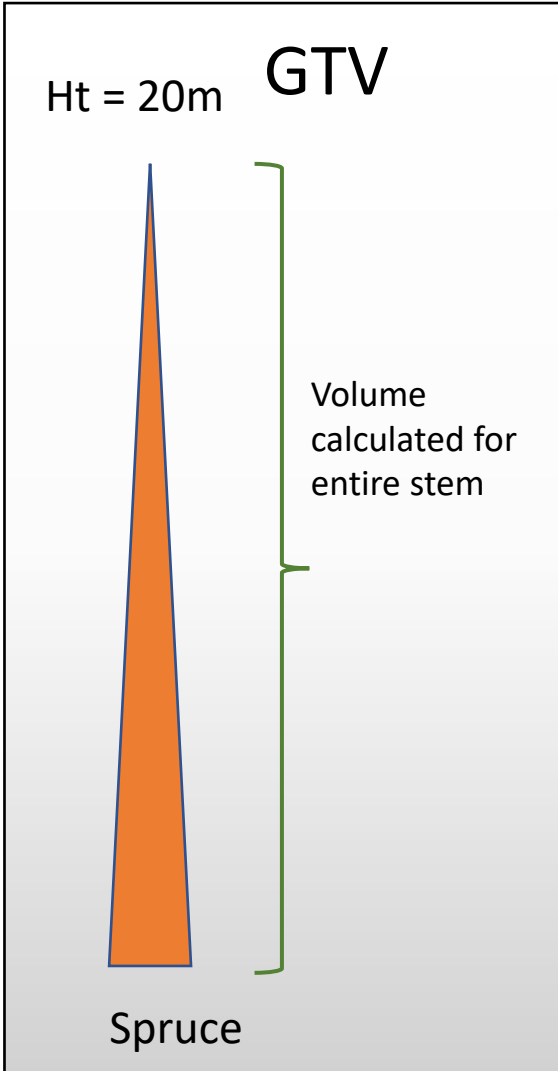
## Area level

- Basal area, Basal area merch
- Volume - GTV, GMV\_NL, GMV\_WL
- Biomass



# Plot Compilation - volumes

Species	Minimum Diameter Outside Bark (DOB)
Hardwoods (not poplar/white birch)	18cm class, 17.1 cm
Conifers (not White & Red Pine, Hemlock)	10cm class, 9.1 cm
White & Red Pine, Hemlock	14cm class, 13.1 cm
Poplar, White Birch	14cm class, 13.1 cm



# Plot Compilation – SFL specific volumes

**GMV\_UtilPoles (m<sup>3</sup> ha<sup>-1</sup>)**

**For Red/Jack Pine species\* only**

Stump Height = 30cm

Diameter @ 30cm + 6' (2.13m) = 30cm

Top Diameter = 14cm (5")

Minimum Length = 10.668m (35')



\* Based on T1 Species Composition Information

# Plot Compilation – BA/volume by size class

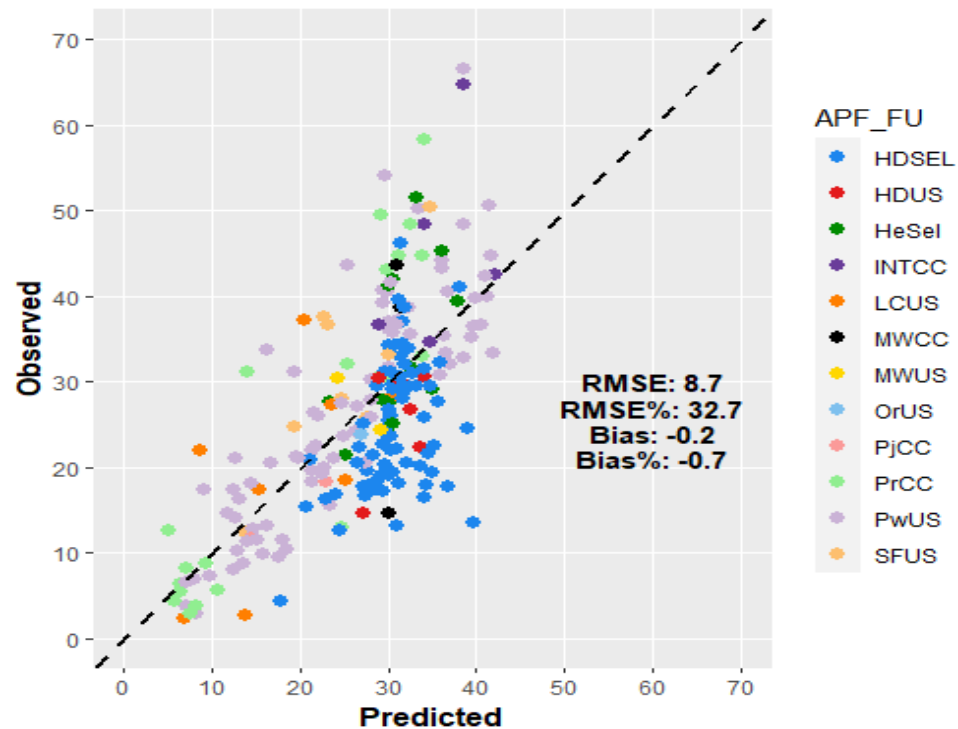
Inventory Attribute	Description
Poles	[9 < Dbh ≤ 25 cm]
Small Sawlogs	[25 < Dbh ≤ 37 cm]
Medium Sawlogs	[37 < Dbh ≤ 49 cm]
Large Sawlogs	[Dbh > 49 cm]

- Only one GMV being modeled (GMV<sub>nl</sub>)
- 9m threshold for size class predictions

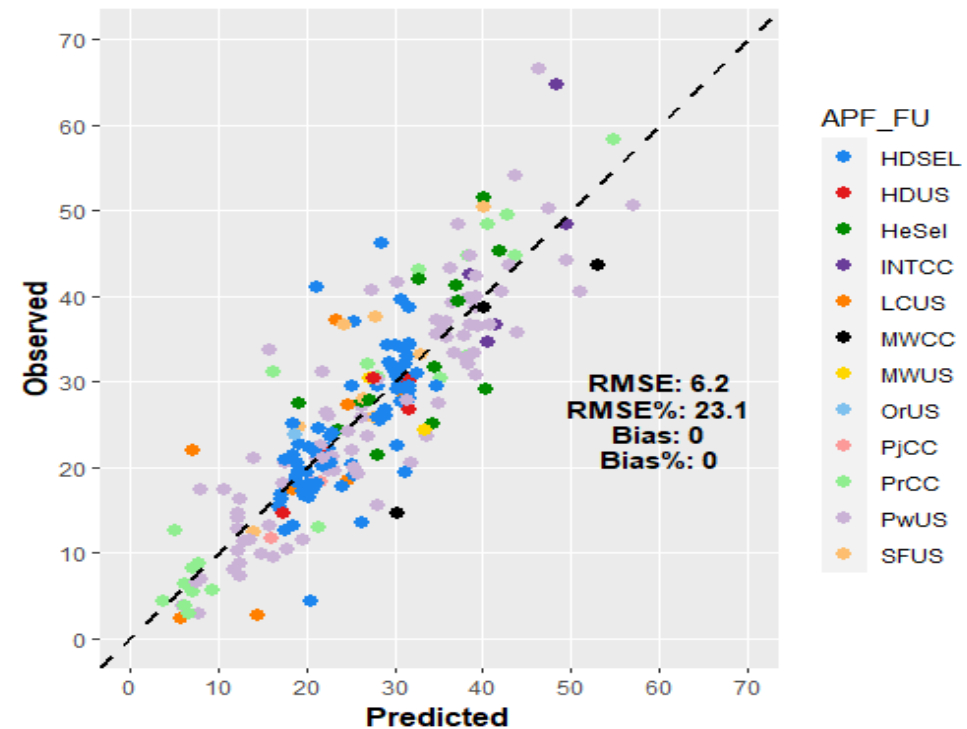
# LiDAR Model Development

- Examination of model results indicated a need to implement a stratified modeling approach

Basal Area (m2 ha) from Single RF Model



Basal Area (m2 ha) from 2 Strata RF Models

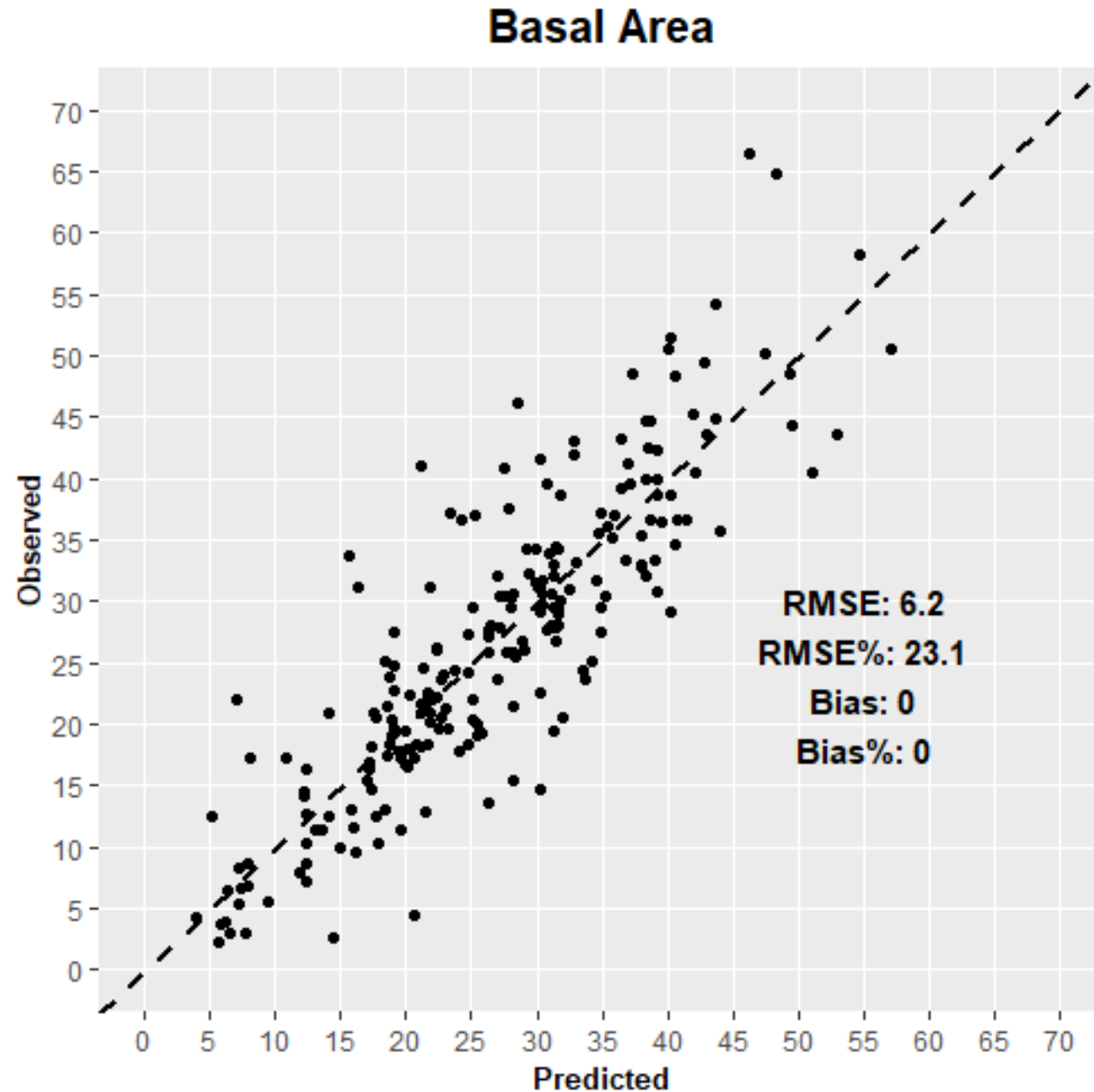


- 2 Strata:
  - Tolerant/Mid Hardwoods > 50%
  - Conifer + Intol Hwds

# LiDAR Model Development

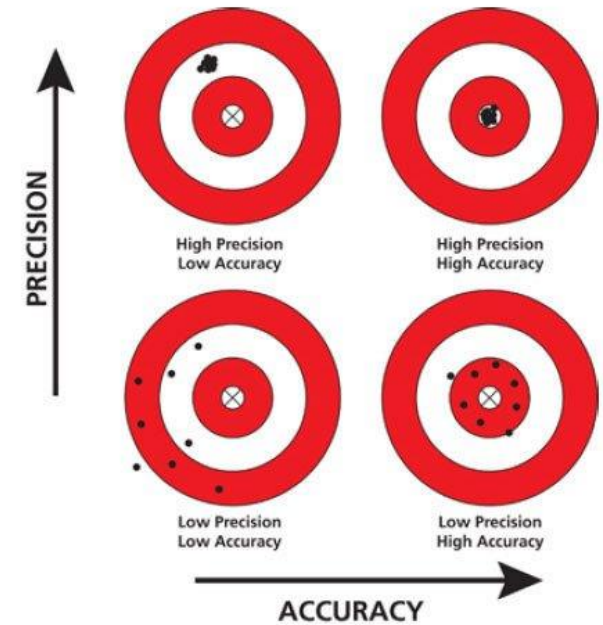
Inventory Attribute	Modeling Approach
<b>Topht</b>	Single Strata Model
<b>CDht</b>	Single Strata Model
<b>LoreyHt</b>	Single Strata Model
<b>Vbar_gtv</b>	Single Strata Model
<b>Biomass</b>	Single Strata Model
<b>gmvnl_ratio</b>	Single Strata Model
<b>gmvwl_ratio</b>	Single Strata Model
<b>UtilPole_ratio</b>	Single Strata Model
<b>Ba by Size Class</b>	Single Strata Model
<b>GMV by Size Class</b>	Single Strata Model
<b>Basal Area</b>	Two Strata Model -Tolerant Hardwood >50% , Conifer + Intolerant Hardwoods
<b>Basal Area Merch</b>	Two Strata Model -Tolerant Hardwood >50% , Conifer + Intolerant Hardwoods
<b>QMD</b>	Two Strata Model -Tolerant Hardwood >50% , Conifer + Intolerant Hardwoods

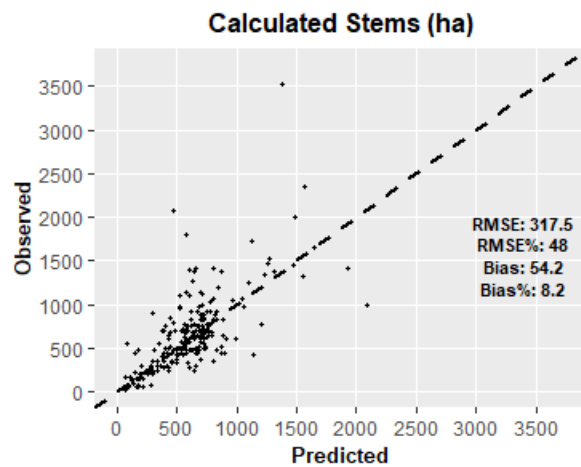
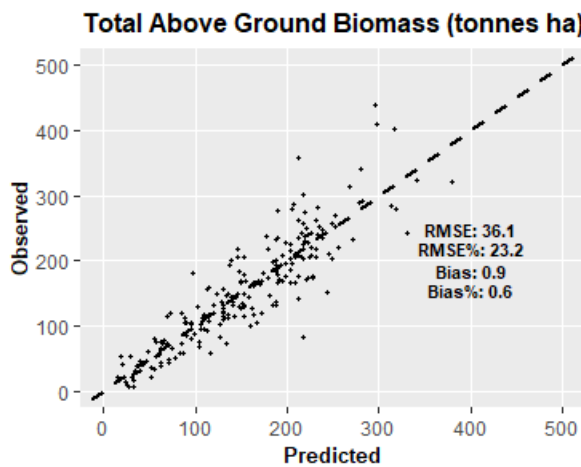
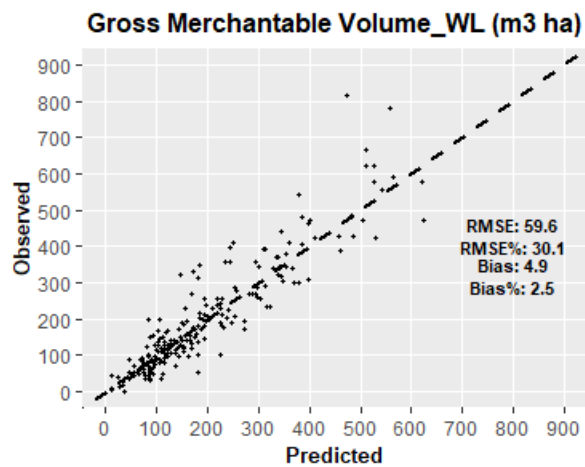
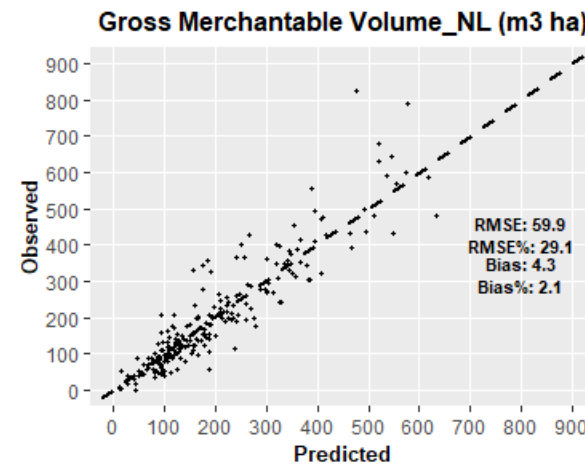
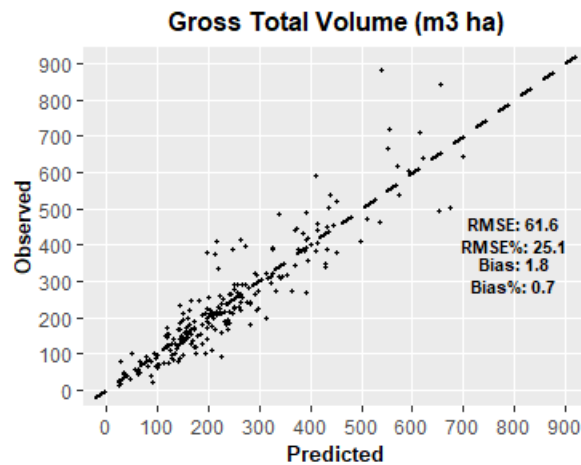
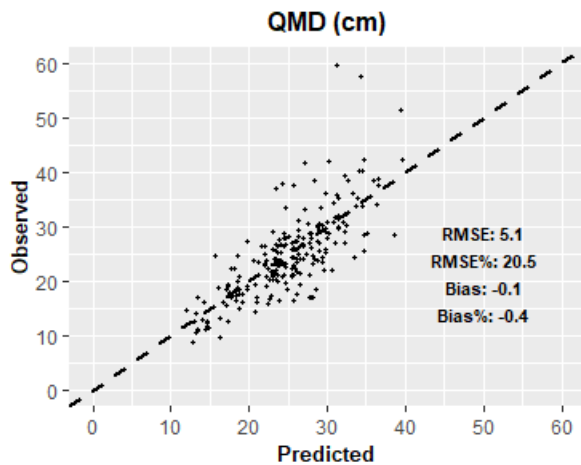
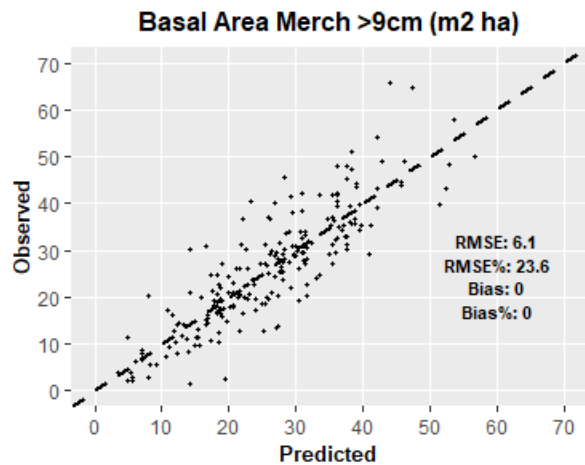
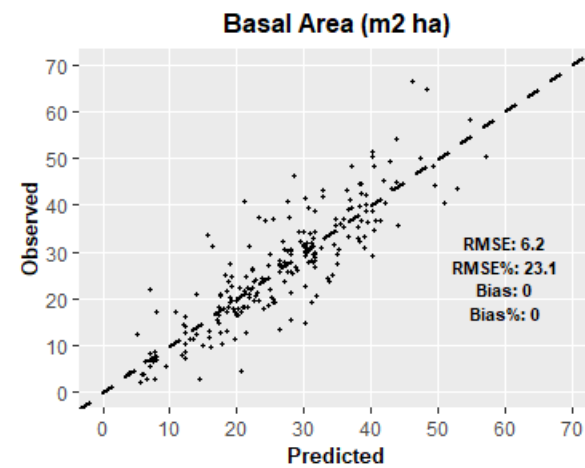
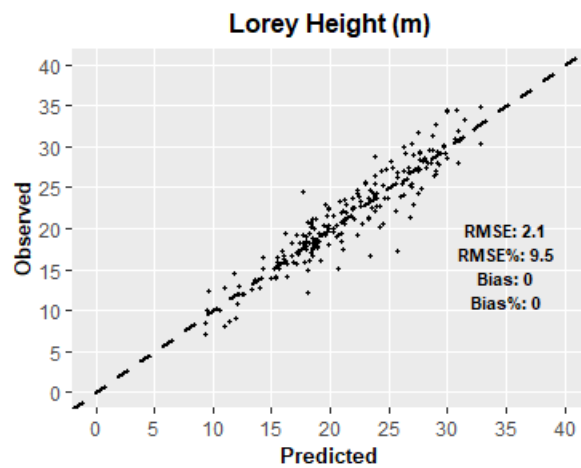
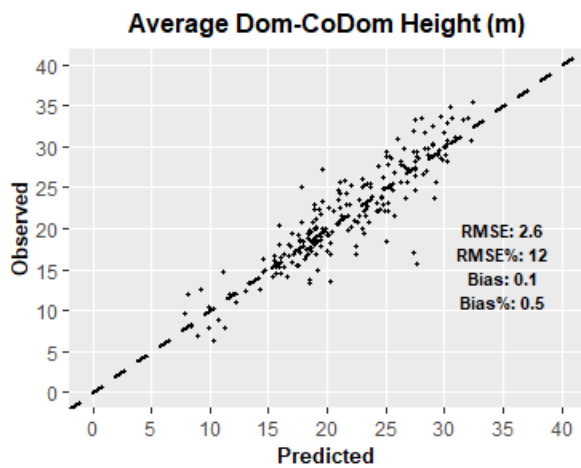
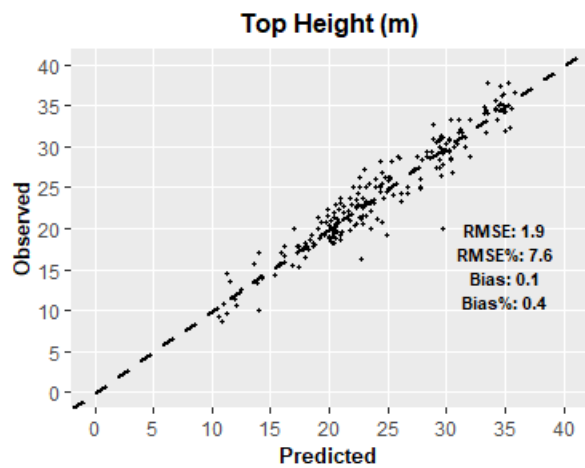
# Modeled APF Basal Area (>7cm)



The RMSE is a measure of precision –  
**How consistent are we?**

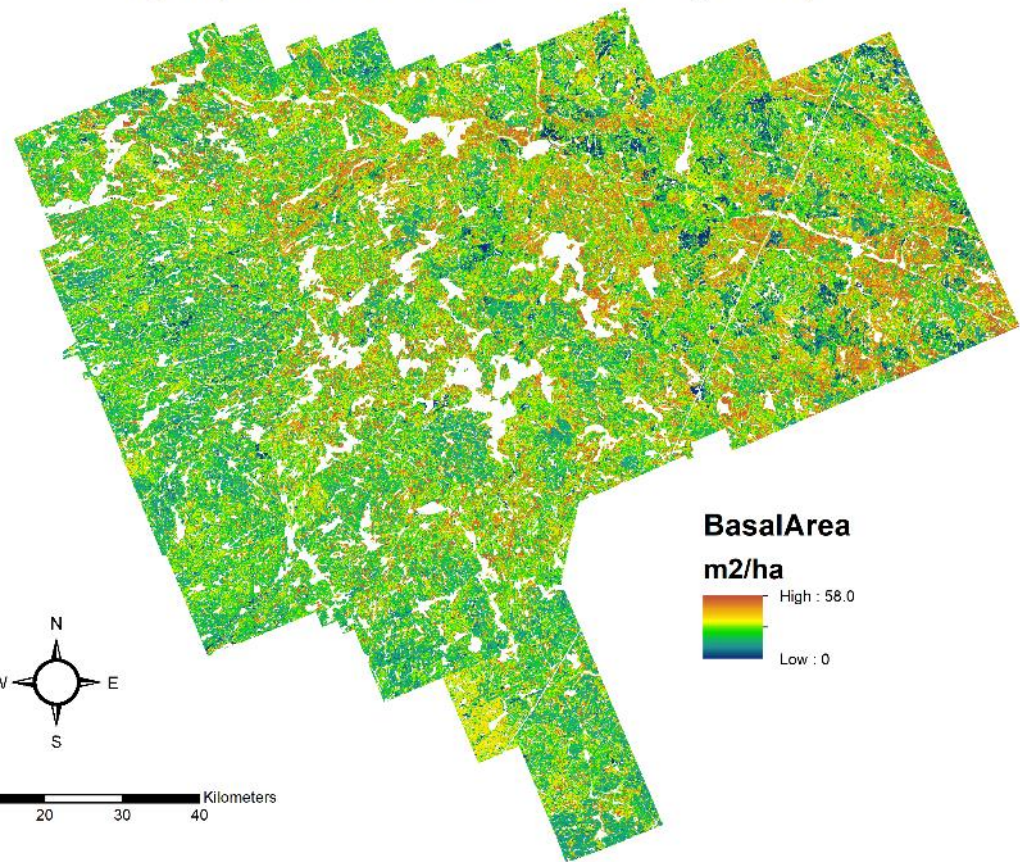
Bias is a measure of accuracy –  
**How close are we to the target?**



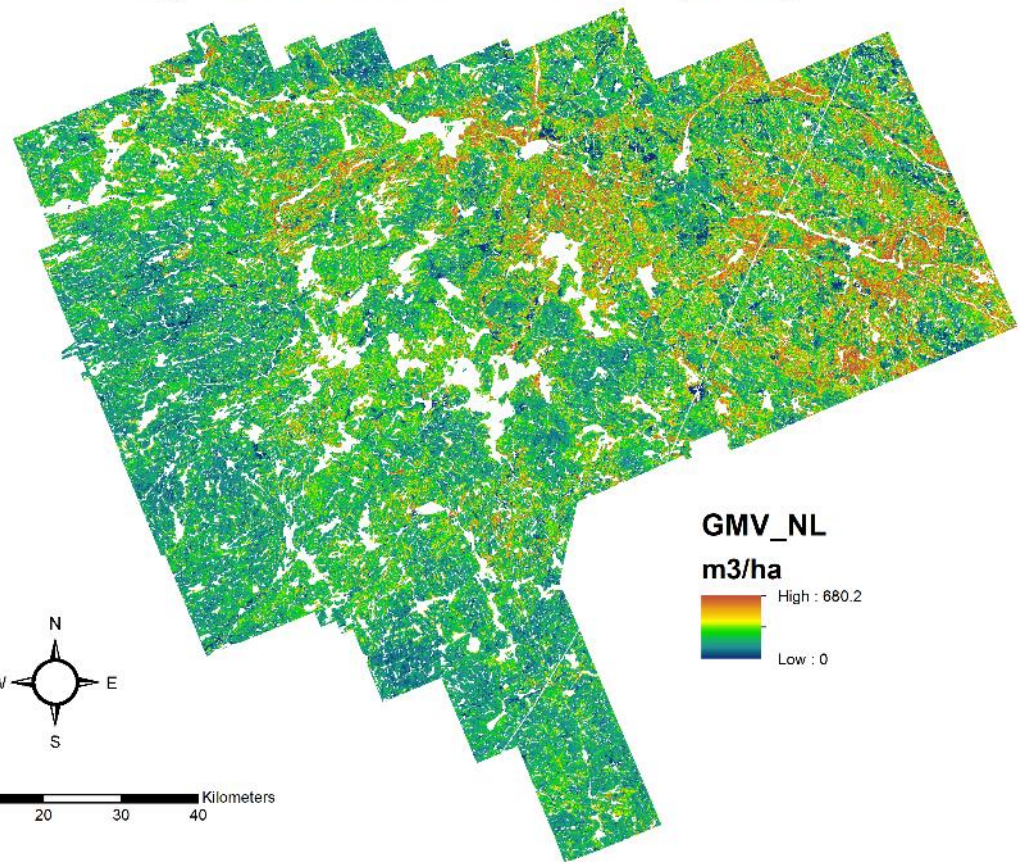


**Algonquin Park Forest**  
Two Strata RF Model Results

Algonquin Park Forest - Basal Area (m2/ha)

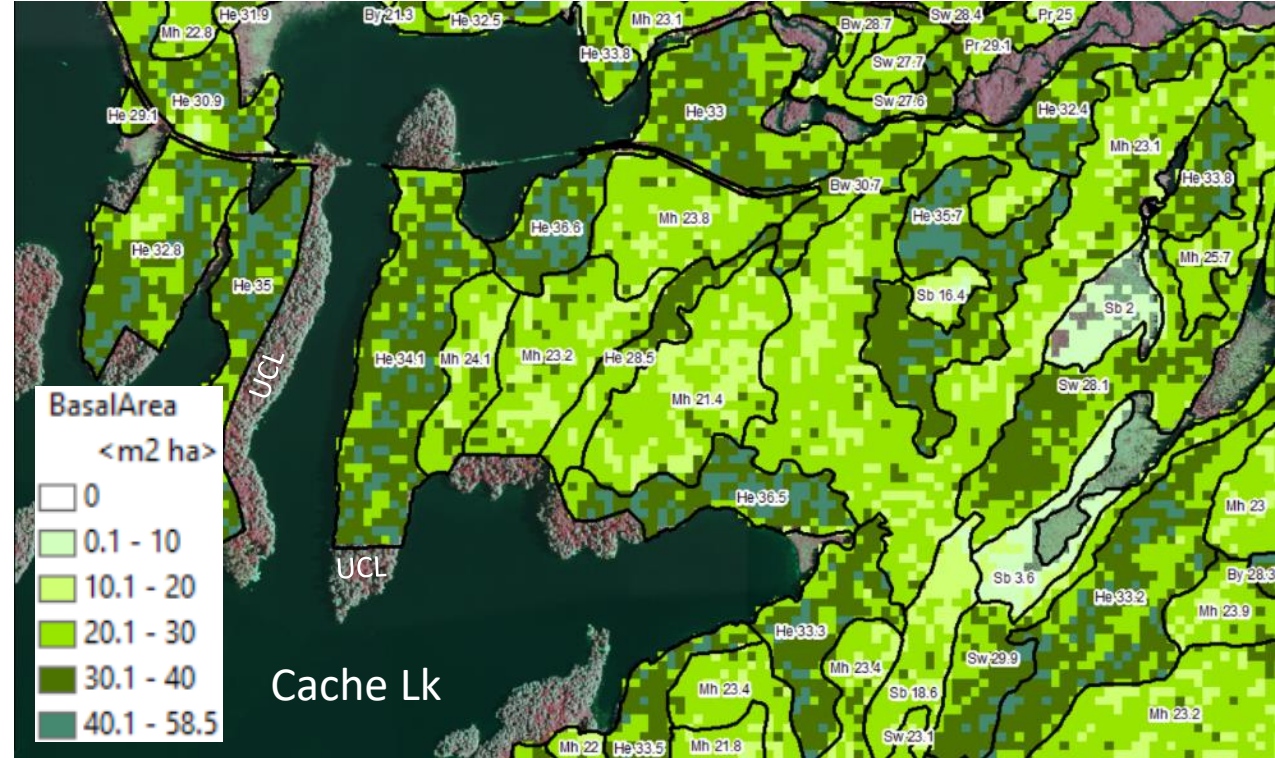


Algonquin Park Forest - GMV\_NL (m3/ha)

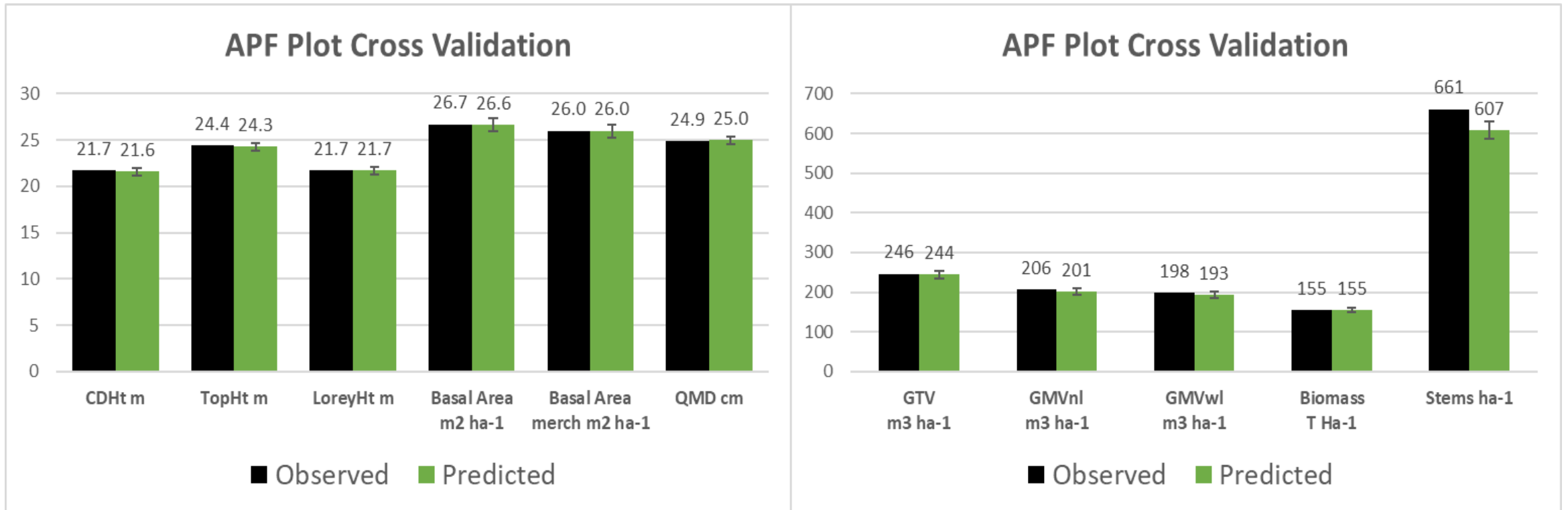




# APF LiDAR Basal Area Inventory Raster

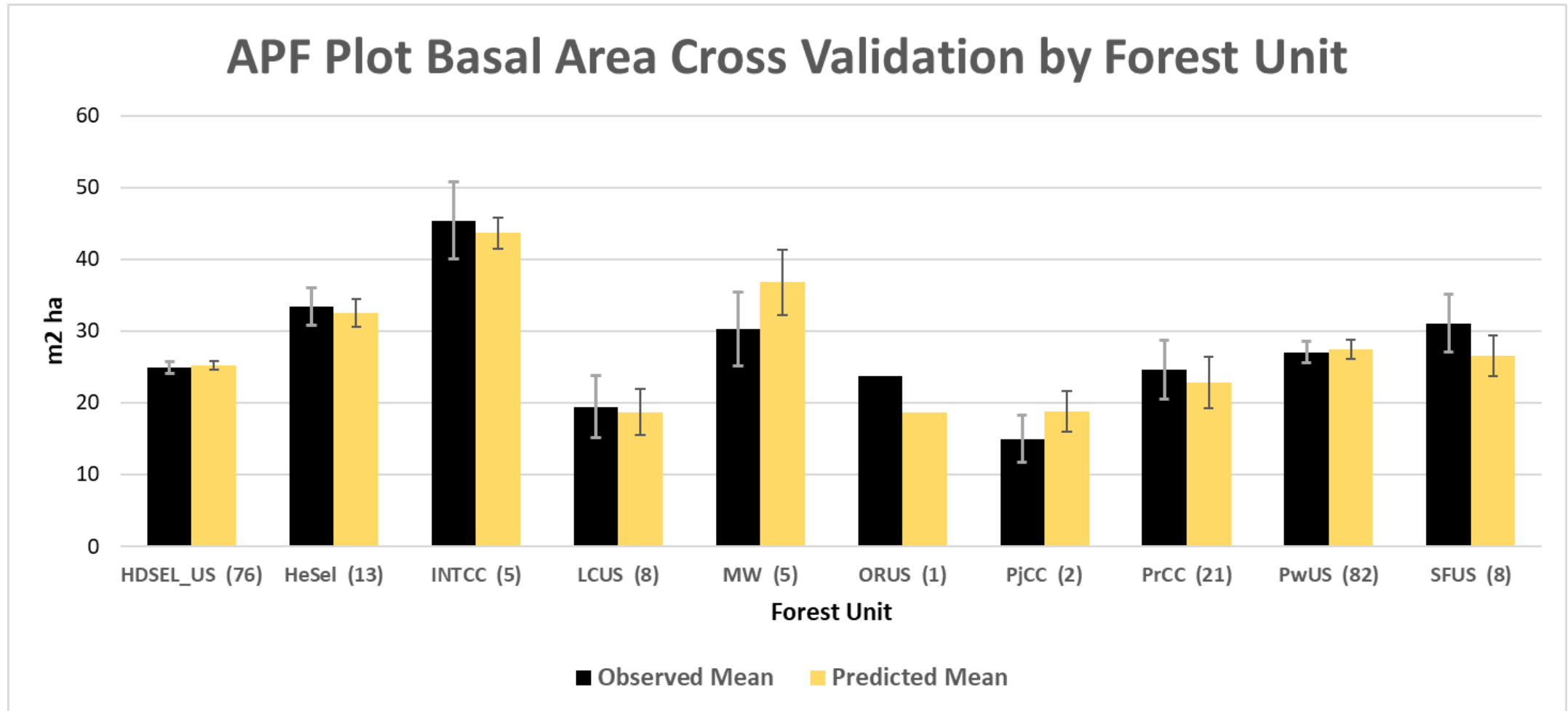


# LiDAR Modelling – Plot Level Cross Validation



┆ Standard Error

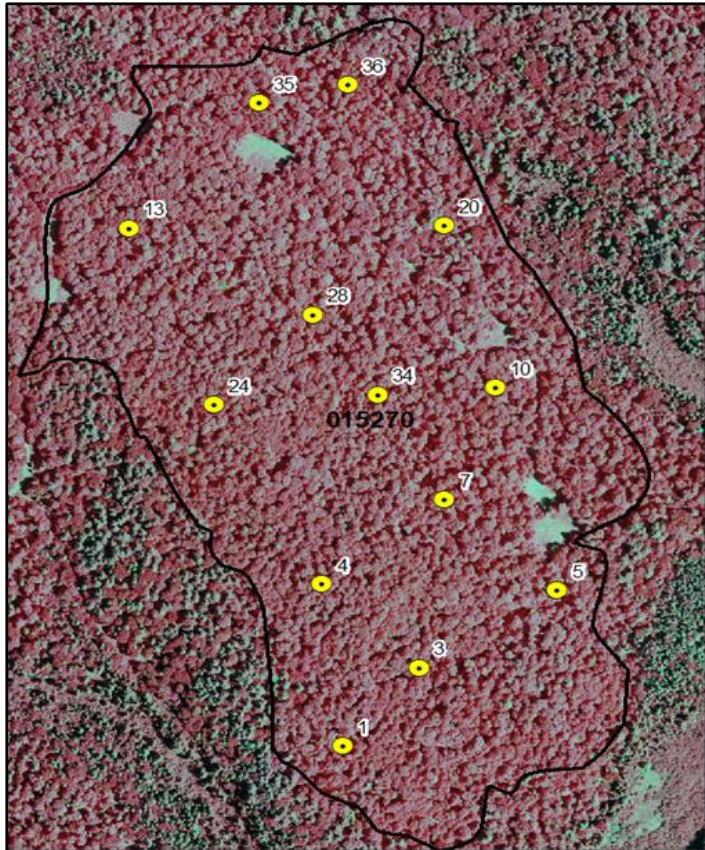
# LiDAR Modelling – Plot Level Cross Validation



┆ Standard Error

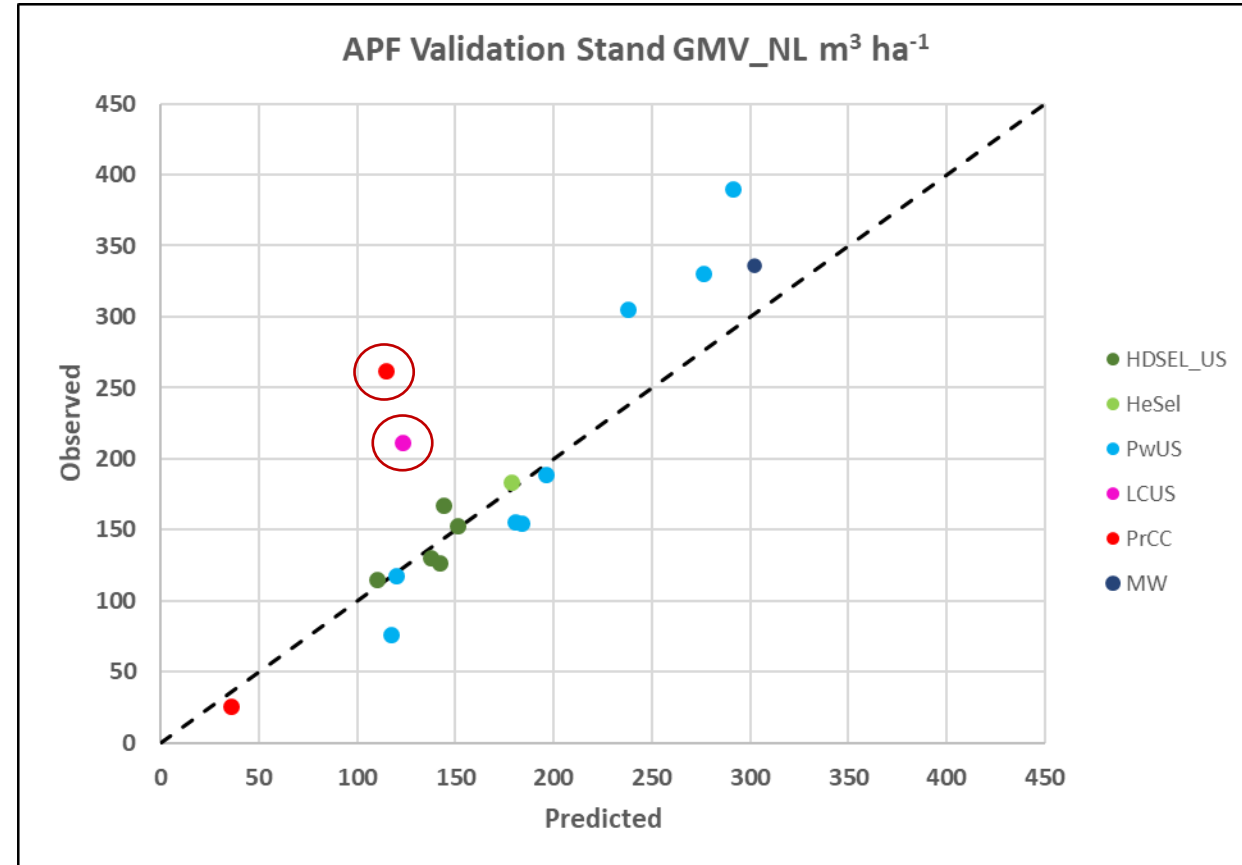
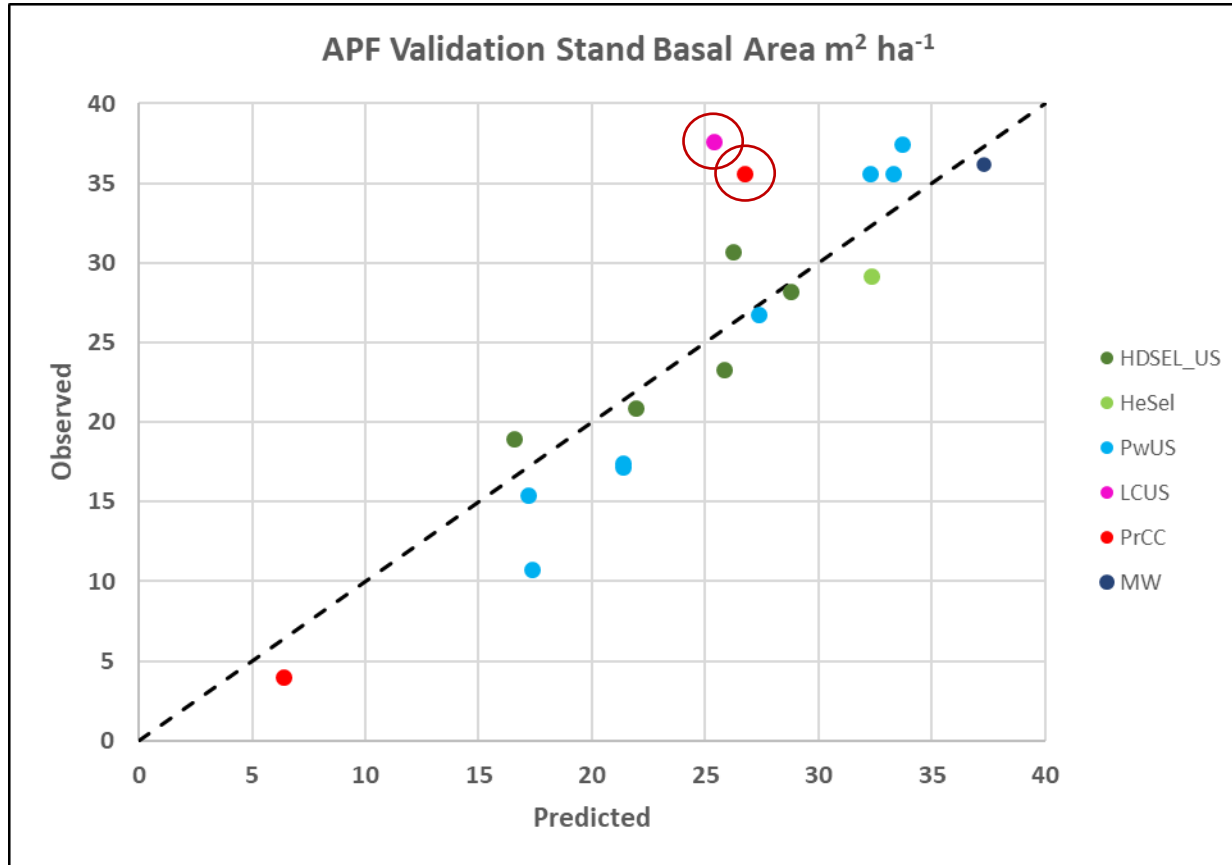
# Stand Level Validation

- 18 APF Polygons sampled by AFA
- Range of Structures/Forest Units
- BAF 2 Prism Cruise
- Mixed Species Compositions

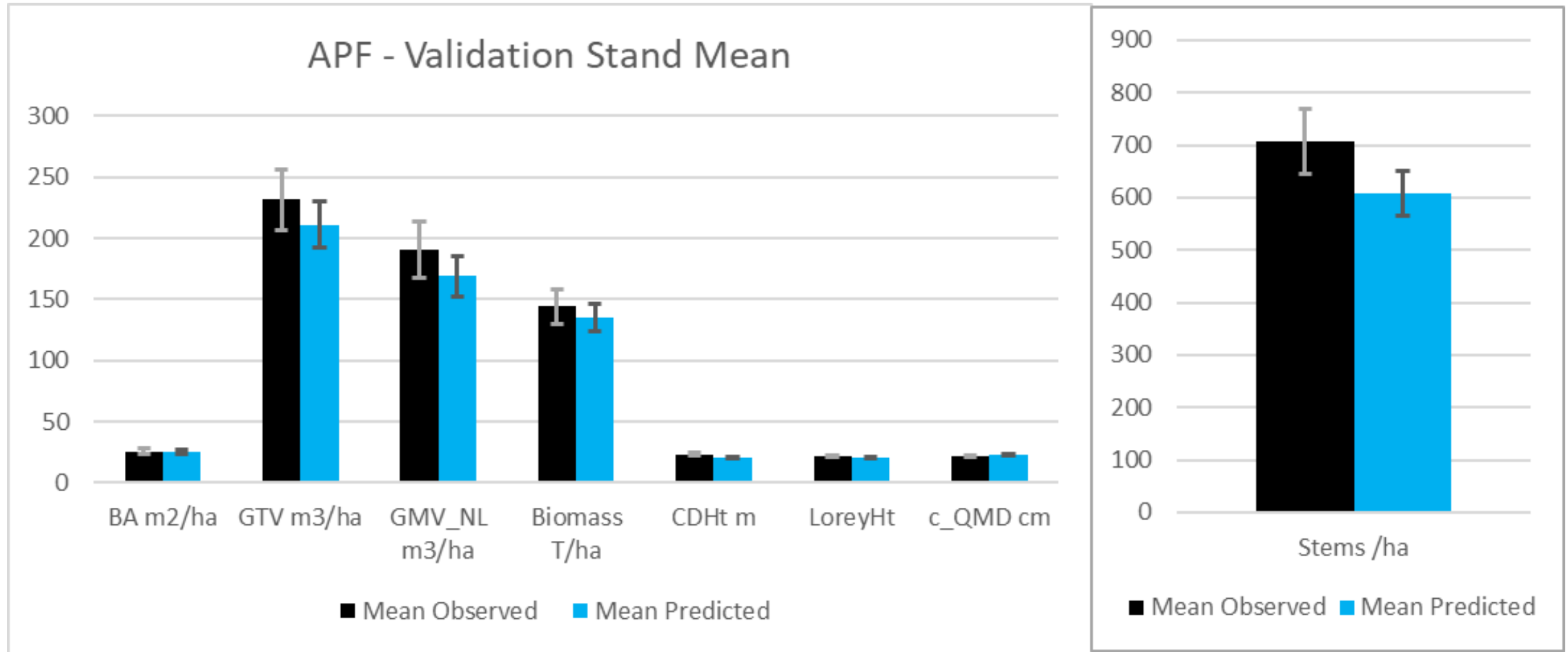


Polygon	Cruised Species Composition	Reporting FU	Area (ha)	Stations	~ Sampling Intensity
15270	Mh 84 By8 Be4 He2 Ce1 Sw1	HDSEL_US	32.7	13	2%
25404	Be 36 Mh33 By16 He5 Sw4 Cb4 Mr1 Sr1	HDSEL_US	17.9	13	3%
26147	He 24 Mh19 By15 Sb11 Bf9 Mr9 Sw8 Ce3 Be1 Bw1	HeSel	28.1	13	2%
26847	Mh 72 By8 Be4 Mr4 lw3 Sw3 Bf2 He2 Cb1 Ab1	HDSEL_US	23.6	12	2%
27172	Mh 44 By17 Be14 He11 lw4 Mr3 Aw2 Ab2 Bw2 Cb1	HDSEL_US	21.3	12	2%
68460	Pw 61 Sw27 Mr8 Bf1 Ce1 Po1 Pr1	PwUS	9.1	11	5%
70809	Pw 68 Mr15 Po7 Pr3 Sw3 Or2 Be1 Bw1	PwUS	12.8	11	3%
74025	Pw 52 Mr13 Po12 Pr8 Or6 Sw5 Bw2 Bf1 Mh1	PwUS	16.7	11	3%
74133	Ce 68 Sb19 La9 Ab1 Pw1 Bf1 Bw1	LCUS	16.9	11	3%
74329	Pw 51 Po23 Sw7 Pr5 Or5 Mr3 Bf3 Mh2 Be1 Bw0	PwUS	22.5	12	2%
74445	Po 28 Pw24 Mh11 Or10 Mr9 Sw6 Bf5 Ab3 Be2 Sb2	MW	13.5	11	3%
74732	Pw 47 Bf24 Sw9 Mr6 Or6 Bw2 Mh2 Po2 Pr2	PwUS	17.0	11	3%
88543	Pr 63 Po19 Or6 Pj6 Pw6	PrCC	23.9	9	2%
89916	Pr 68 Pj31 Pw1	PrCC	14.6	11	3%
90147	Po 26 Pr24 Pw14 Bf13 Pj8 Mr7 Or3 Sw3 Bw2	PwUS	16.5	11	3%
90863	Be 48 Pw20 Or9 Mh8 Po8 By2 lw2 Mr2 Pr1	HDSEL_US	14.2	11	3%
92778	Pr 36 Pw27 Mr8 Bf8 Ce6 Po6 Ab5 Sw2 Bw1 By1	PwUS	31.4	11	1%
100453	Pw 50 Or32 Mr8 Be4 Pr3 Bw1 lw1 Po1	PwUS	15.6	11	3%
Average		All	19.4	11.4	2.4%

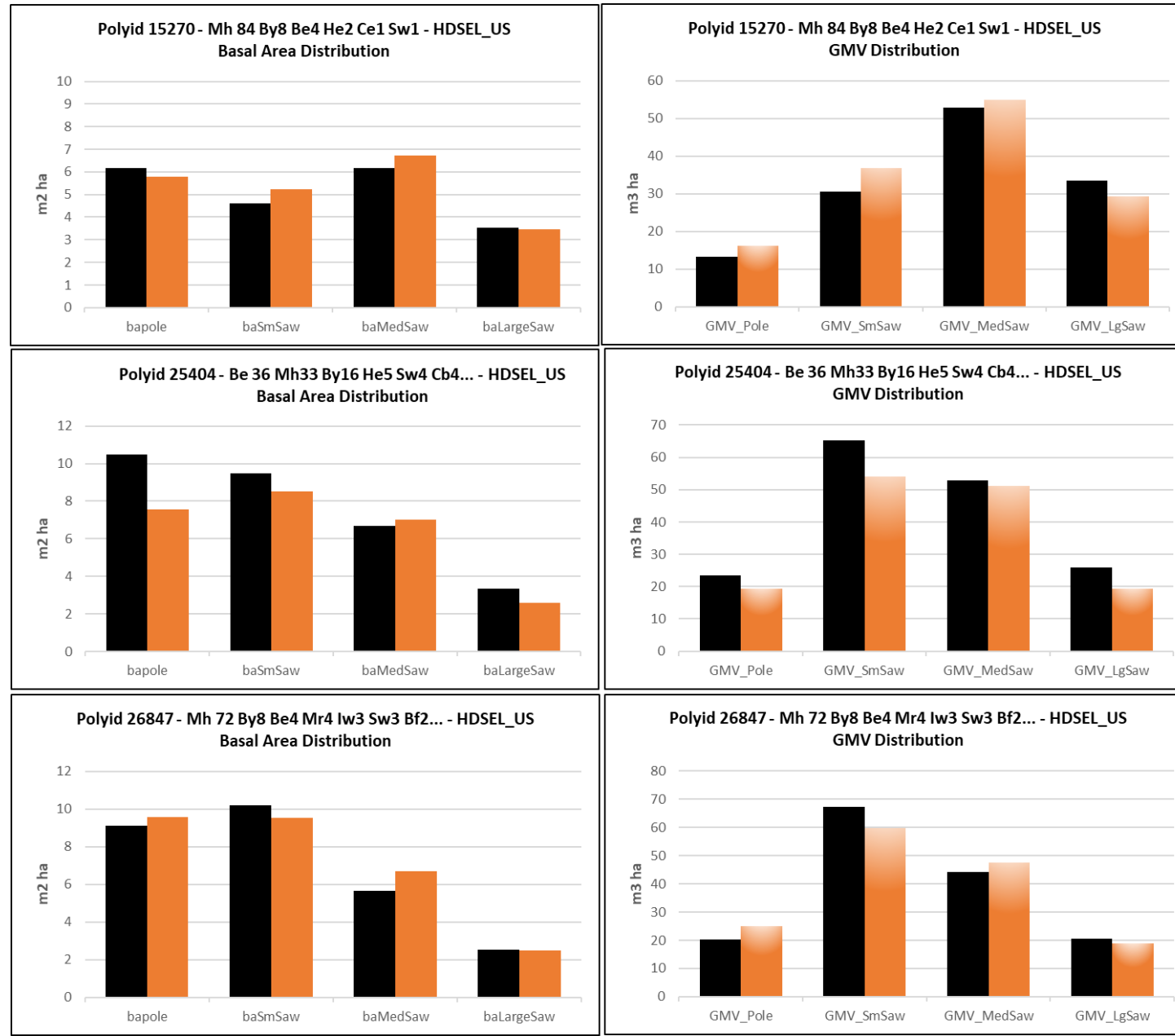
# Stand Level Validation (N =18)



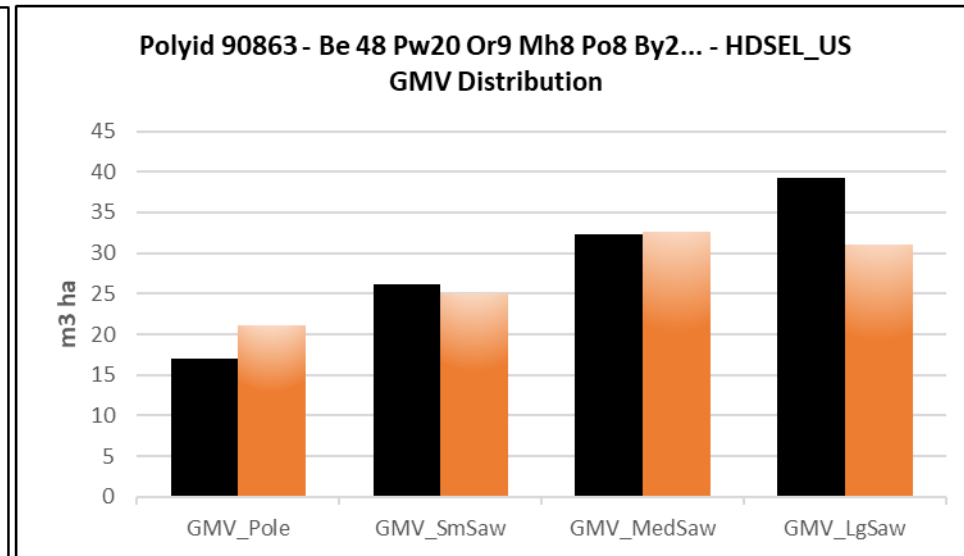
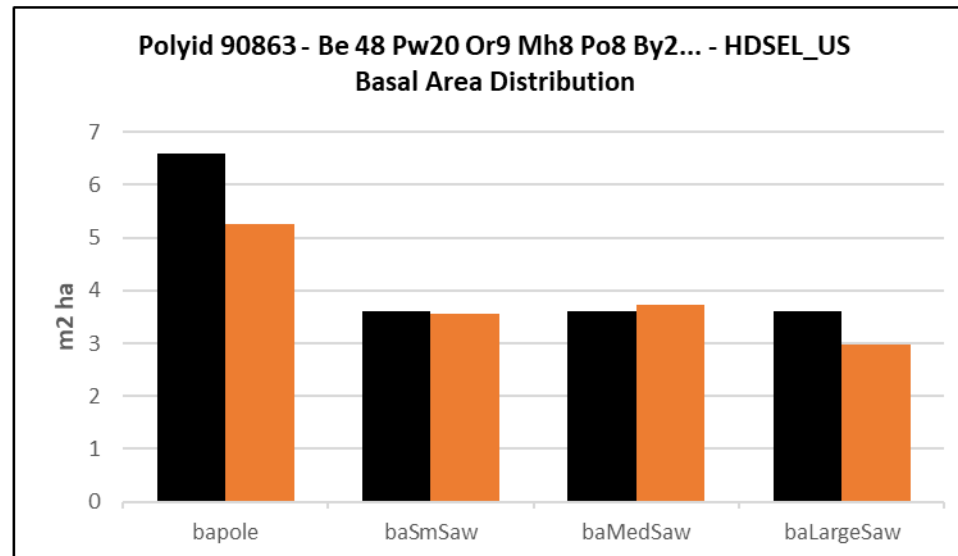
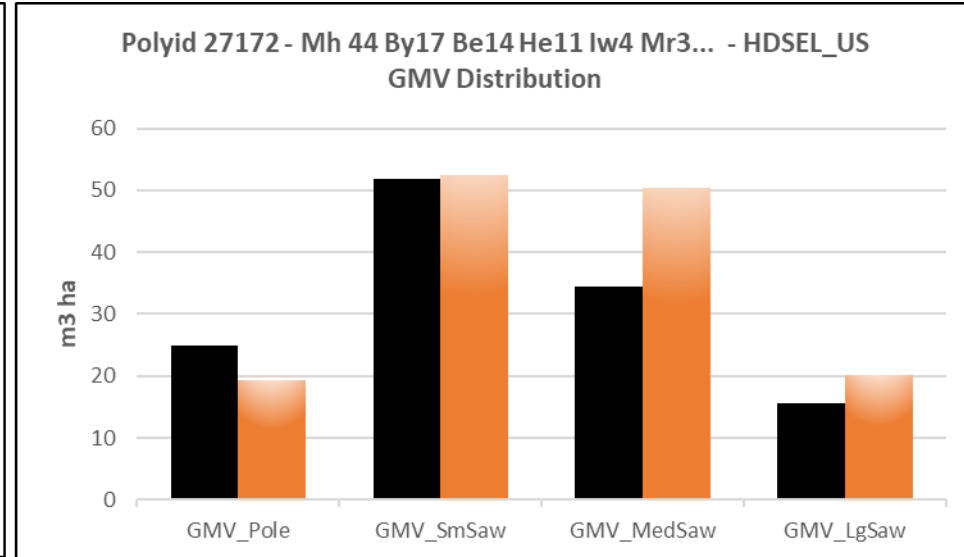
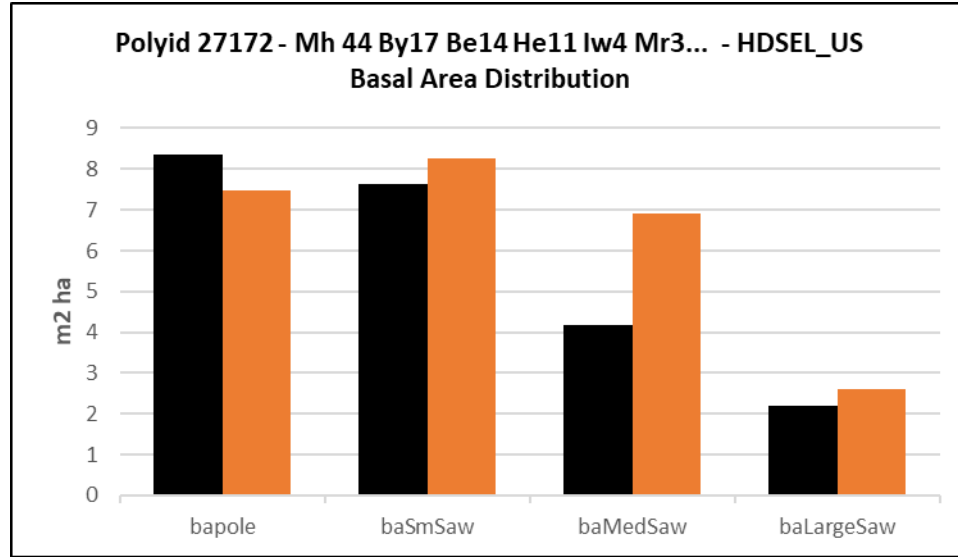
# Stand Level Validation (N =18)



# Stand Level Validation - Tolerant Hardwood Stands

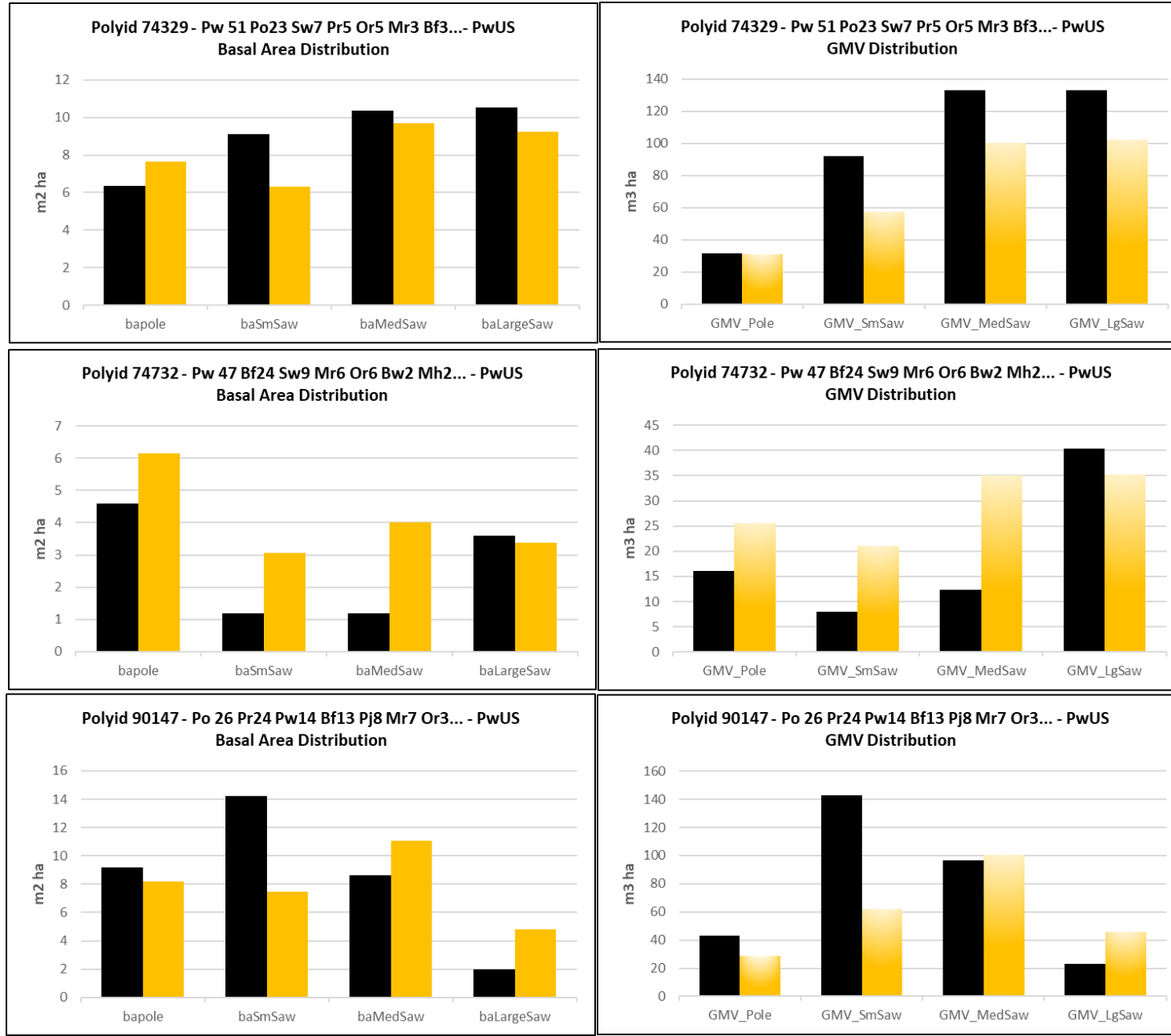


# Stand Level Validation - Tolerant Hardwood Stands

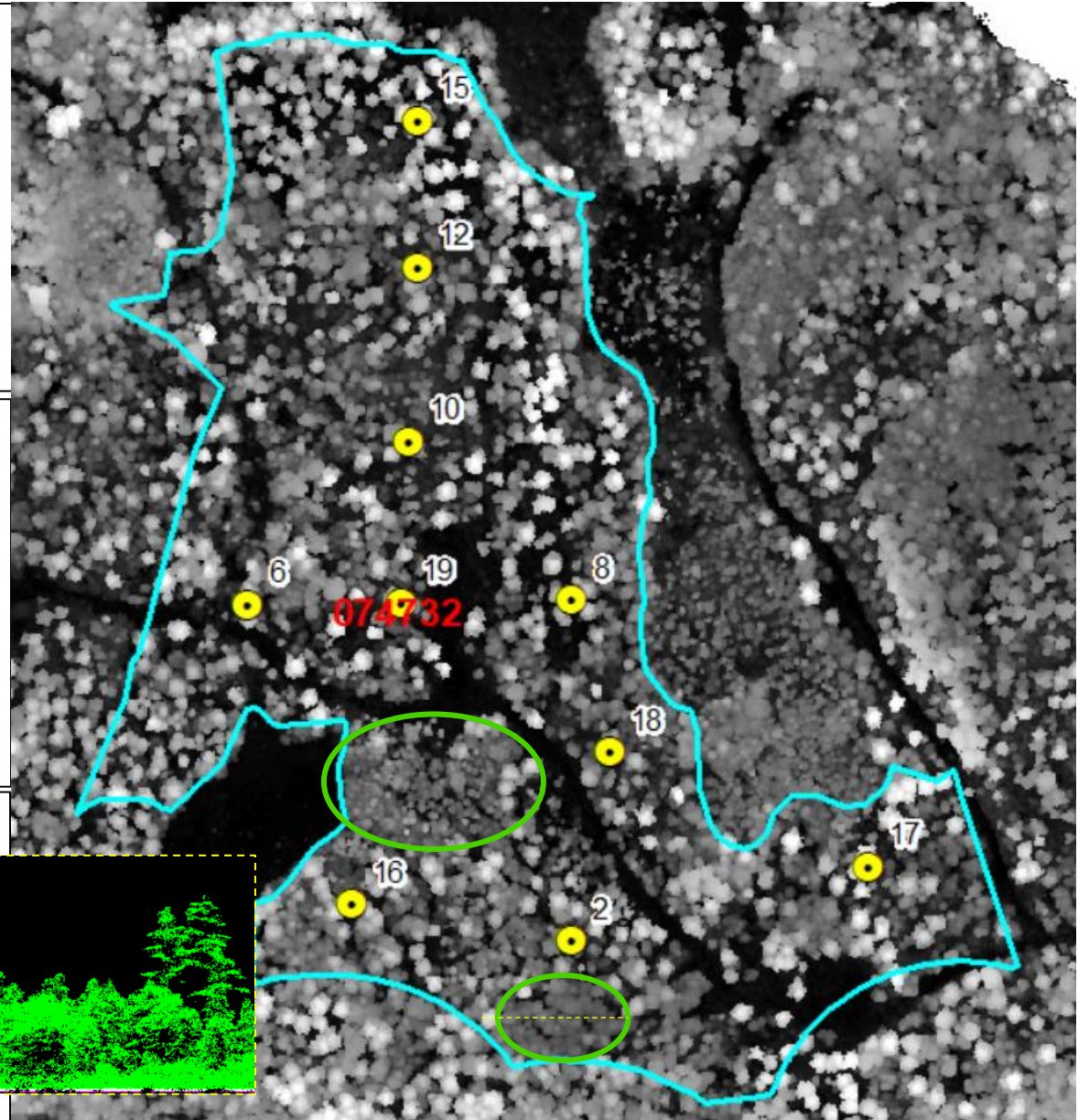
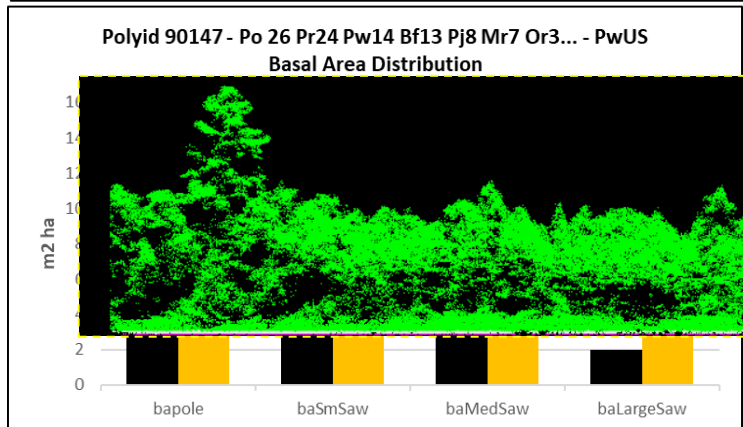
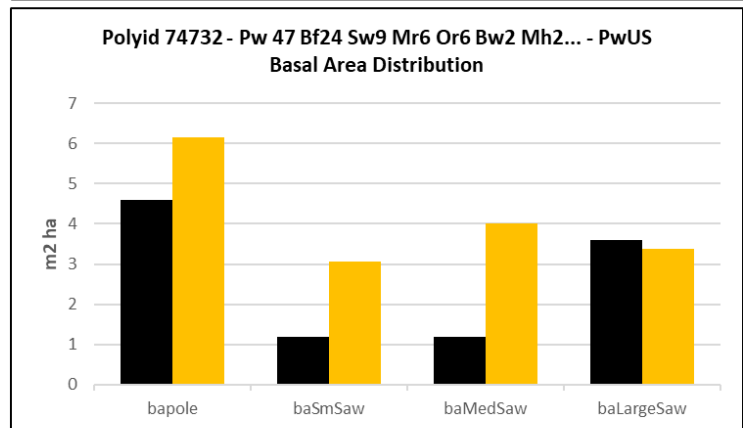
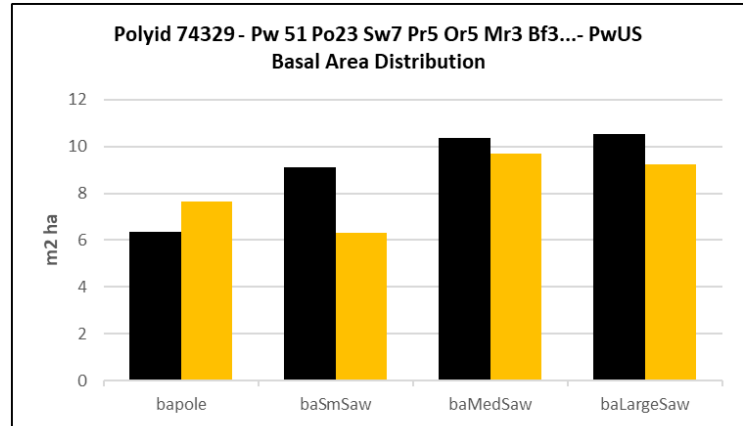




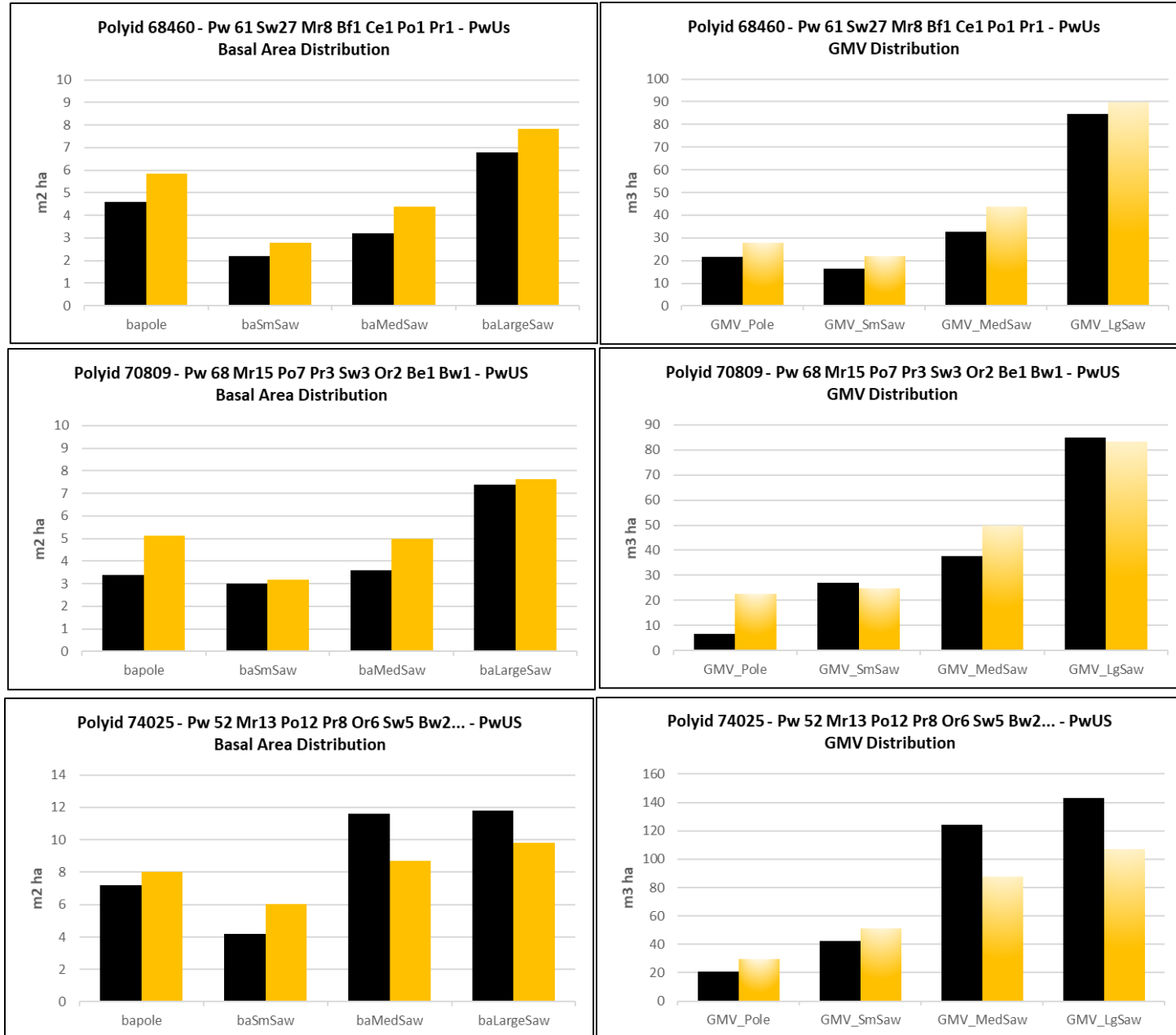
# Stand Level Validation – Pine Shelterwood Stands



# Stand Level Validation – Pine Shelterwood Stands

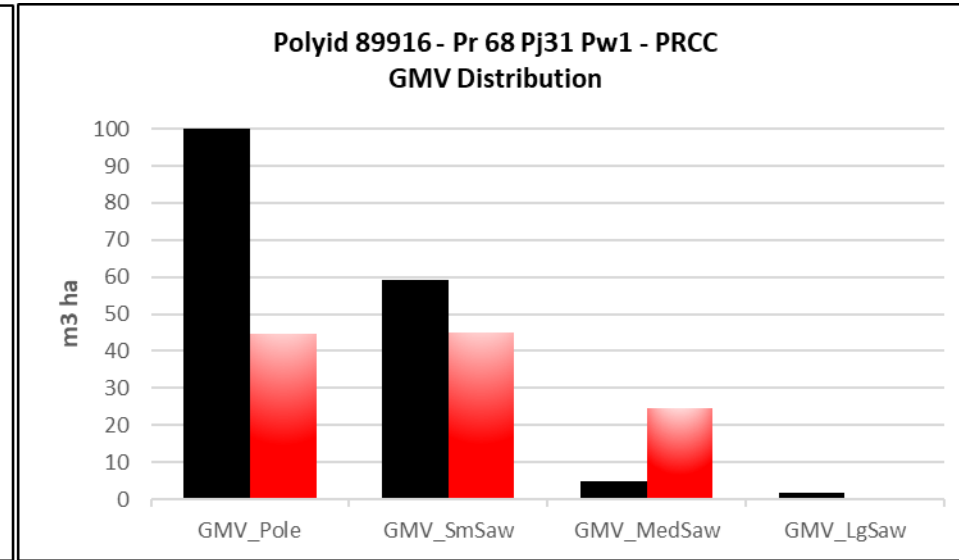
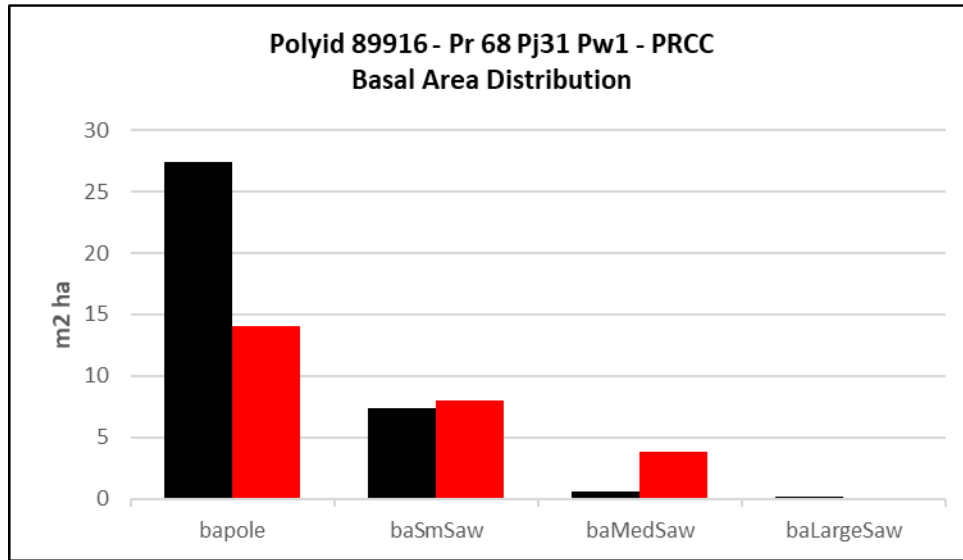


# Stand Level Validation – Pine Shelterwood Stands



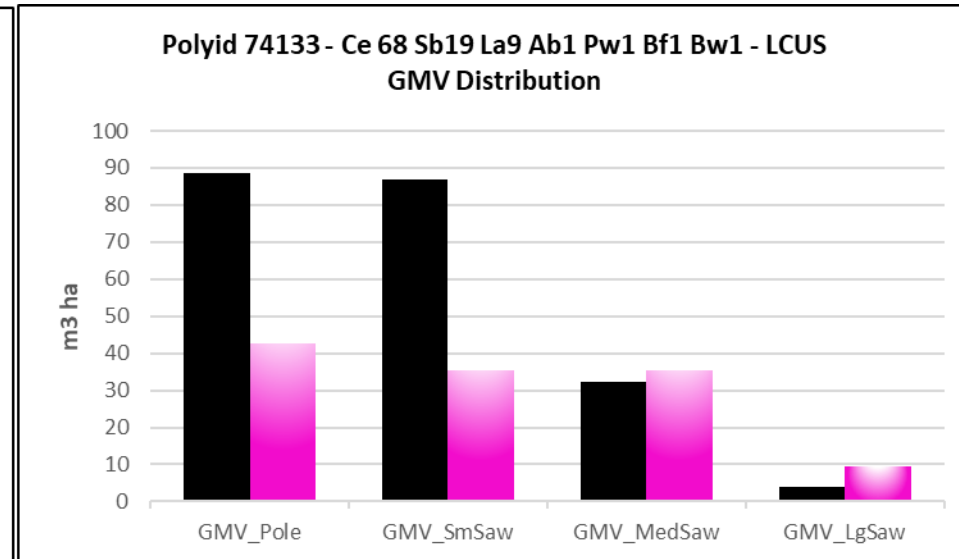
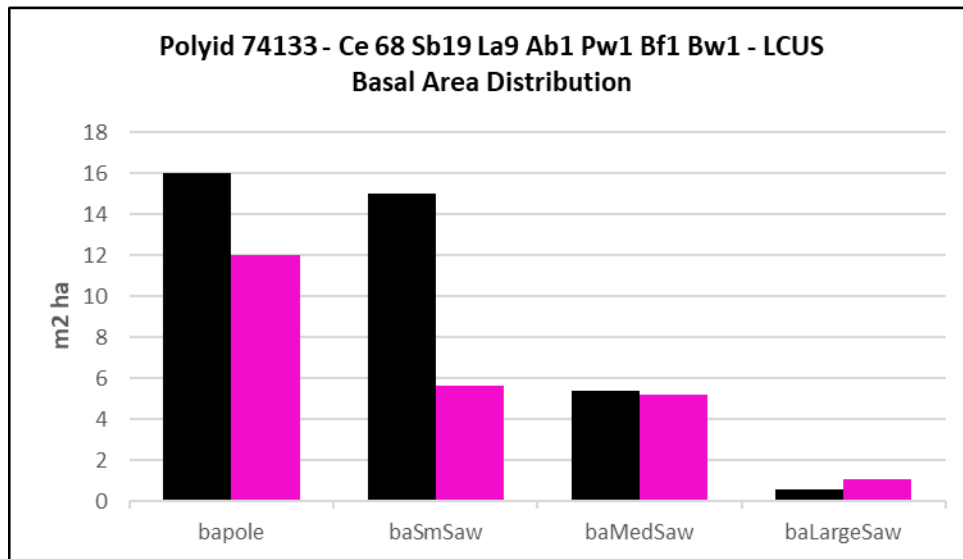
# Stand Level Validation – Pr Plantation – Lowland Conifer

Plantation  
Red Pine

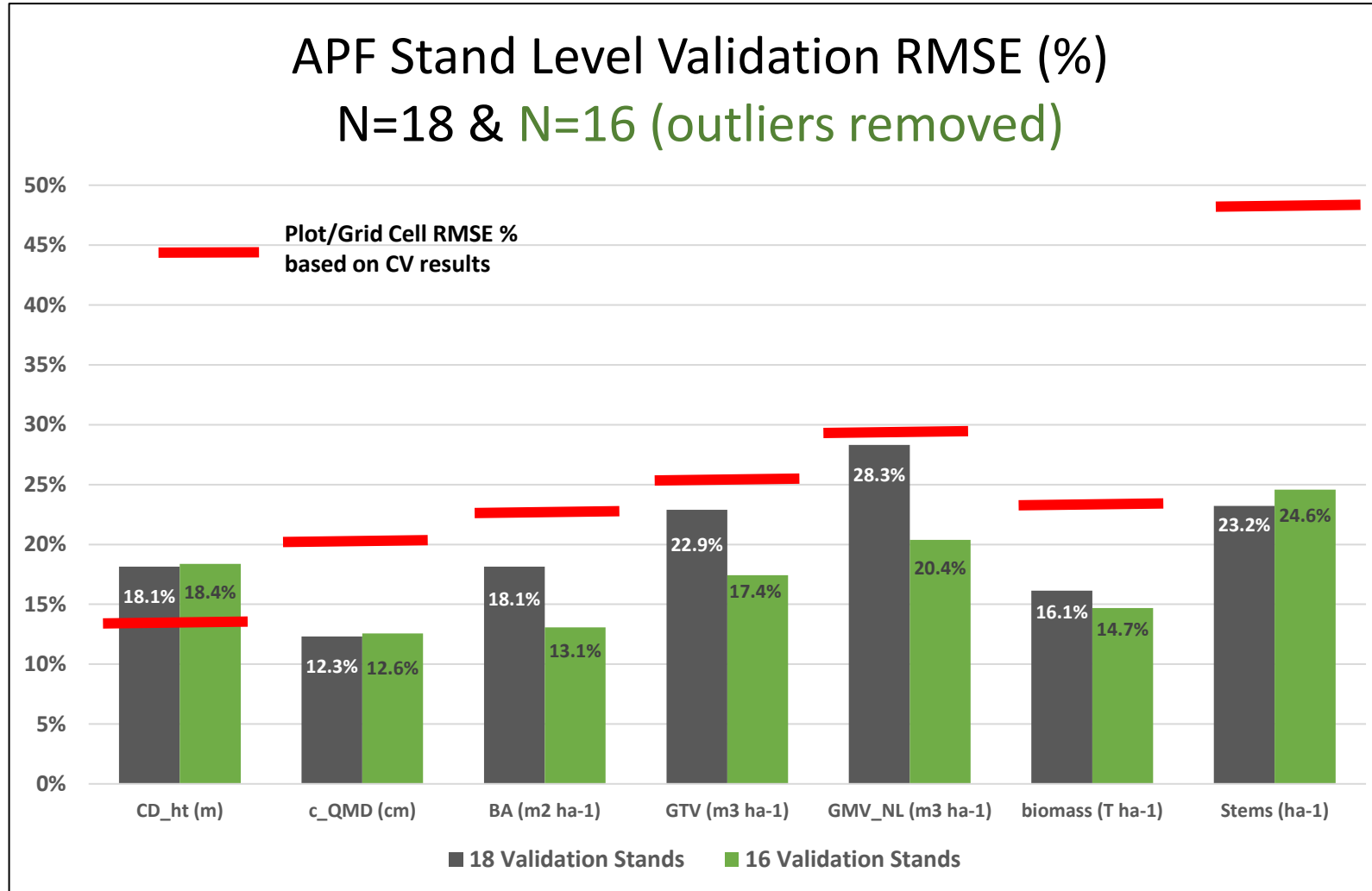


**These Forest Units combined represent ~2% of the APF forested area**

Lowland Conifer



# Stand Level Validation RMSE



# Updating T1 Inventories to T2 with LiDAR

# Producing T2 – Raster summarized to Polygon Mean

From T1 Inventory

Value for Biologists

$$\text{Site Index} = f(\text{Lead Spec, Age, Topht})$$

POLYID	SPCOMP	AGE	CC2m	CC10m	SI	stocking	TOPHT	CDHT	LoreyHT	BA	BAmerch	Stems	QMD	GTV	GMV_NL	GMVnIQ15	GMVnIQ85	GMV_WL	Biomass
201	Mh 40Mr 20He 20By 10Be 10	97	95.1	86.7	13.1	0.9	21.5	19.2	19.5	24.7	24.0	610	22.7	189	144	109	183	136	173
202	He 40Mh 30By 10Sw 10Be 10	152	82.8	64.1	9.6	1	22.1	19.9	19.9	28.5	27.8	636	23.9	225	180	128	240	170	134
203	He 60By 20Pw 10Sw 10	132	98	84.5	10	1.2	22.1	19.4	19.7	32.5	31.9	723	23.9	253	192	134	255	182	161
204	He 70Mh 20By 10	107	85.6	70.4	10.6	1.2	20.5	18.5	18.3	29.5	28.8	692	23.3	215	160	130	197	149	132
205	Mh 50Mr 20By 20Pt 10	97	92.5	81.7	13.3	0.9	21.3	19.5	19.5	22.6	22.1	522	23.5	177	136	106	175	128	168
206	Mh 70By 10He 10Be 10	92	80.7	66.7	13.6	0.8	21.7	19.5	19.4	19.7	19.1	597	20.5	152	119	95	143	113	132
207	By 60Mh 20Mr 10He 10	92	92.8	78.5	14	0.8	21.8	19.5	19.6	21.8	21.1	567	22.1	169	131	98	171	123	157
73231	Pr 60Pj 20Pw 20	87	78.9	53	12.2	0.6	19.9	17.6	17.2	23.8	22.8	698	20.8	168	123	99	145	114	102

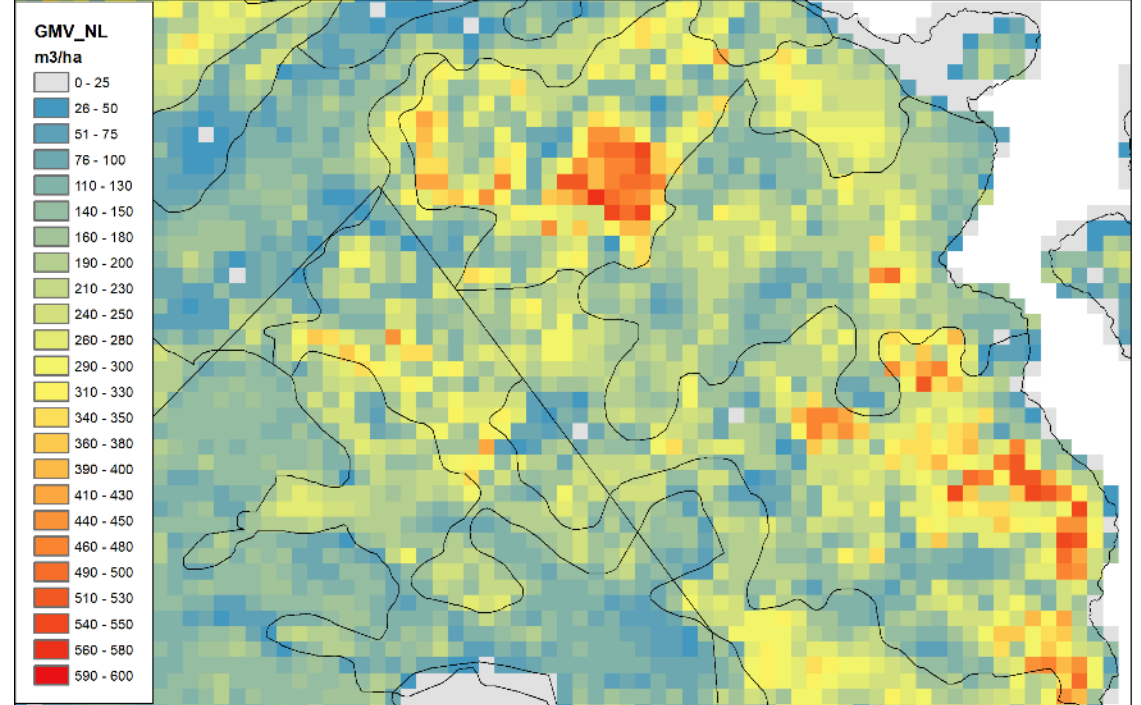
Size Class Predictions & NMV

$$\text{Stocking} = f(\text{Lead Spec, Age, BA, SI})$$

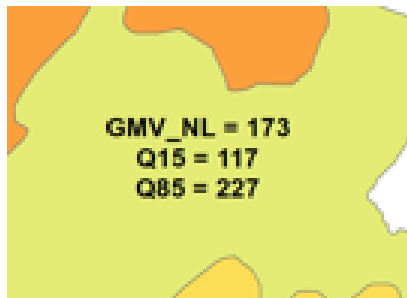
POLYID	SPCOMP	AGE	BA_Pole	BA_SmS	BA_MedS	BA_LgS	GMV_Pole	GMV_SmS	GMV_MedS	GMV_LgS	GMV_Util	Cull_frac	NMV_NL	NMV_WL	NMV_Util
201	Mh 40Mr 20He 20By 10Be 10	97	6.6	7	7	3.4	17.9	46.7	53.7	26.1	0	0.2	114	107	0
202	He 40Mh 30By 10Sw 10Be 10	152	8.3	6.5	9.2	3.8	27.6	45.1	75.2	31.6	0	0.2	144	136	0
203	He 60By 20Pw 10Sw 10	132	9.7	8.7	8.6	4.9	28.5	58.5	66	39.4	0	0.1	164	155	0
204	He 70Mh 20By 10	107	10.2	7.8	8.3	2.5	29.3	51.6	60.4	18.3	0	0.1	138	129	0
205	Mh 50Mr 20By 20Pt 10	97	6.1	7.2	6.7	2.1	17.2	49.4	52.4	17.2	0	0.3	101	95	0
206	Mh 70By 10He 10Be 10	92	6.3	4.2	6	2.6	20.3	29.7	47.6	21.6	0	0.2	93	88	0
207	By 60Mh 20Mr 10He 10	92	6.1	6.1	6.3	2.7	18.2	41.1	49.5	22	0	0.2	102	96	0
73231	Pr 60Pj 20Pw 20	87	10.6	5.5	5.1	1.6	36.7	35.8	38.1	12.4	13	0.0	120	112	13

# New GMV information

- Mean GMV
- Q15 GMV
- Q85 GMV

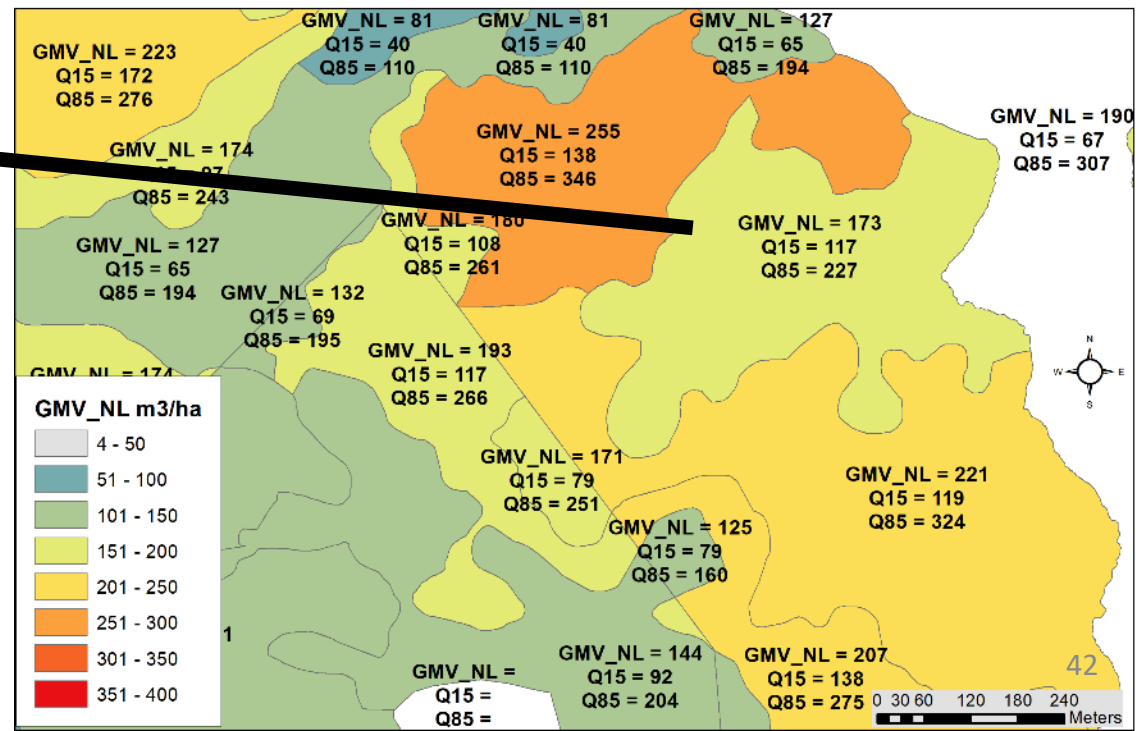


## Example



Mean Stand GMV = 173 m<sup>2</sup> ha<sup>-1</sup>

With 70% of grid cell GMV being between 117 & 227 m<sup>2</sup> ha<sup>-1</sup>





# T2 LiDAR Stand Constraints

Each polygon has full suite of inventory attributes **except:**

- If Stand age < 20 years old – No LiDAR derived attributes
- If zq99 < 5m, only CDht is replaced by zq99 ht and CC2 provided
- If zq99 < 9m, no merchantable volumes are estimated – or Ba/GMV by size classes are provided

	Polygon CDHT <5m	Polygon 5m > CDHT <9m	Polygon CDHT >9m
CC2m			
TOPHT	NULL		
CDHT	Zq99		
LoreyHT	NULL		
BA	0		
BAmerch	0	0	
Stems	0		
QMD	NULL		
GTV	0	0	
GMV_NL	0	0	
GMV_WL	0	0	
GMV_Util	0	0	
NMV_NL	0	0	
NMV_WL	0	0	
NMV_Util	0	0	
Biomass	0	0	
BA_Poles	0	0	
BA_SmSaw	0	0	
BA_MedSaw	0	0	
BA_LgSaw	0	0	
GMV_Poles	0	0	
GMV_SmSaw	0	0	
GMV_MedSaw	0	0	
GMV_LgSaw	0	0	
Site Index	NULL		
Stocking	NULL		
Cull Fraction	NULL	NULL	

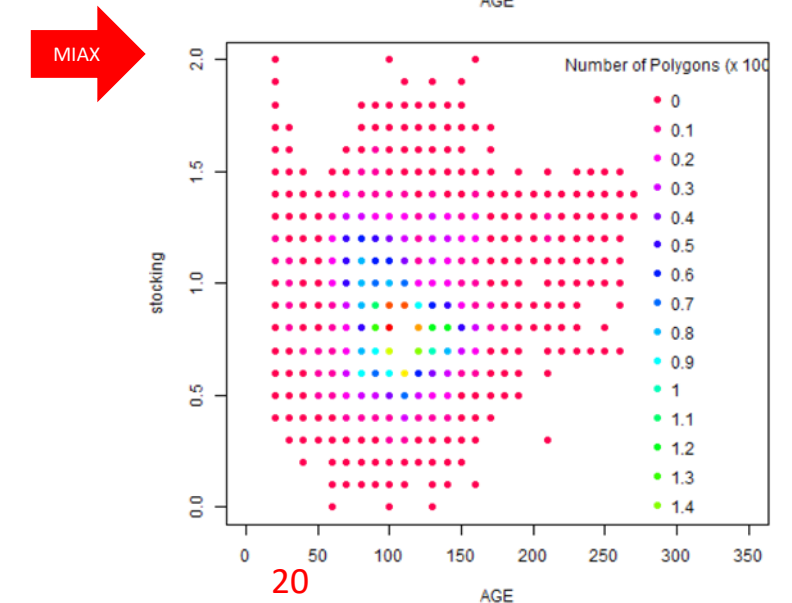
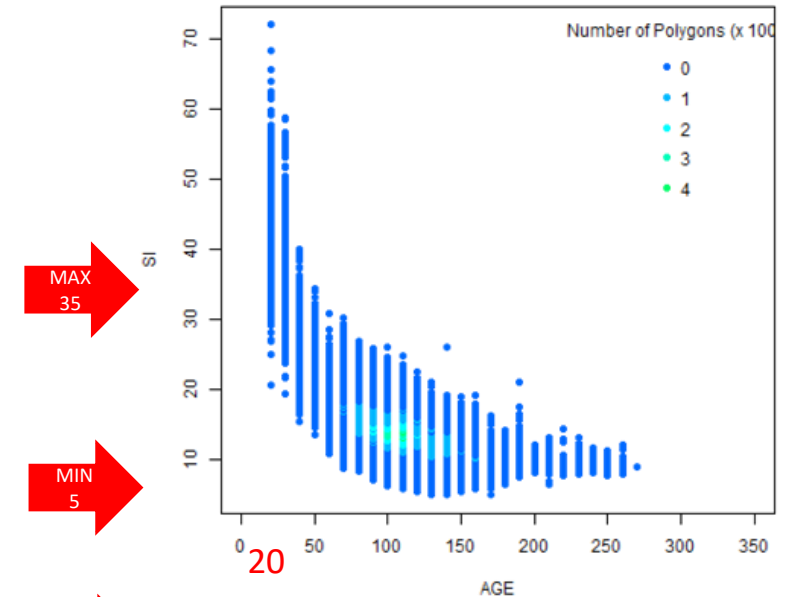
# Producing T2 – Challenges

- **SI calculation**

- challenging with young stands
- issue when interpreted age is low and LiDAR height is high

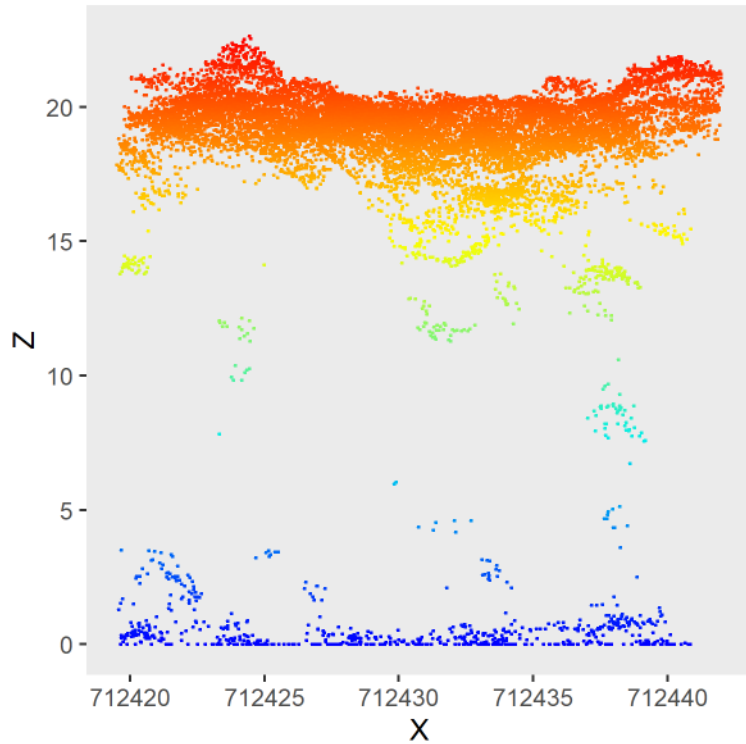
- **Stocking calculation**

- Issue for young stands – requires BA – we have a 7.1cm min threshold



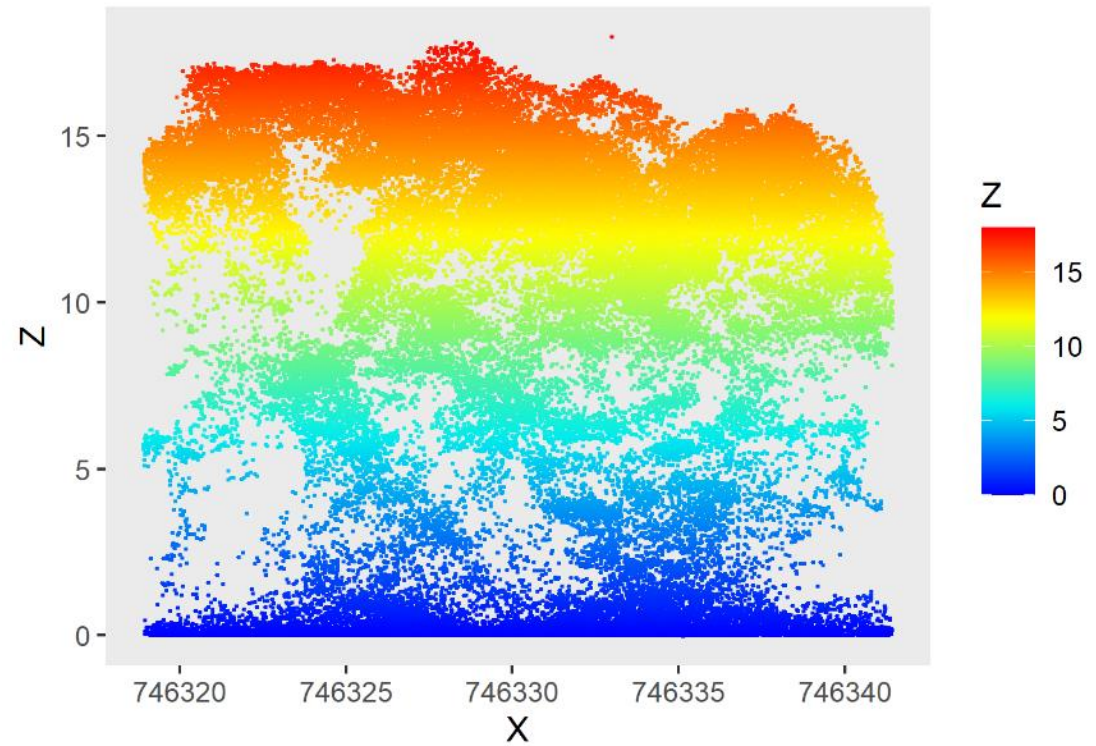
# Next Steps – Current Research Focus

# Vertical Structure – what is it?



APF 004

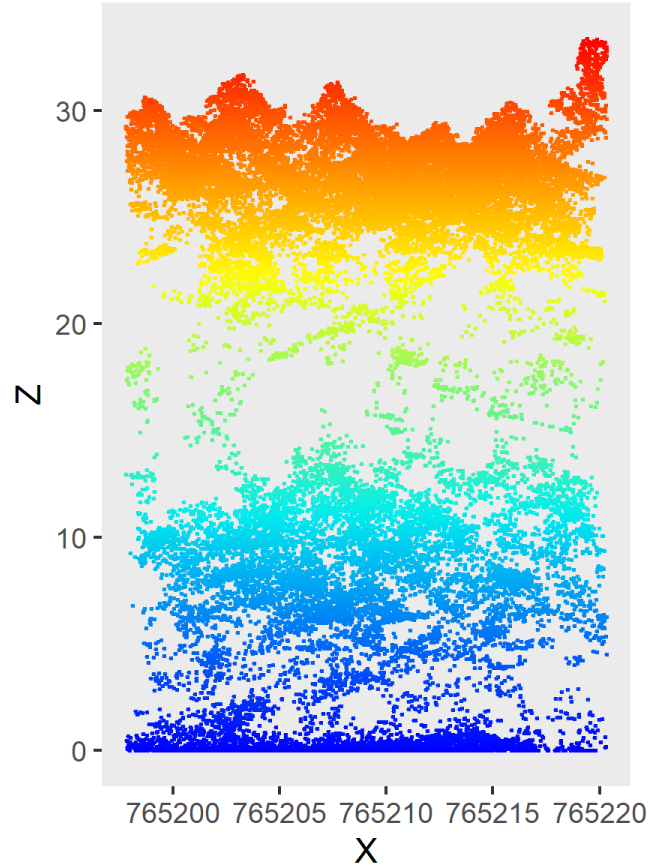
Cw 83 Bf 10 Bw 4 Sw 3 OH 0



APF 231

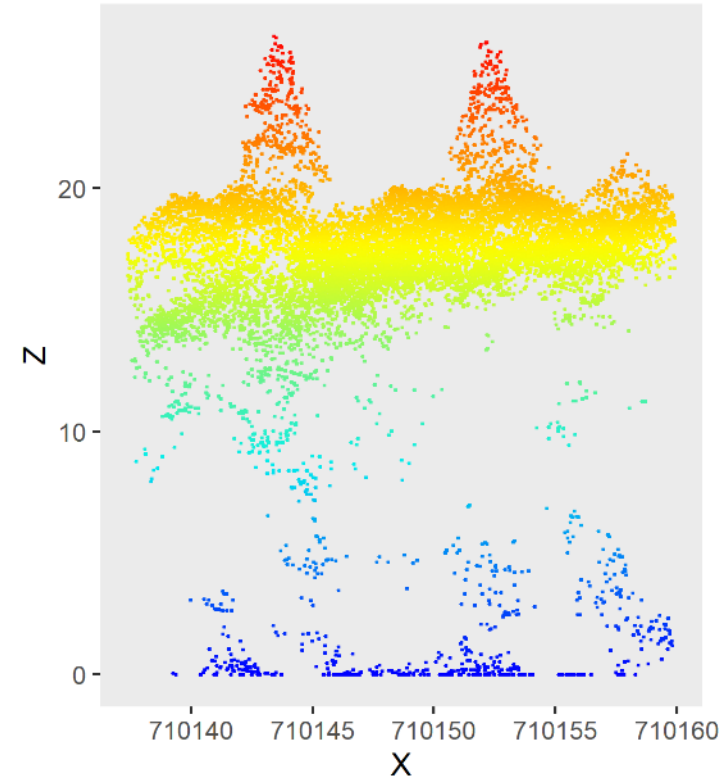
Or 63 Pw 21 Mr 8 Bf 5 Sb 3

# Vertical Structure – what is it?



APF 015

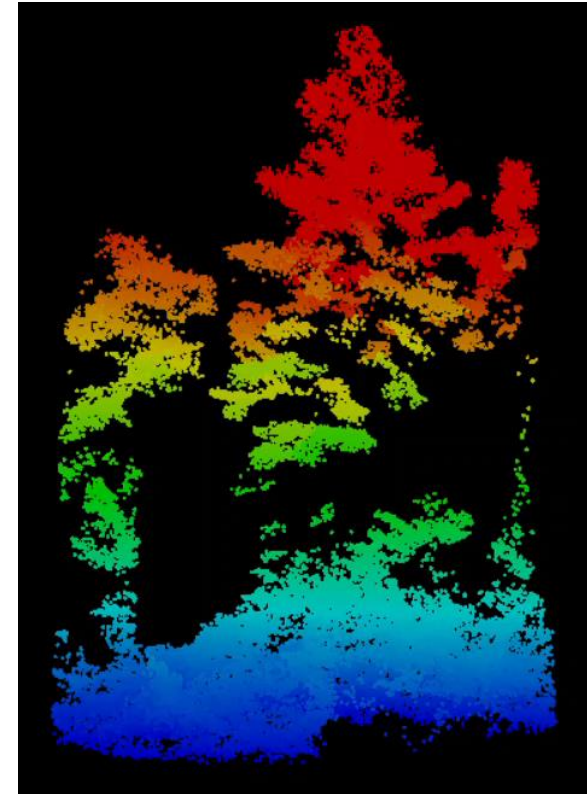
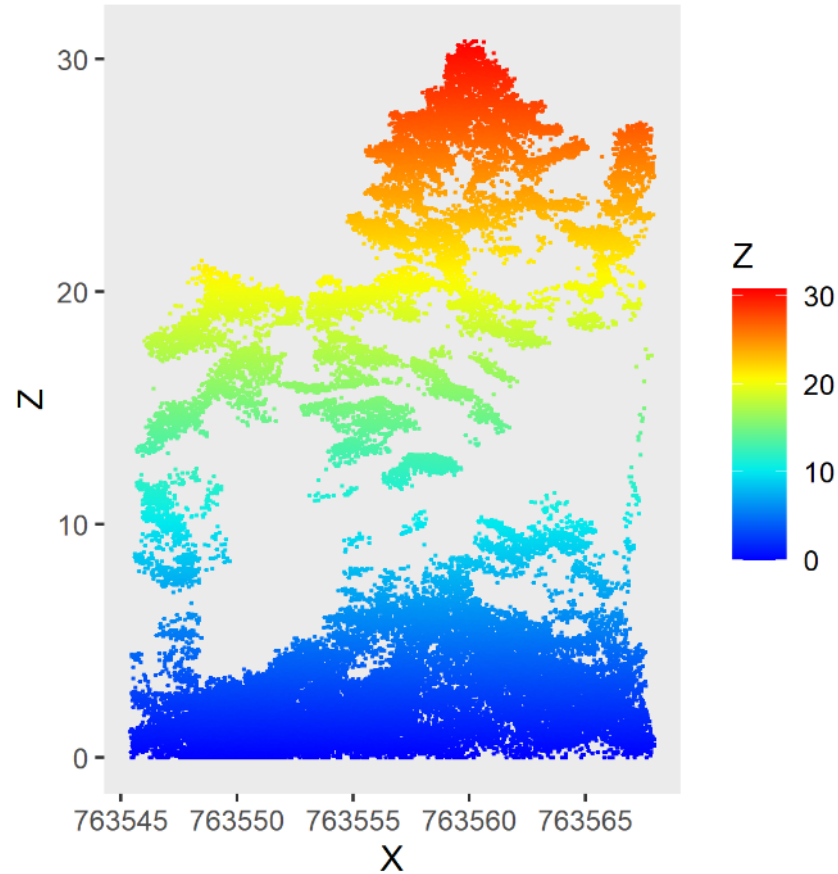
Pr 73 Pw 24 Mr 2 Or 1 Pl 0



APF 178

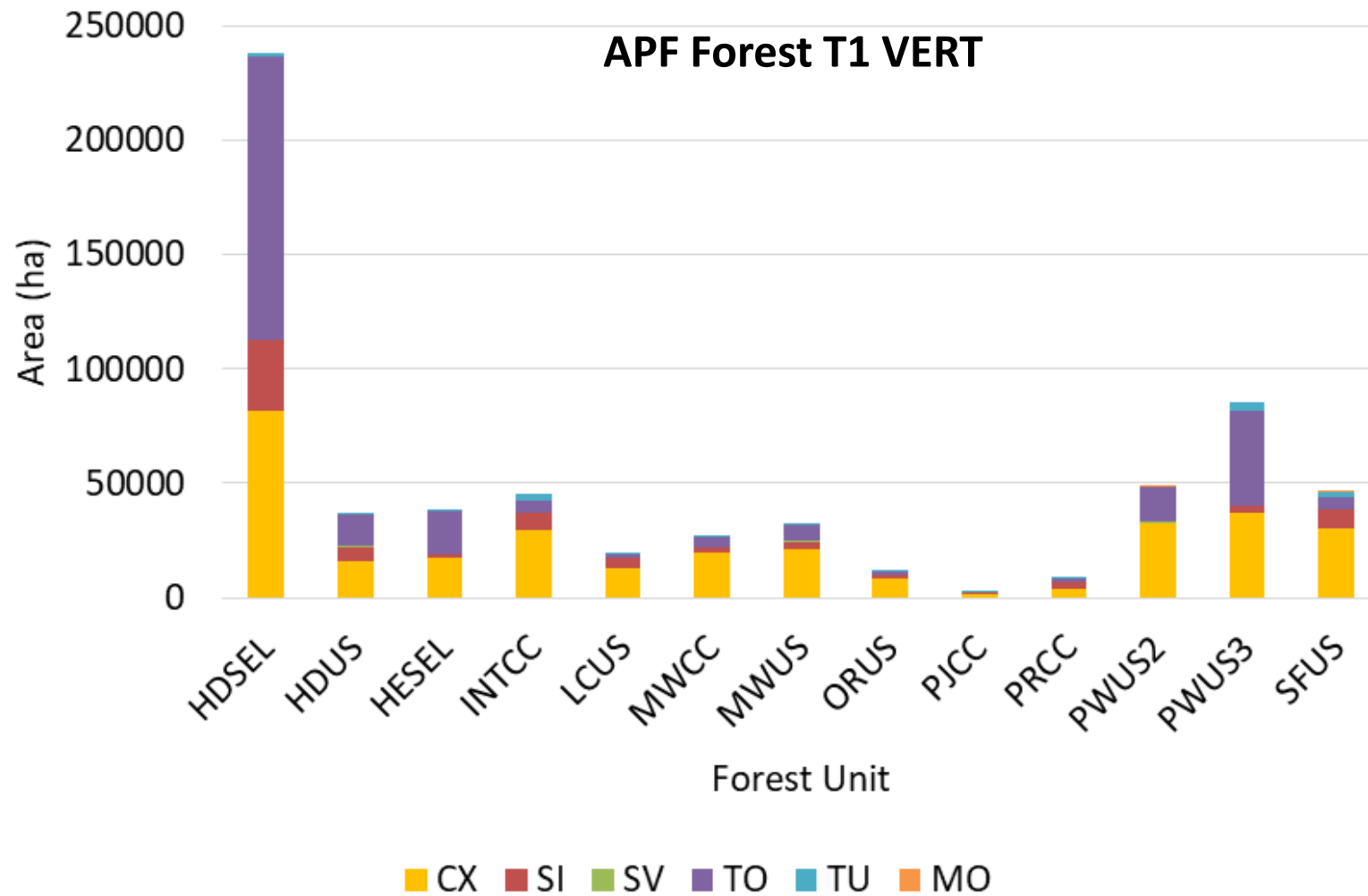
Mh 56 Cw 29 Sw 14 Yb 1 Be 1 Bf 0

# Vertical Structure – what is it?

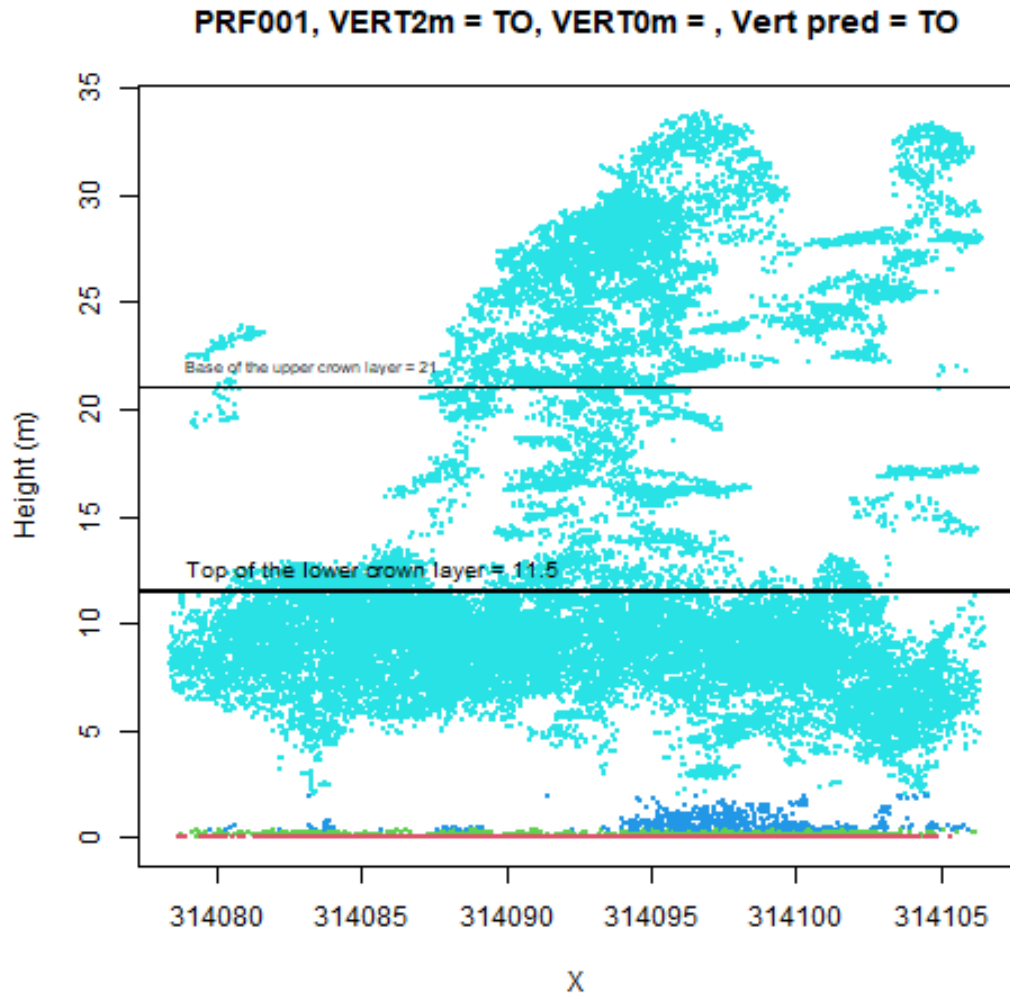


APF 194  
Pw 99 lw 1

# Vertical Structure – how common?



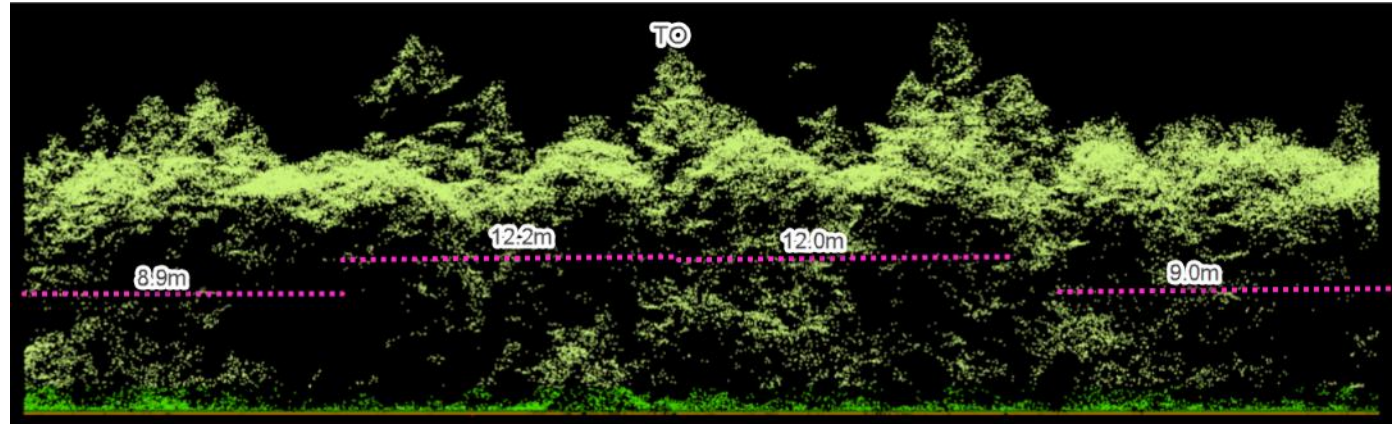
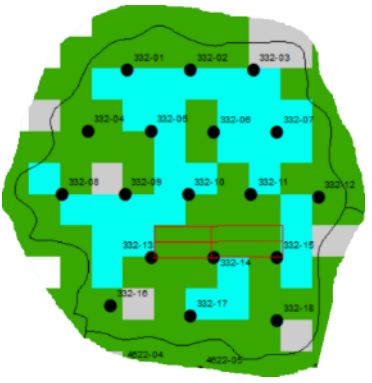
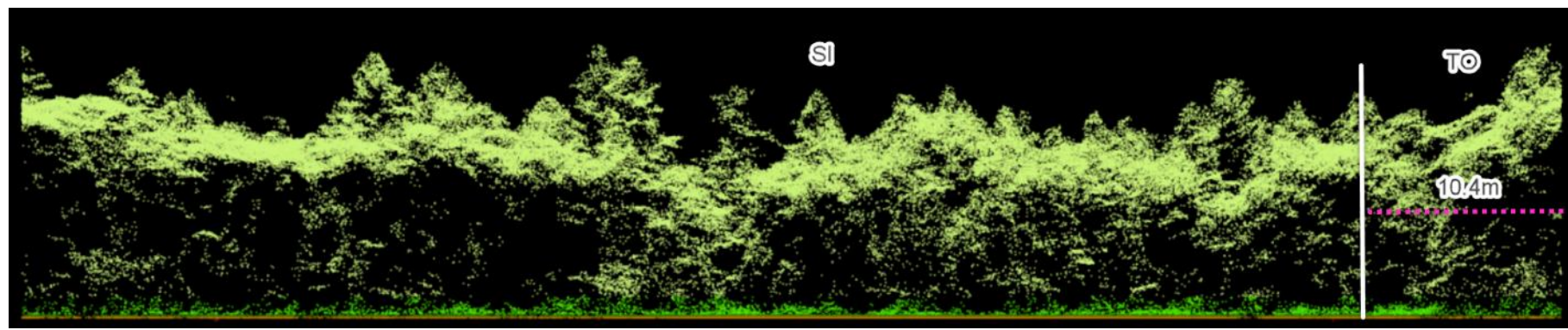
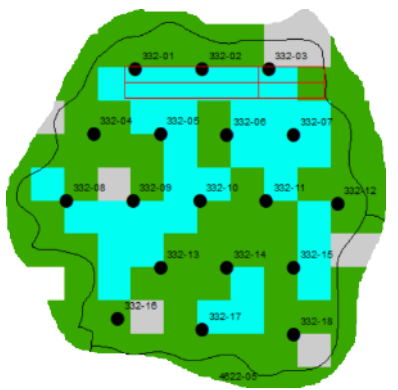
# Vertical Structure



Can we automate the detection of layers?  
Can we partition inventory attributes by layer?  
Can we scale pixels to polygons?



# Vertical Structure – PRF polyid 332



# Vertical Structure

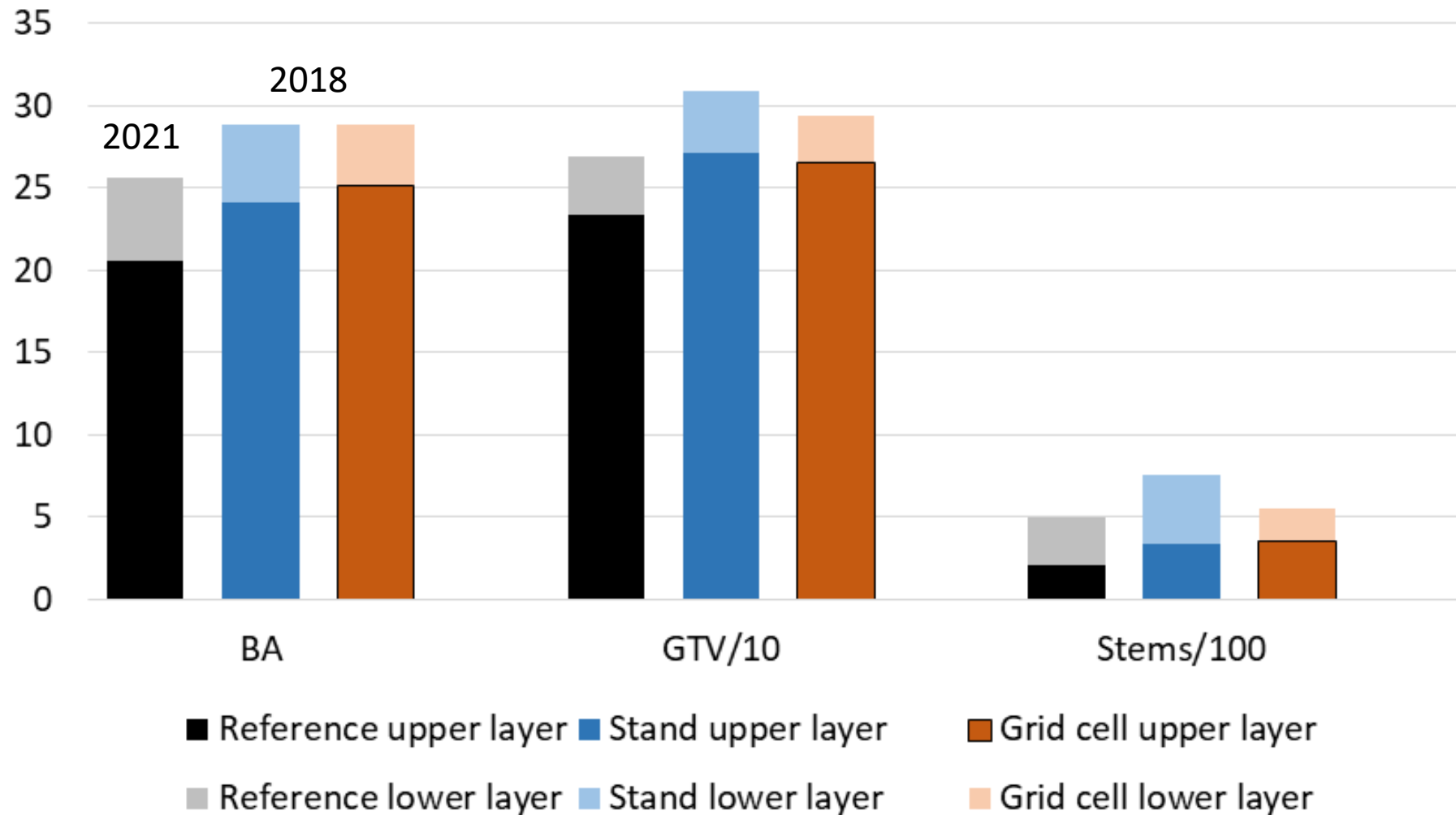
Predicting 4 VERT classes  
Agreement is 68%

	Predicted				
Actual	CX	SI	SV	TT	
CX	14	5	2	16	38%
SI	2	63	2	17	75%
SV	3	4	9	6	41%
TT	10	15	3	95	77%
	48%	72%	56%	71%	68%

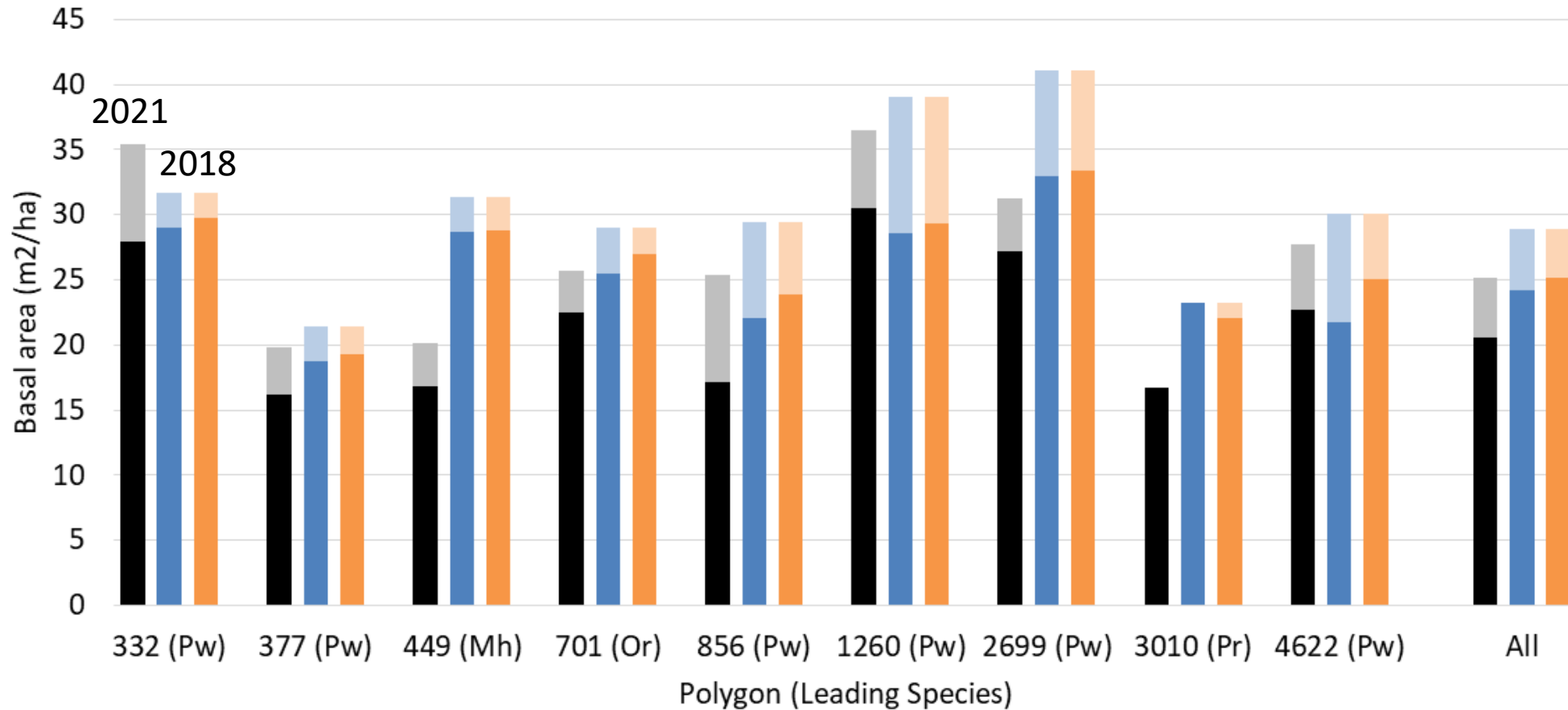
If we only care about 1 layer vs. 2 layer,  
Agreement increases to 74%

	Predicted		
Actual	CX or SI	SV or TT	
CX or SI	84	37	69%
SV or TT	32	113	78%
	72%	75%	74%

# Vertical Structure

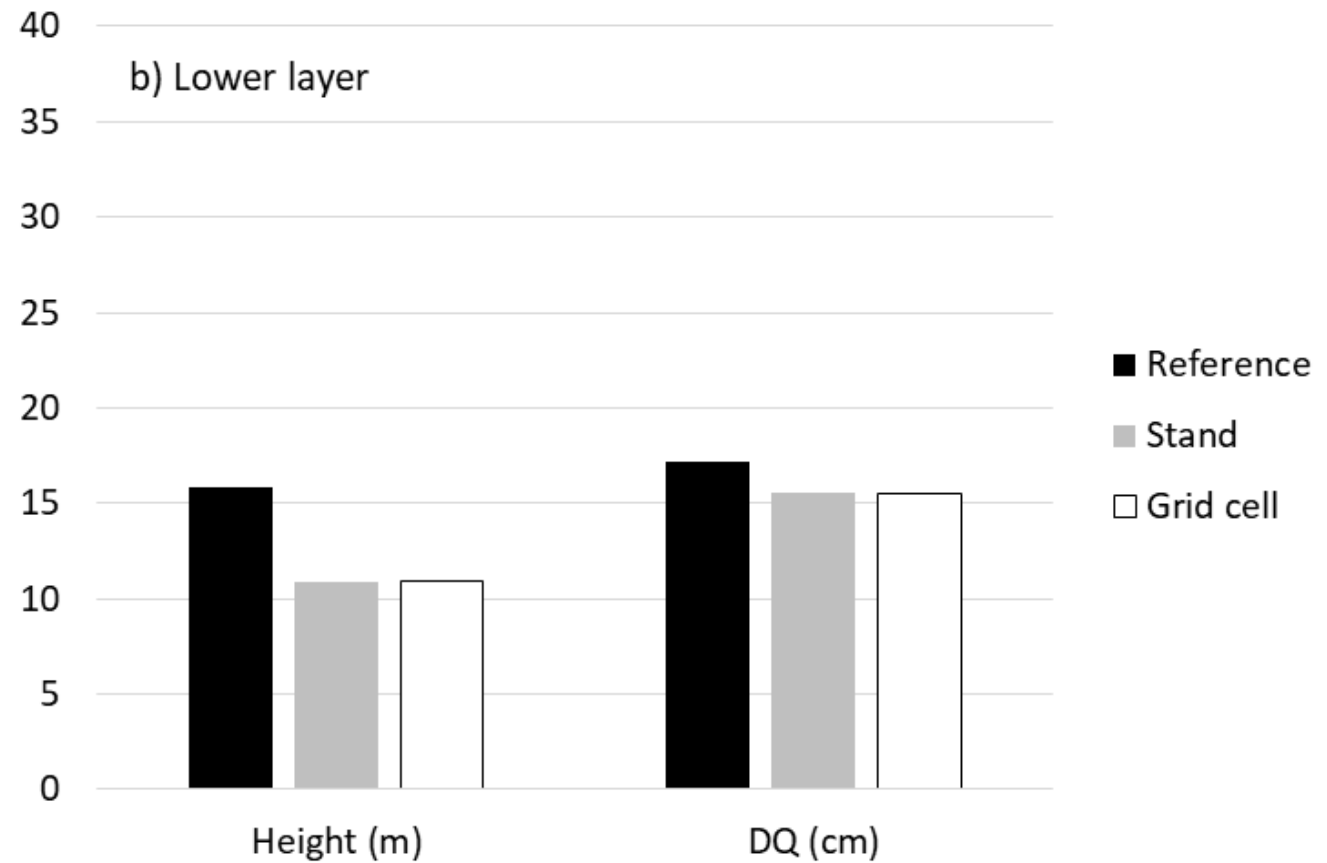
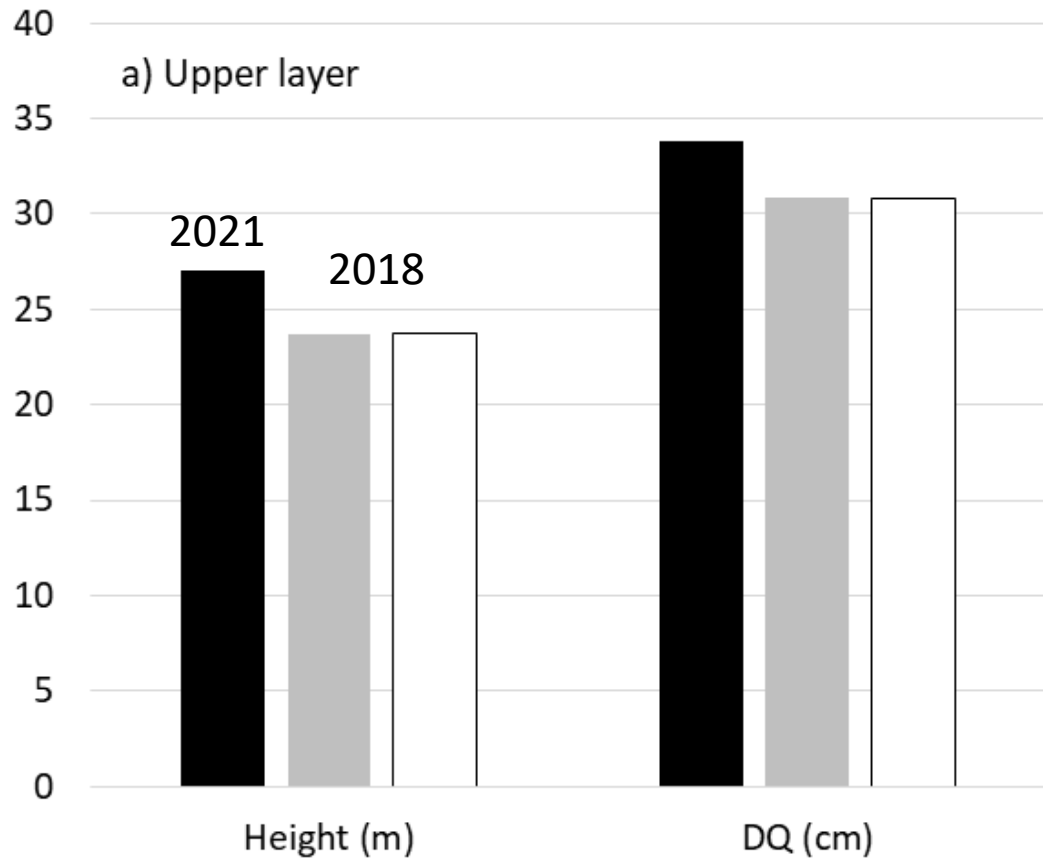


# Vertical Structure

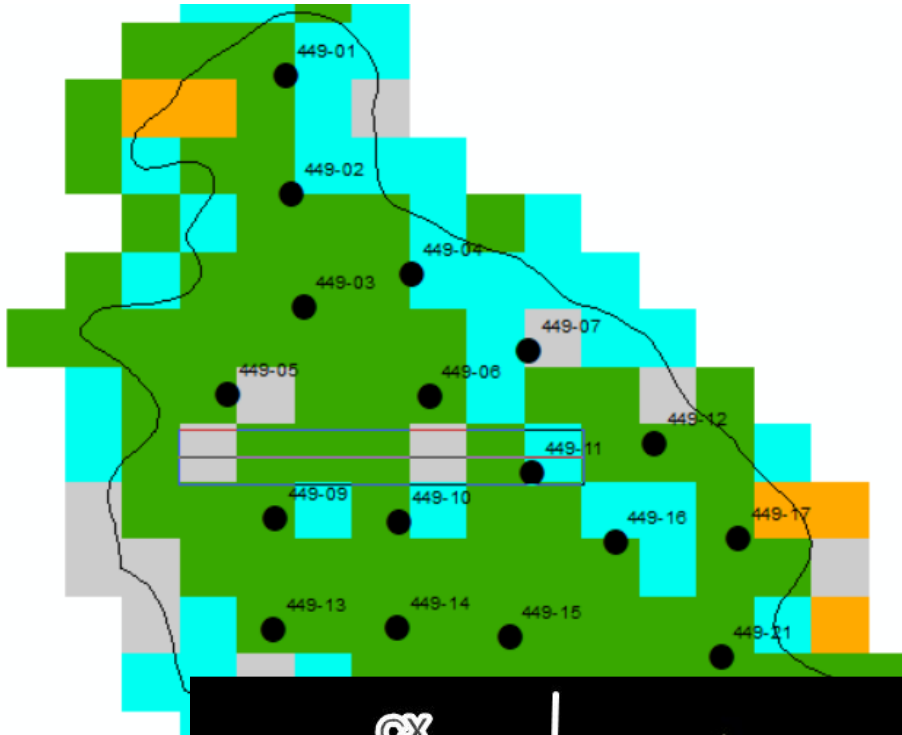


- a) Reference - upper layer
- b) Stand predictions - upper layer
- c) Grid cell predictions - upper layer
- lower layer
- lower layer
- lower layer

# Vertical Structure

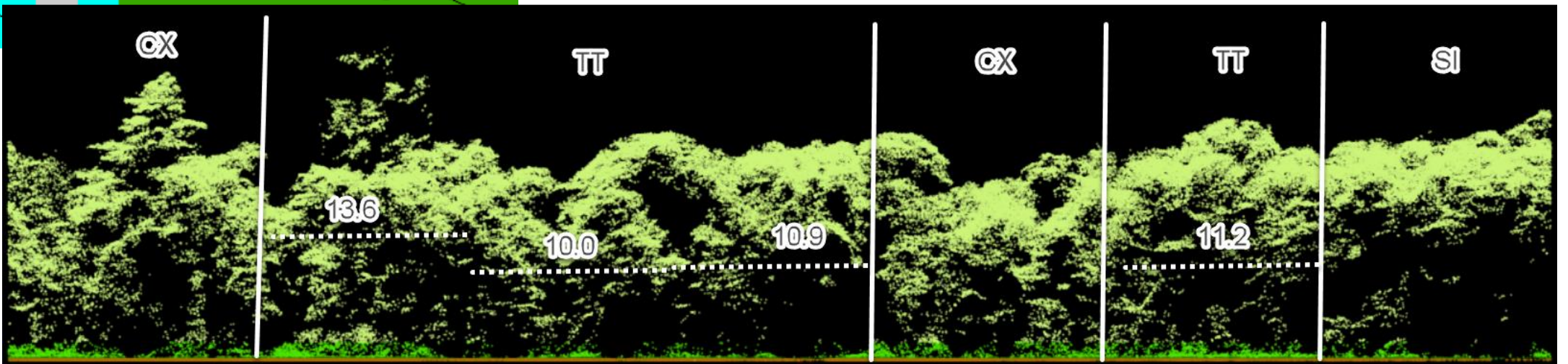
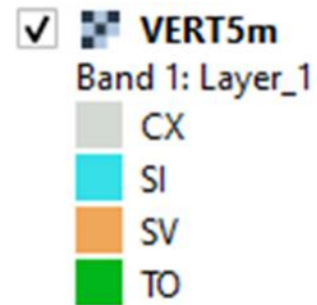


# Vertical Structure



POLYID – 449

Mh 46 Be22 Bd8 Bw8 Pw5 By4 Iw3 Or2 Sw1 Bf1



# Thank you!



Ministry of Natural  
Resources and Forestry

## Comments? Questions?

Contact Information:

Margaret Penner - [mpenner@forestanalysis.ca](mailto:mpenner@forestanalysis.ca)

Murray Woods – [woods.murray@gmail.com](mailto:woods.murray@gmail.com)