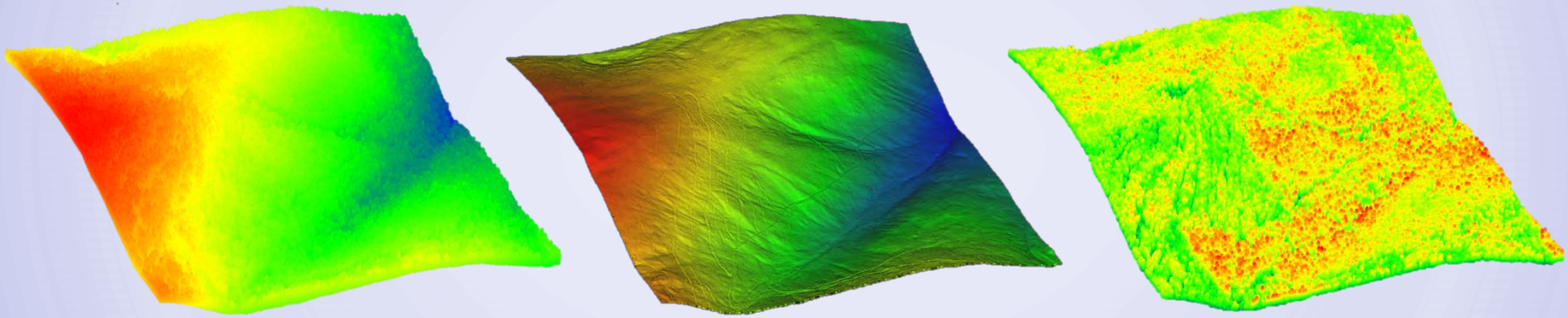
Ministry of **Forests, Lands, Natural Resource Operations and Rural Development**

Predictive Forest Inventory in British Columbia:

A Test Site for Advancing Forest Inventory Methods



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BCTS BC Timber Sales

INTERFOR

Boundary TSA: *Predictive Forest Inventory*

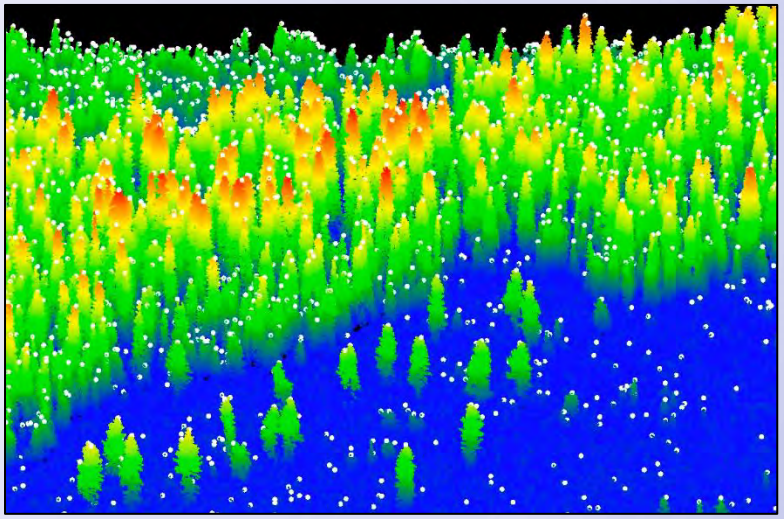
Outline

- Background
  - Predictive Forest Inventory
  - Study site
  - Data sampling
  - Reference & target data
- PFI-1 methods
  - Hybrid individual tree & area based approach
- PFI-2 methods
  - Imputation
- PFI preliminary results
  - PFI-1 Empirical modeling
  - PFI-2 Machine learning
  - Vegetation Resource Inventory/Forest Information Planning vs. PFI-1
- Summary
- Questions/Discussion

Boundary TSA: *Predictive Forest Inventory*

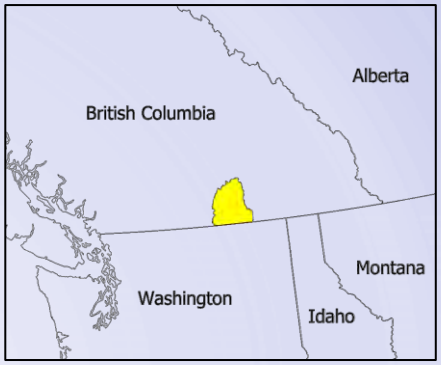
Predictive Forest Inventory

- Objectives
  - Standardize new generation of forest inventory
  - Spatially and thematically improved over VRI
  - Data integration for information synergies
- Active airborne laser scanner
  - Vertical/horizontal structural characterization
  - Operationally mature technology
- Passive spaceborne optical
  - Spectral/texture (colour, vigor, structural) traits
  - Long thought to be species specific



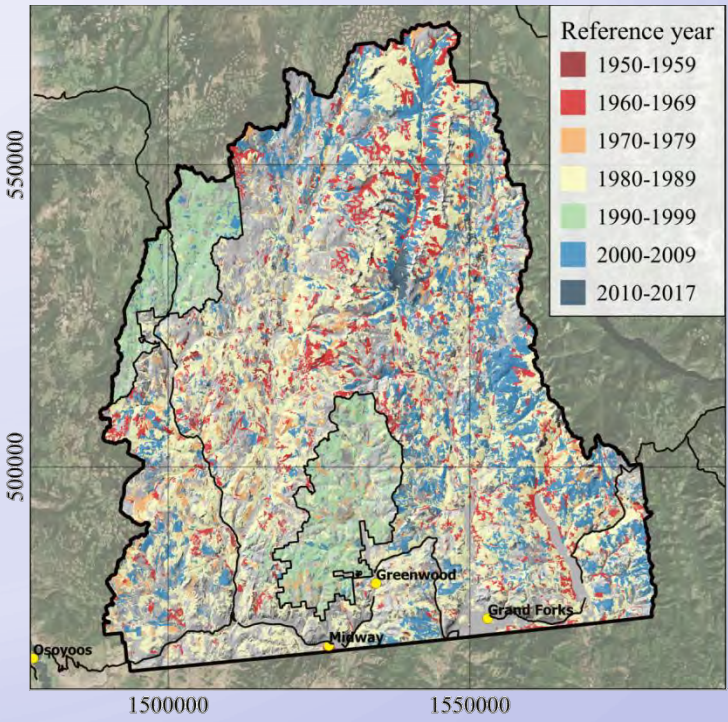
- Spatial extrapolation
  - PFI-1: Deterministically associated attributes: regression based prediction
  - PFI-2: Others are estimated through imputation approaches, PFI-1 spatial extrapolation

Boundary TSA: *Predictive Forest Inventory*



Study site: Boundary Timber Supply Area

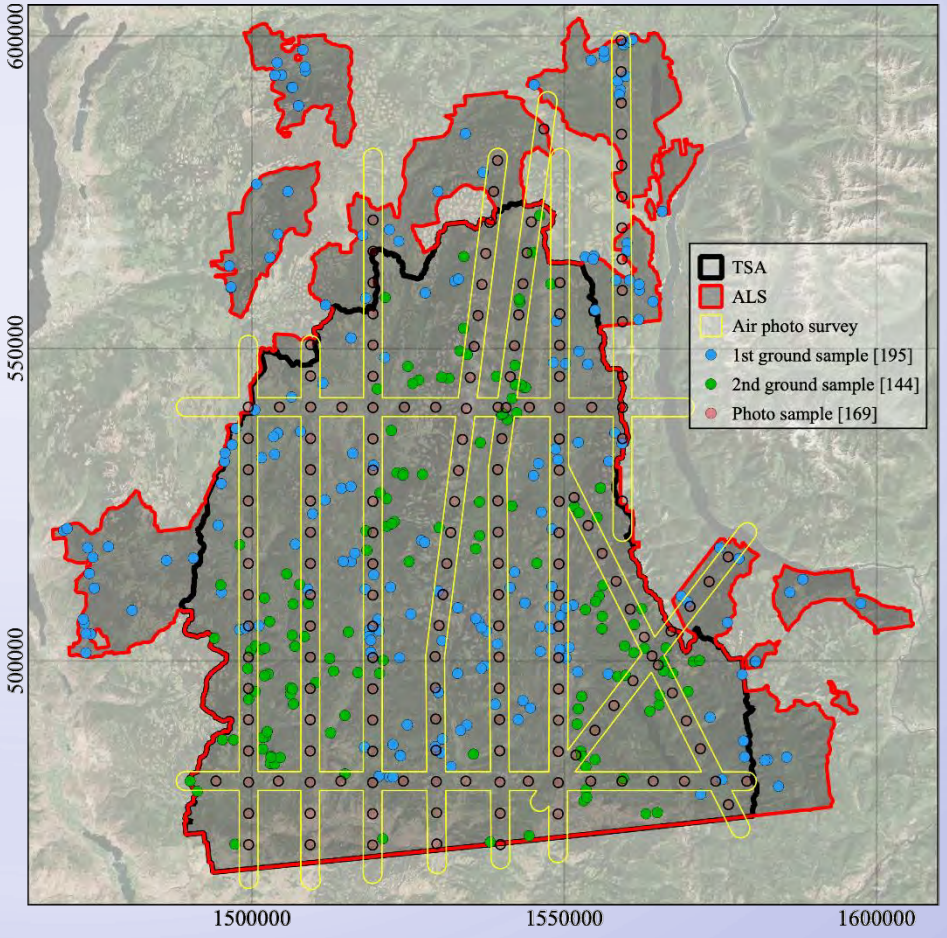
- Kootenay Boundary Region
- 659K ha (82% classed as treed)
- Vintage of VRI
  - 50% of VRI has a reference year of 1988
- Recently dynamic land base
  - TSA commercial activity
    - 26% of TSA in RESULTS
    - 58% of RESULTS is FTG (15% of TSA)
  - Disturbance recovery (TSR update)
- Considerable forest attribute variation
  - Large number of intimately mixed species
  - Diversity of structural development stages
  - Five biogeoclimatic ecosystem classification zones
  - High variation is problematic for traditional LEFI



Boundary TSA: *Predictive Forest Inventory*

Reference data

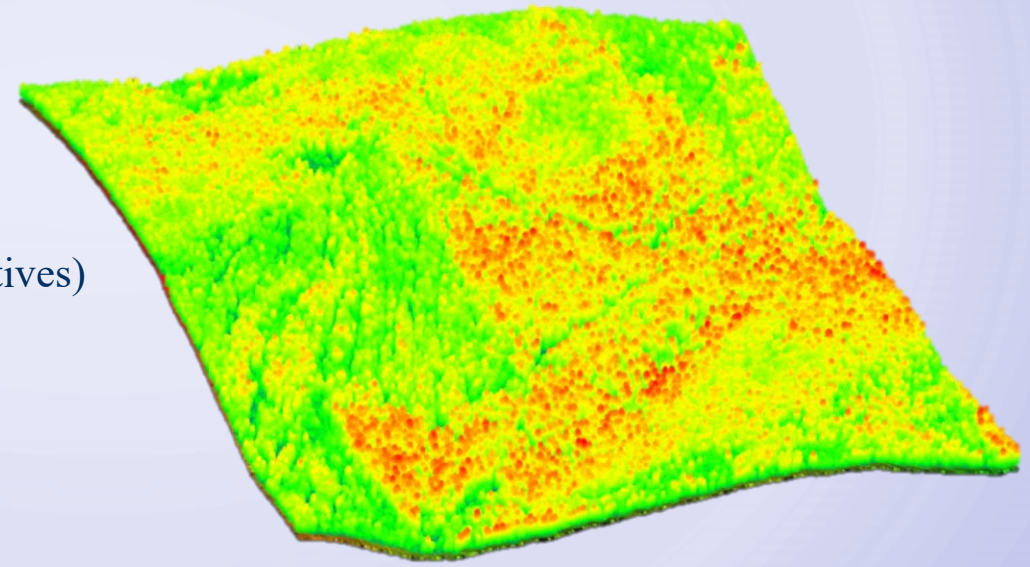
- Ground data
  - 342 modified CMI type-L (11.28m)
    - Primary: n=195
    - Secondary: n=144 (*unprocessed)*
  - Quality GNSS
  - Stem mapping
  - Structurally guided sampling
- Photoplot data
  - 169 photoplot samples
  - 8,481 segments (μ: 3ha)
  - 10cm RGBI stereo photo interpretation with VRI standards
  - Treed attributes only
- Product audit sampling
  - 130 unbiased 10x5km grid (*planned)*



Boundary TSA: *Predictive Forest Inventory*

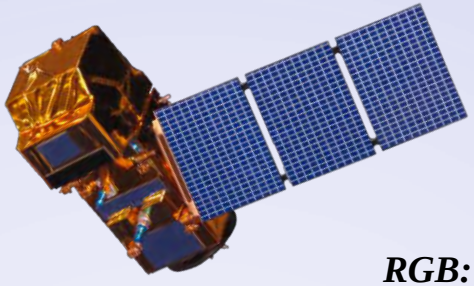
Target data: ALS Pre-processing

- Cloud processing
  - Noise & borders (1,291 tiles) (duplicates, local density)
  - Consolidated data (9,545 tiles)
- Raster production
  - DSM, BEM, CHM (1 & 5m derivatives)
  - Metrics (20m derivatives)
- Metric production
  - Lastools (20m)
  - Fusion (20m)
  - TT metrics (tree level, 20m)



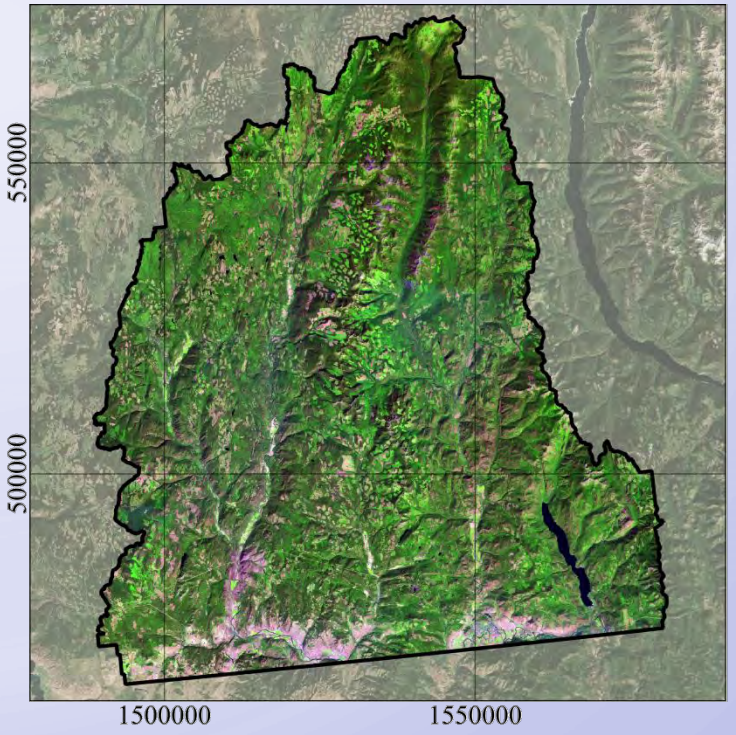
Boundary TSA: *Predictive Forest Inventory*

Target data:



- ALS data
  - CHM metrics
  - TT metrics
  - BEM metrics
  - Intensity metrics
- Landsat-8 Operational Land Imager (OLI)
  - Reflectance, indices, 30m
- Sentinel-2 Multi Spectral Imager (MSI)
  - Reflectance, indices, VNIR 10m, SWIR 20m
  - Multi-temporal metrics (Oct 2018, Aug 2019)
- Climate BC
  - Input 100m ALS BEM
  - Annual, seasonal, monthly metrics
  - Two 30yr normal periods (1961-90, 1981-2010)

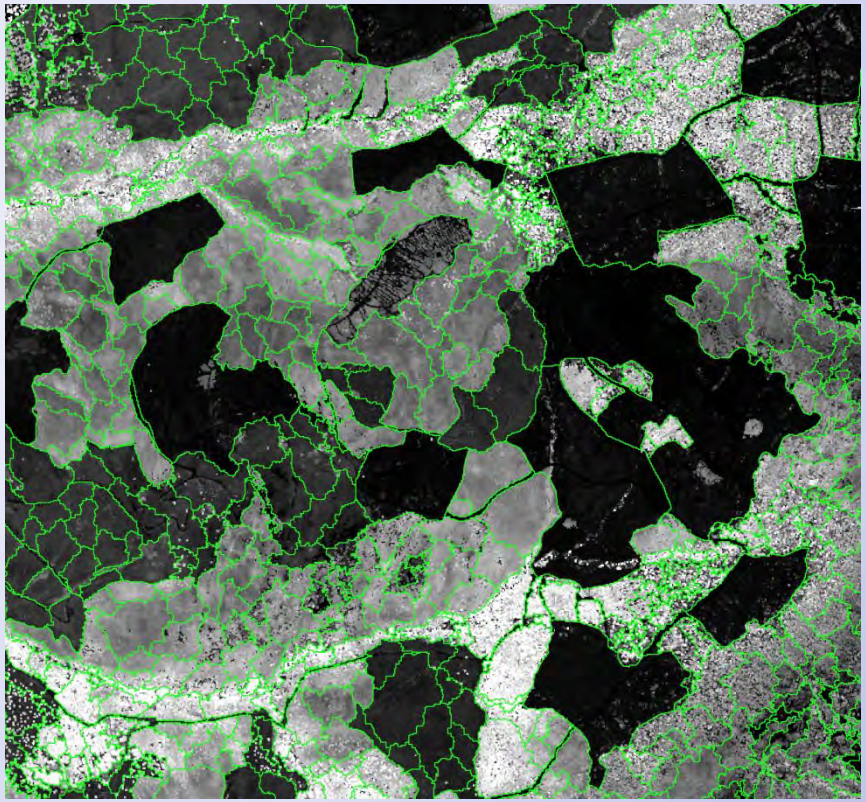
Sept 2, 2017
RGB: 1609,865, 655nm (SWIR2, SWIR1, R)



Boundary TSA: *Predictive Forest Inventory*

PFI Geometry

- eCognition segmentation
  - 5m CHM
  - 20m Gap fraction
  - RESULTS
  - TRIM layers
  - Minimum polygon area
- PFI-1 generalization
  - Polygon attribute = *f* (grid level estimates)
  - Query PFI-2 reference data
- PFI-2 training data
  - Univariate descriptions
    - Raster metrics, points, TT, PFI-1 estimates, shape attributes and pre-existing inventory



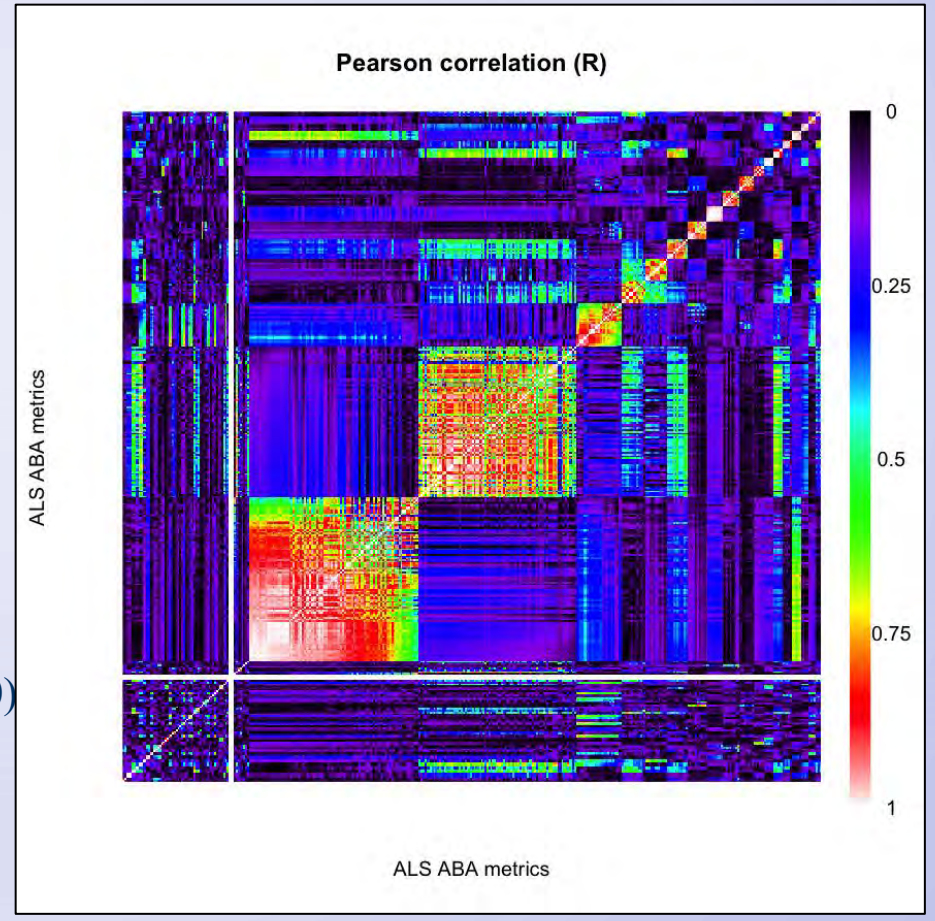
Boundary TSA: *Predictive Forest Inventory*

PFI-1 independent variables (384)

- Point cloud/TT metrics (98)
- BEM, ClimateBC (98)
- TT proximity & dominance (61)
- Crown shape (16)
- Lidar intensity (18)
- Topographic derivatives (15)
- Others… (78)

PFI-2 independent variables (>4,600)

- min, max, Q1-3, mean, trimmed mean, mode, sd, var, Hartigan's dip test stat and sig.



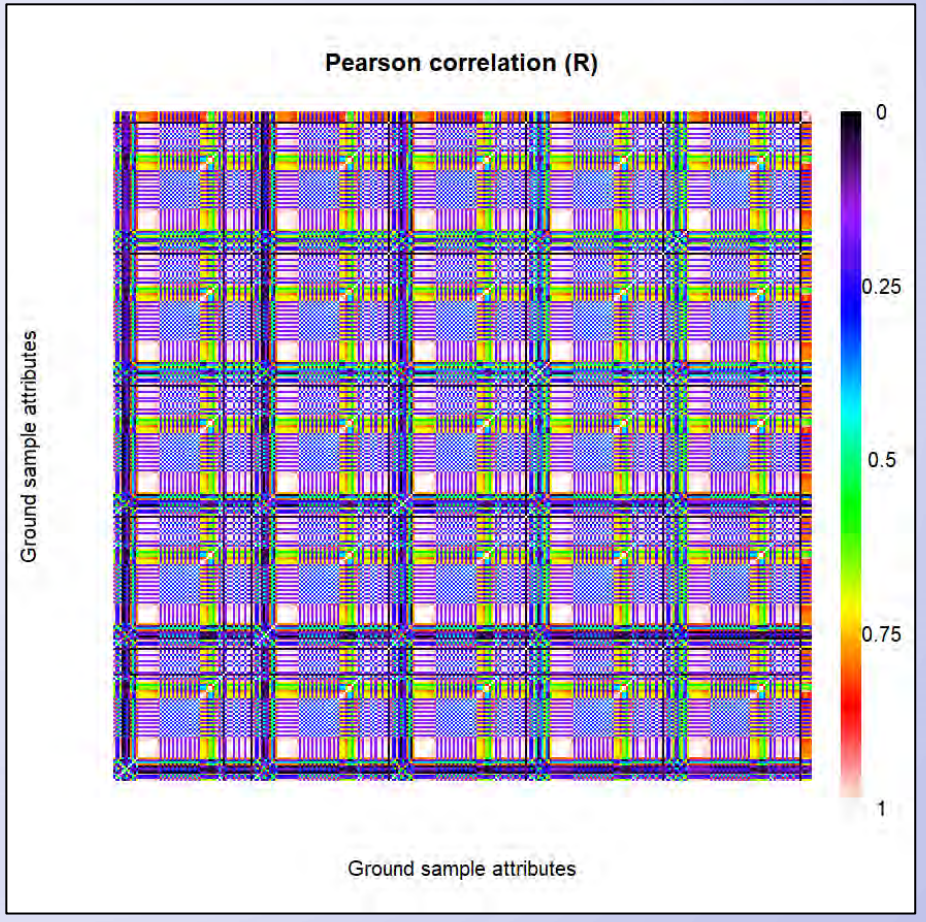
Boundary TSA: *Predictive Forest Inventory*

PFI-1 dependent variables (332)

- 5 utilization levels
- Live, dead and total attributes
- Basal area
- Density
- QMD
- Volumes
- Heights
- Age

PFI-2 dependent variables

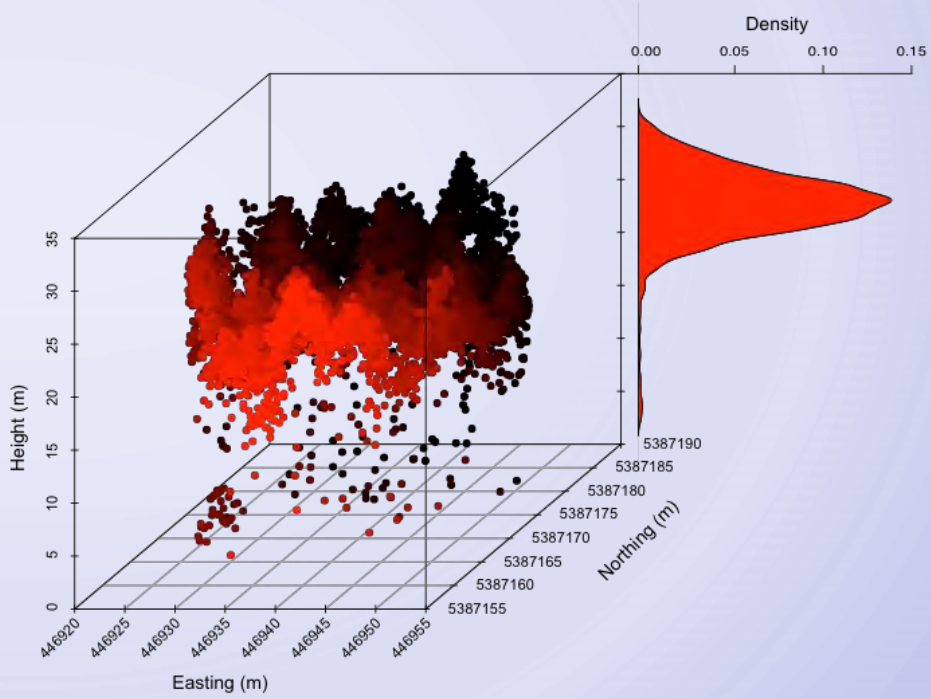
- Species (leading, groupings)
- Age



Boundary TSA: *Predictive Forest Inventory*

PFI-1 method: ABA lidar forest inventory

- Ground sampling campaign
  - Field measured attributes
- Airborne campaign
  - Lidar metrics
- Model cal/val
  - Field=f(lidar metrics)
- Attribute extrapolation
  - Predictions for ALS survey area

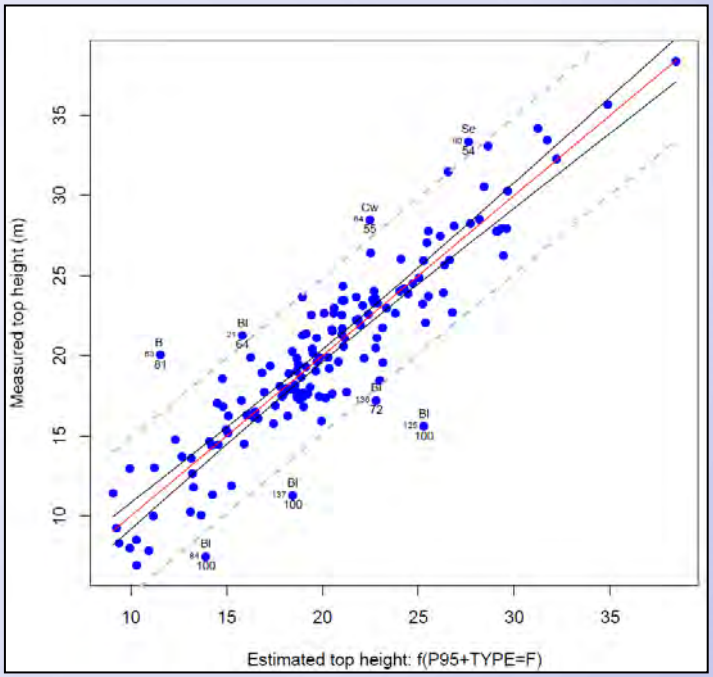


Boundary TSA: *Predictive Forest Inventory*

PFI-1 method: ABA lidar forest inventory

Modelling process

- Blind feature selection and fitting
- 1-3 feature exhaustive best subset regression
- Features must be physically rationalized
- Evaluated for influential observations
- Evaluated for linearity
- Evaluated for heteroscedasticity



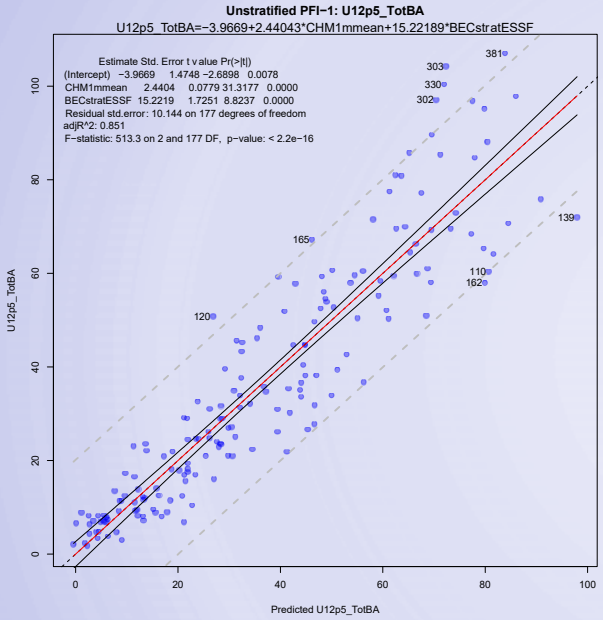
Boundary TSA: *Predictive Forest Inventory*

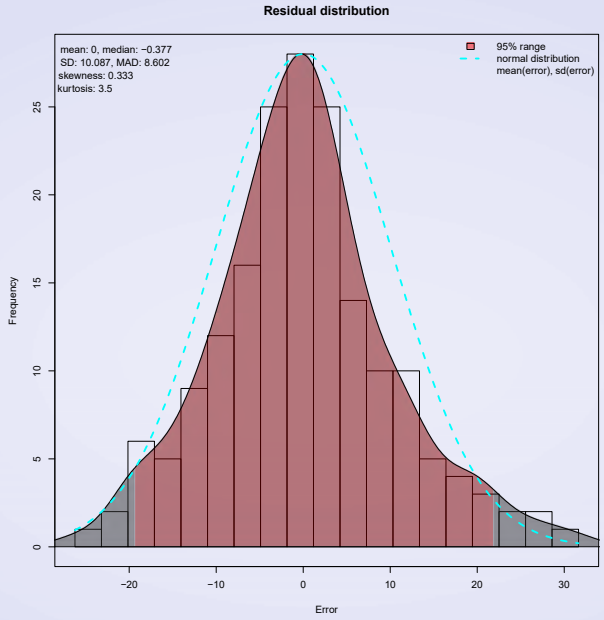
PFI-1 method: ABA lidar forest inventory

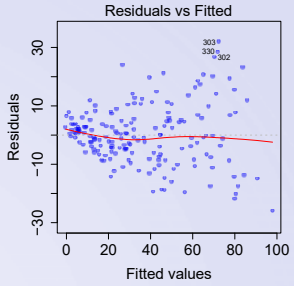
Modelling process with strata

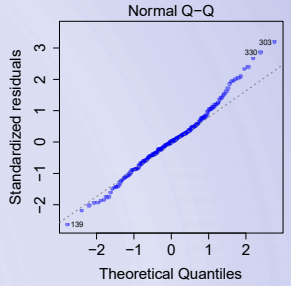
- Force base model with BEC dummy variable
- Exhaustive best subset regression
- Repeat with BEC strata, feature selection is BEC specific
- K-fold cross-validation
  - n per fold=30 for cv model stability
  - k=10 for summary metric stability

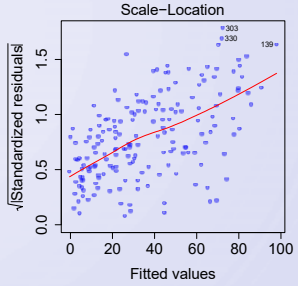
Boundary TSA: *Predictive Forest Inventory*

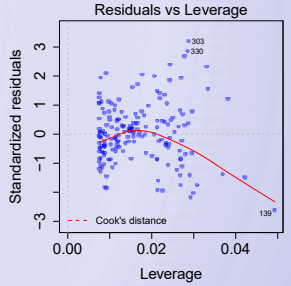








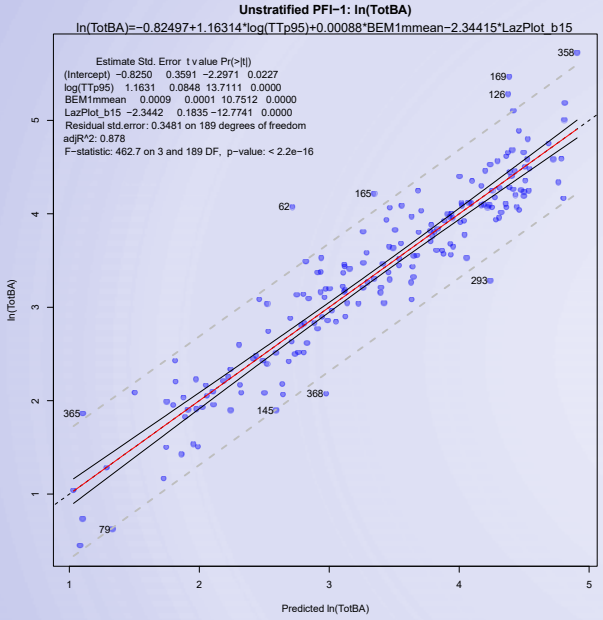


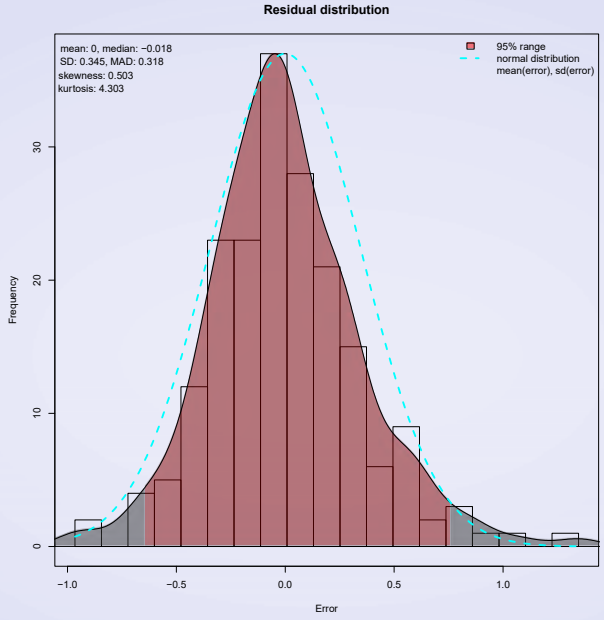


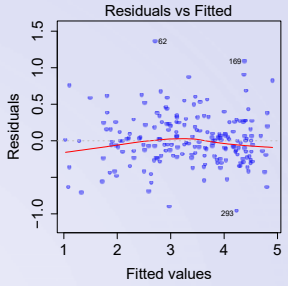
Stratified 10-fold cross validation

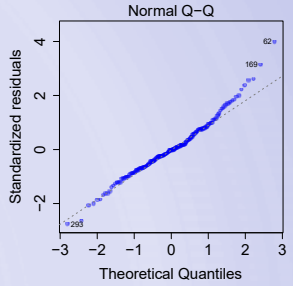
summary	Rsqr	RSS	P97.5	P2.5	Bias	RMSE	MAE
mean	0.863	10.247	18.360	-16.040	0.000	9.661	7.290
median	0.857	10.578	17.750	-16.548	0.000	9.974	7.144
stdev	0.030	1.527	4.307	3.562	0.000	1.439	1.394
min	0.824	7.863	12.855	-20.872	0.000	7.414	5.438
max	0.909	12.051	27.805	-9.402	0.000	11.362	9.766

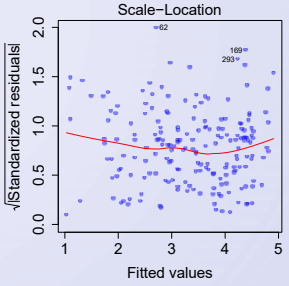
Boundary TSA: *Predictive Forest Inventory*

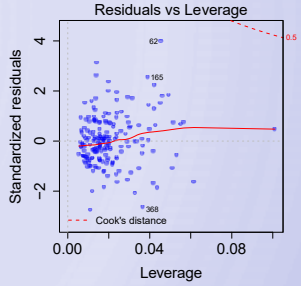






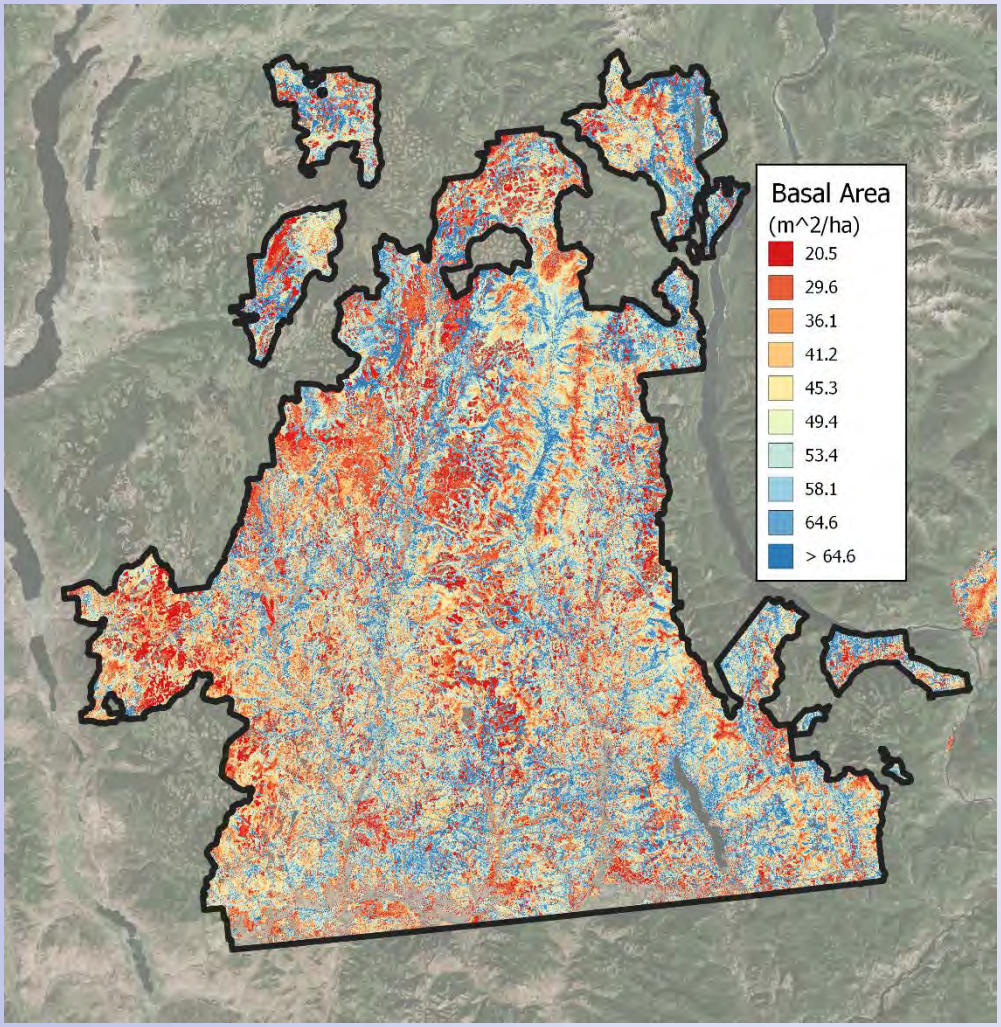


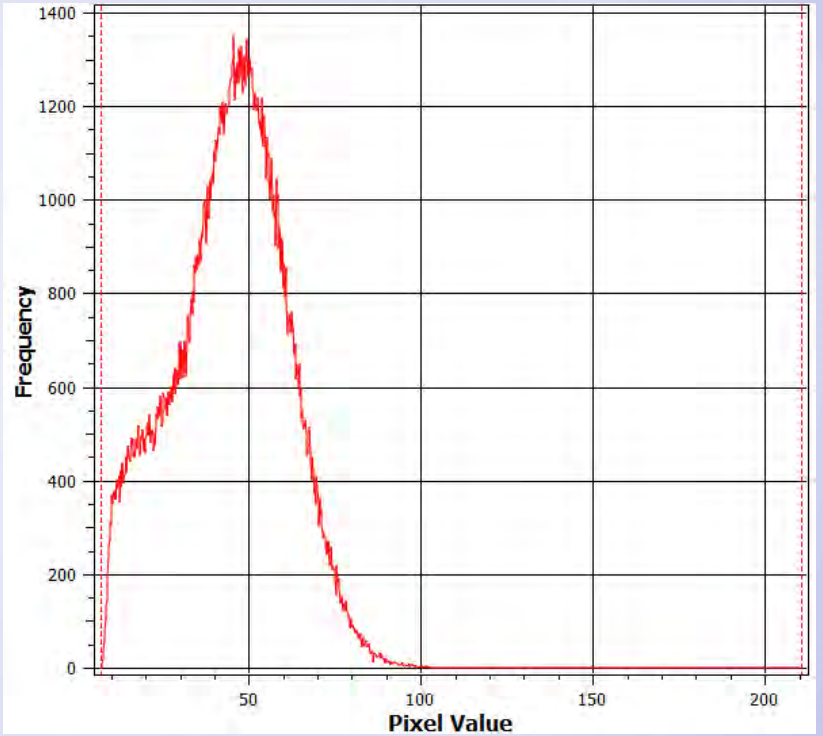




Stratified 10-fold cross validation

summary	Rsqr	RSS	P97.5	P2.5	Bias	RMSE	MAE
mean	0.870	0.365	0.602	-0.610	0.000	0.346	0.276
median	0.892	0.340	0.545	-0.586	0.000	0.322	0.268
stdev	0.074	0.109	0.216	0.201	0.000	0.103	0.081
min	0.728	0.208	0.351	-0.909	0.000	0.197	0.151
max	0.958	0.524	1.016	-0.244	0.000	0.496	0.406


Basal Area
(m^2/ha)
20.5
29.6
36.1
41.2
45.3
49.4
53.4
58.1
64.6
> 64.6


Frequency
1400
1200
1000
800
600
400
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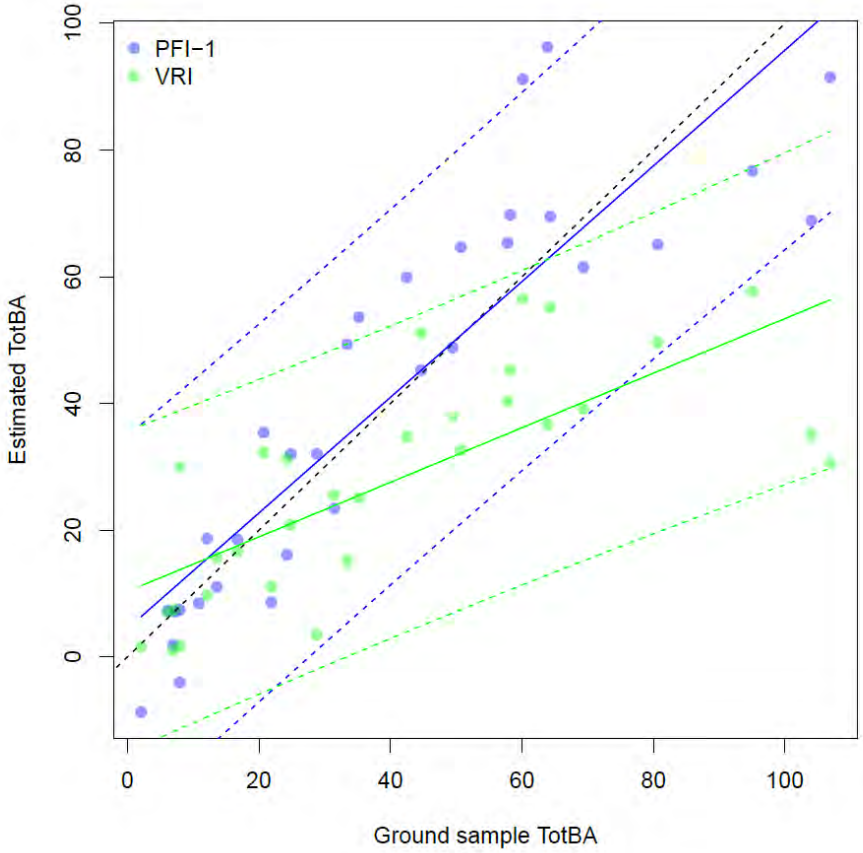
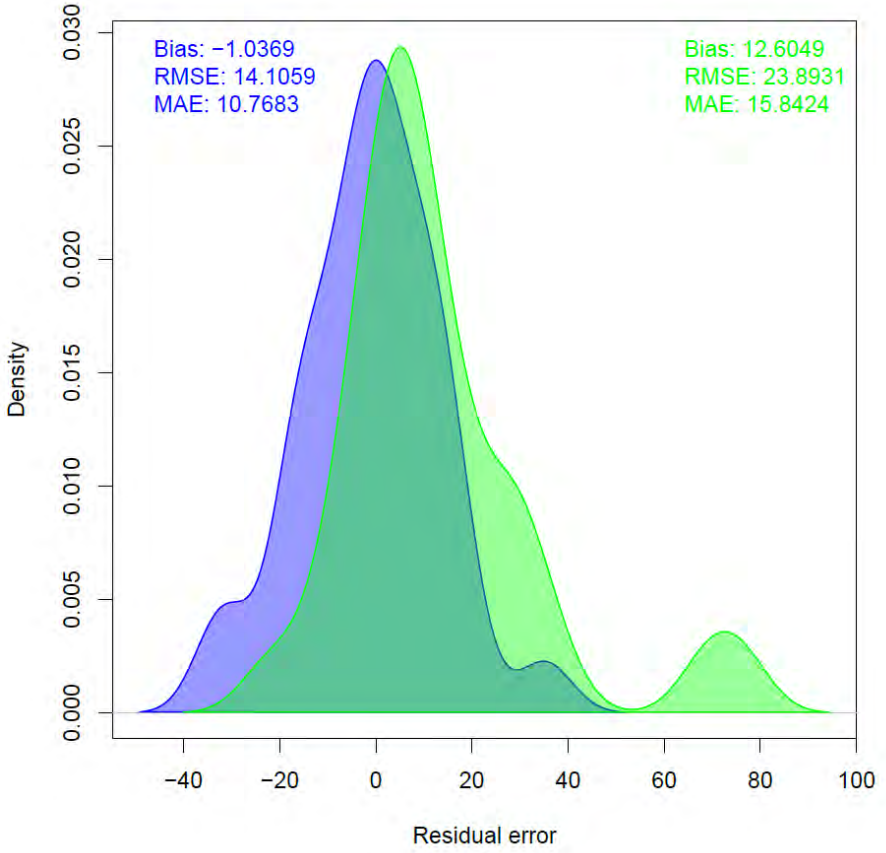
0
50
100
150
200
Pixel Value





Independent stratified random sample (n=30) FIP comparison

- Bias: FIP 12x> PFI-1, RMSE: FIP 1.7x> PFI-1
- FIP severely underestimates BA at higher BA

PFI-1 Result: Structural attribute modelling

Dep.	Independent	R2	RSS	Mean CV R^2	Mean CV RSS	VRI/FIP Bias	VRI/FIP RMSE
Ln(BA)	Ln(TTp95), BEM mean, b15	0.88	0.348	0.87	0.365	12x >	1.7x >
Ln(QMD)	K8HD mean, K8dHT sd, p70	0.75	0.188	0.77	0.190	1.5x >	1.2x >
Ln(SPH)	BEM mean, K8HD Q3, b10	0.73	0.418	0.74	0.412	2.4x >	1.5x >
Ln(WSV)	TTp95^0.5, BEM mean, dns_gap	0.90	0.405	0.91	0.397	10.4x >	2.3x >
Lorey's Ht	p85	0.95	2.37	0.95	2.35	4.9x >	2.3x >
Top Ht	TT mean	0.89	3.65	0.88	3.64	NA	NA
Max Ht	TT max	0.97	2.16	0.97	2.07	NA	NA

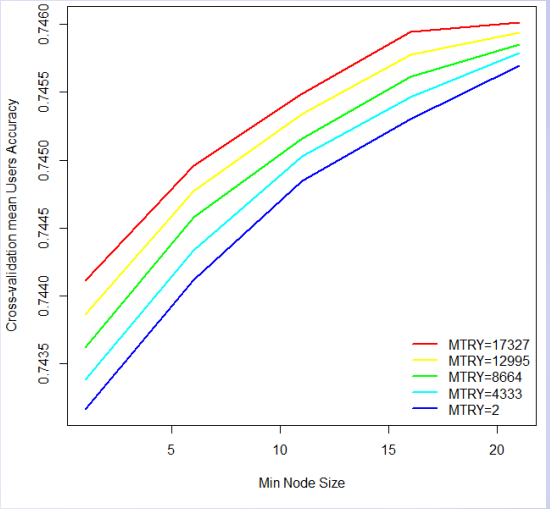
- Height sufficiently modelled with a single variable
- Models are stable according to stratified 10-fold cross validation
- PFI is an improvement over the existing inventory (VRI/FIP)

Boundary TSA: *Predictive Forest Inventory*

PFI-2 method: Species modelling (*in progress*)

Ranger Random Forest classification

- Leading species (SP1 >80%), All features
- Tuned via cross validation
  - Mtry = 17327, sample fraction=1, node size=22 parabolic
- Class balance via subsample, exhaustive resampling
- Mean, sd: OOB, OA, recall (PA), precision (UA), Kappa, CM
- Retain best fold and full sample model



	Bl	Cw	Decid	Fdi	Hw	L	Pl	Py	S	Train N	PAcc %
Bl	233	0	0	3	0	0	10	0	6	252	92.5
Cw	0	24	0	13	0	0	0	0	2	39	61.5
Decid	0	0	25	6	0	6	4	0	1	42	59.5
Fdi	0	1	1	1524	0	10	19	5	3	1563	97.5
Hw	0	3	0	1	17	0	0	0	0	21	81.0
L	0	0	2	31	0	116	18	0	2	169	68.6
Pl	11	0	1	22	0	14	671	1	3	723	92.8
Py	0	0	0	22	0	0	2	1	0	25	4.0
S	9	2	0	11	1	0	13	0	65	101	64.4
Pred N	253	30	29	1633	18	146	737	7	82	2935	NA
UAcc %	92.1	80.0	86.2	93.3	94.4	79.5	91.0	14.3	79.3	NA	OA: 91.2

Full sample confusion matrix

Boundary TSA: *Predictive Forest Inventory*

PFI-2 method: Species modelling (*in progress*)

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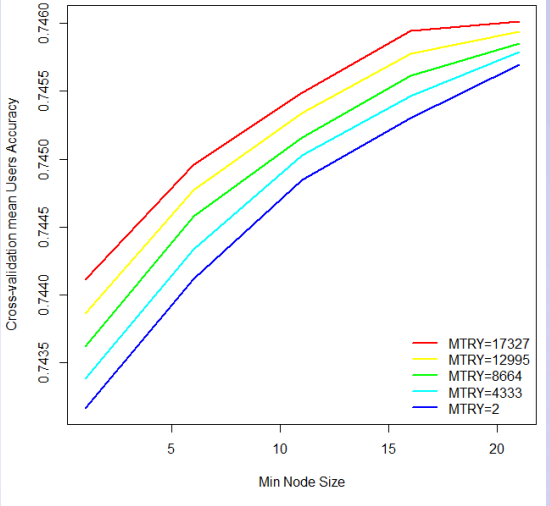

	Bl	Cw	Decid	Fdi	Hw	L	Pl	Py	S	Train N	PAcc %
Bl	27789	33	284	141	22	30	1389	68	1684	31440	88.4
Cw	1	2327	105	152	606	15	19	21	291	3537	65.8
Decid	0	15	2981	105	0	526	76	170	57	3930	75.9
Fdi	872	6327	3783	122500	1093	6312	2528	48781	10985	203181	60.3
Hw	1	125	0	1	1037	7	0	0	8	1179	88.0
L	81	239	2218	1866	509	13204	1285	313	852	20567	64.2
Pl	2390	312	4134	4741	84	5759	68563	2555	4603	93141	73.6
Py	6	2	2	257	0	10	74	1343	9	1703	78.9
S	1802	916	882	584	331	91	1167	173	5713	11659	49.0
Pred N	32942	10296	14389	130347	3682	25954	75101	53424	24202	370337	NA
UAcc %	84.4	22.6	20.7	94.0	28.2	50.9	91.3	2.5	23.6	NA	OA: 66.3

Aggregated validation confusion matrix

Boundary TSA: *Predictive Forest Inventory*

PFI-2 method: Species modelling (*in progress*)

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- Class balance via subsample, exhaustive resampling
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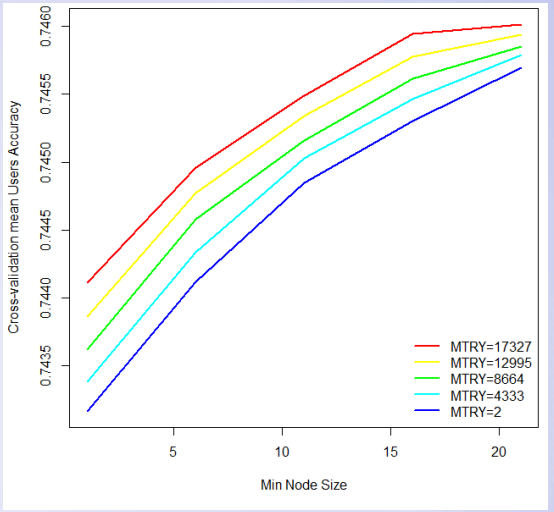
- Retain best fold and full sample model



	OOB error	OA	PA	UA	Kappa
Mean (SD) CV (n=131)	32.6 (4.7)	66.3 (4.0)	71.6 (2.6)	48.2 (2.8)	54.6 (4.1)
Best fold	20.4	79.6	79.6	81.3	77.1
Full sample	8.8	91.2	69.1	78.9	86.0

Boundary TSA: *Predictive Forest Inventory*

Summary

- PFI is a new approach to forest inventory
  - more accurate than current inventory (most attributes)
  - more spatially precise (smaller segments, 20m prediction, tree level)
  - objective statistical derivation
- PFI-2 experiment will test the spatial extrapolation of PFI-1
  - if successful less investment in data acquisition costs
- Lessons learned:
  - Processing all data at once is a significant time benefit
  - maintain redundancy into ground sampling survey procedure
  - Climate data may not significantly contribute to PFI-1
  - small benefit for stratification & merging live and dead
  - large diameter Cw problematic in BA and QMD modelling
  - TT metrics were important in density based models

Boundary TSA: *Predictive Forest Inventory*

Questions and Discussion