Modeling and mapping stand structure attributes operationally from LiDAR-based inventories

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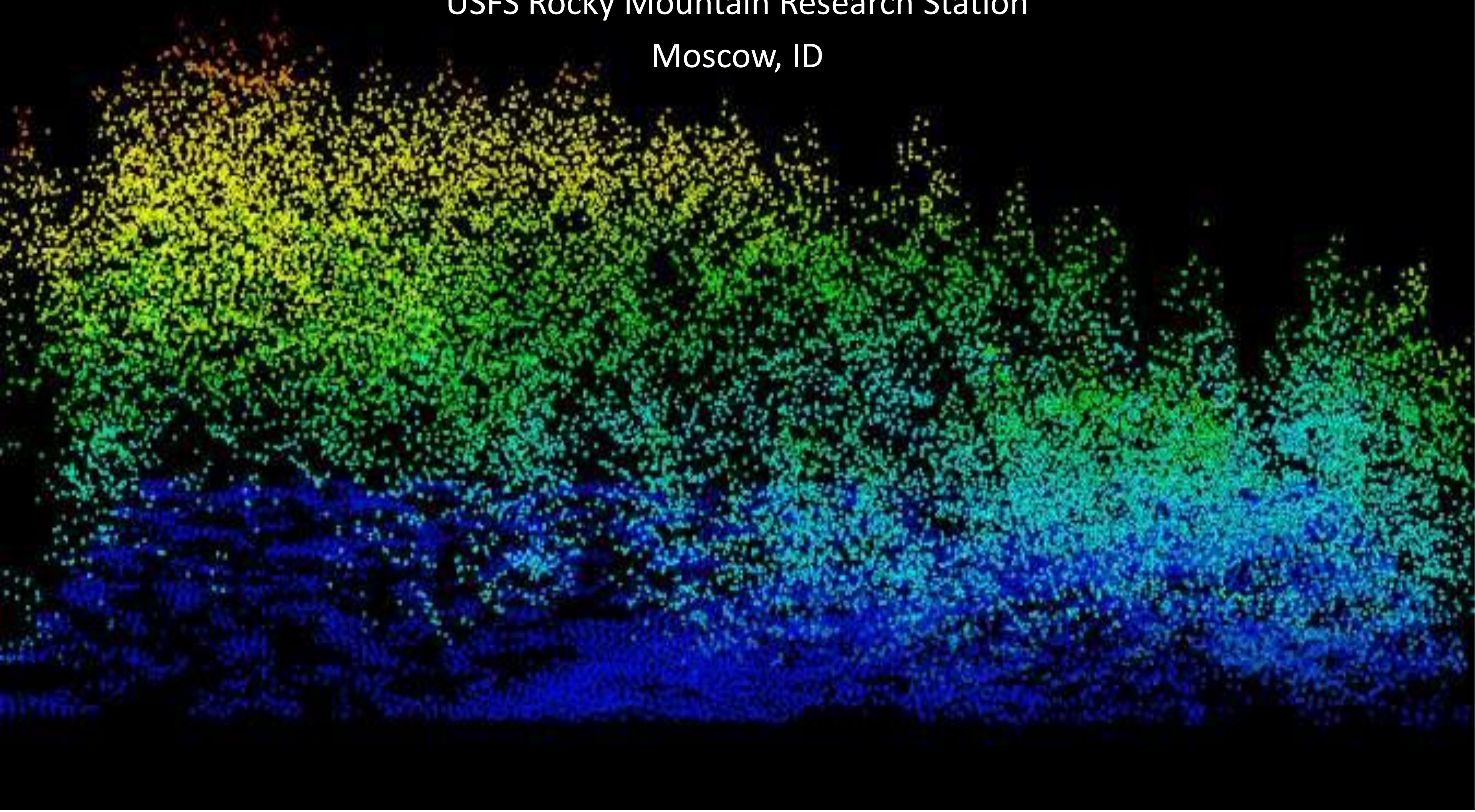
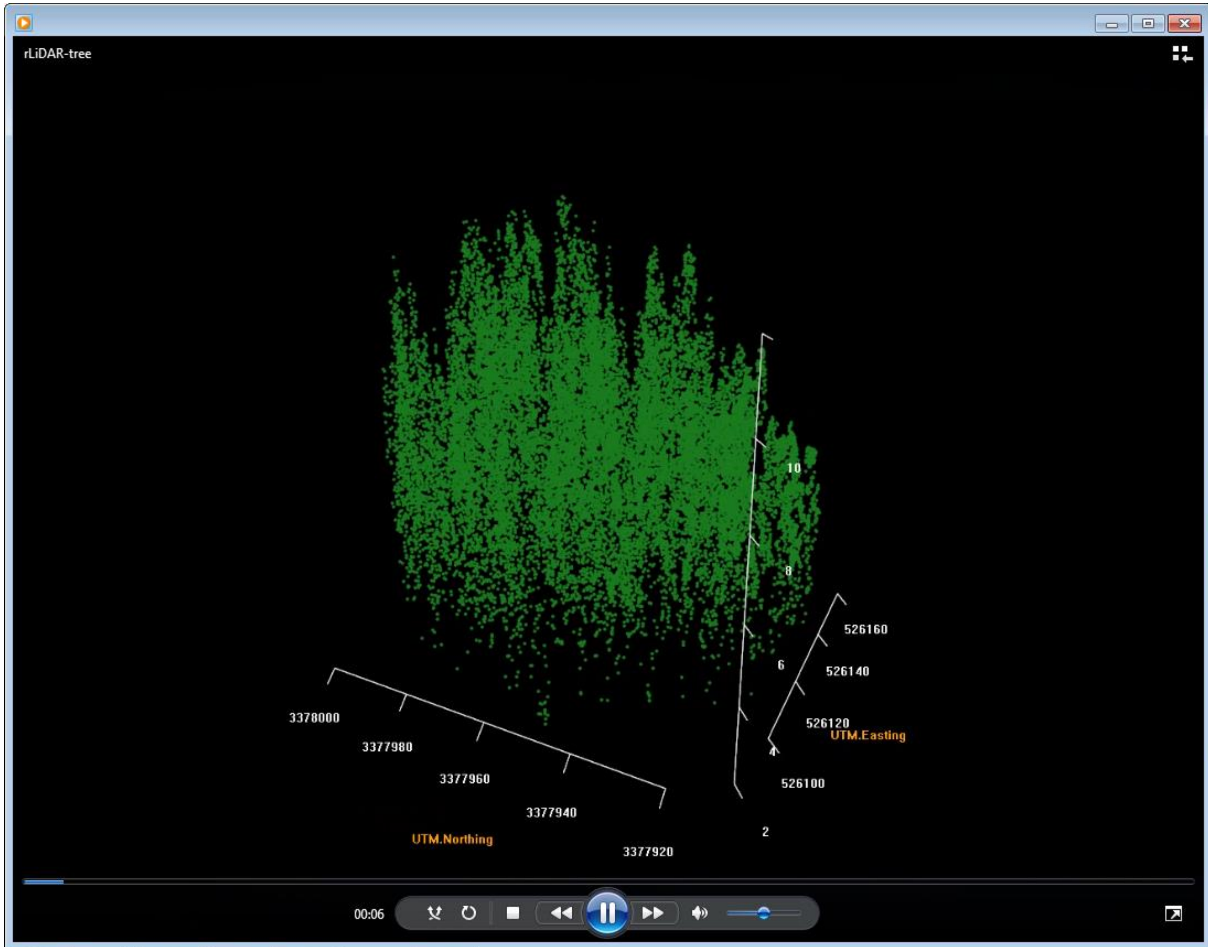


Outline

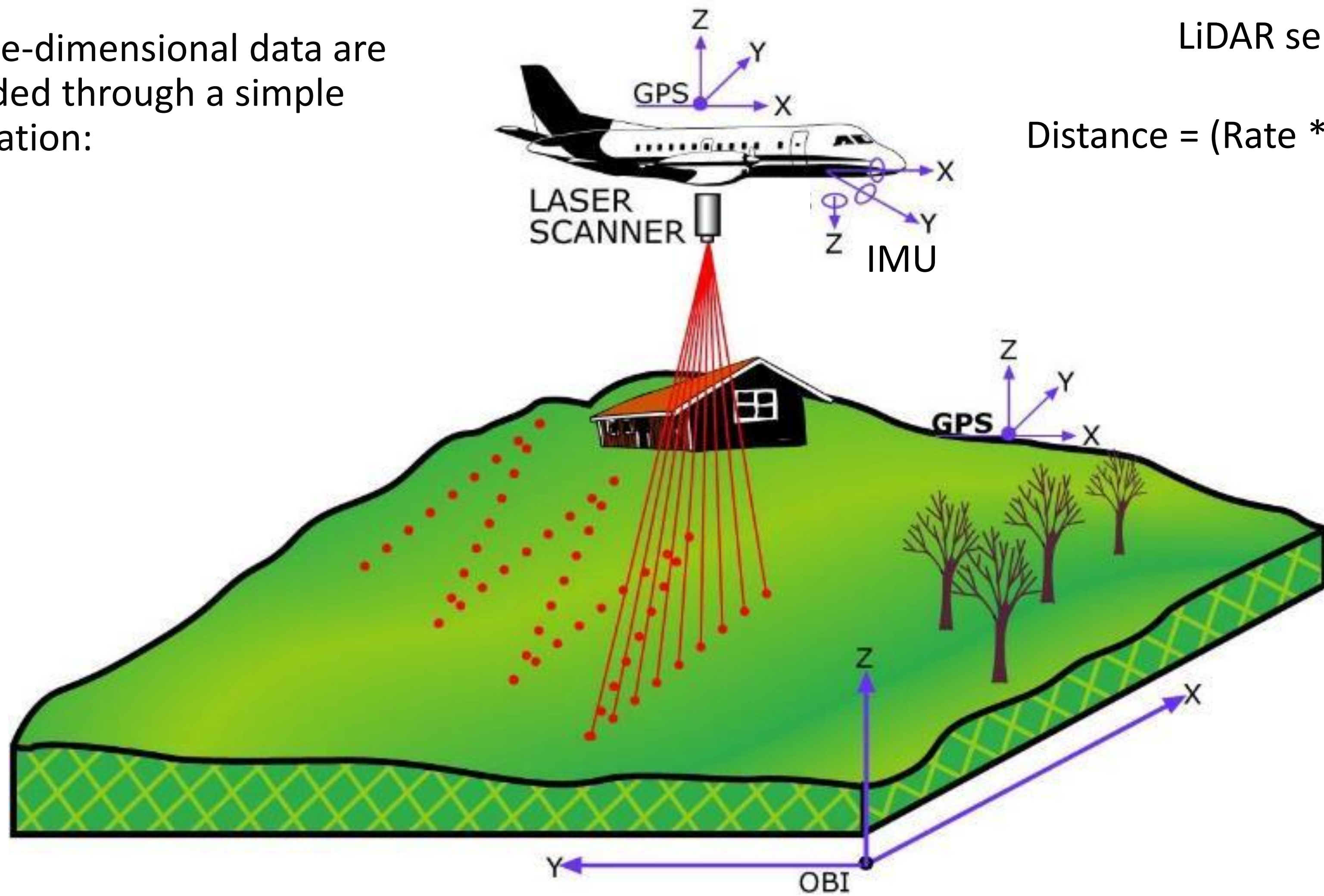
- Light Detection and Ranging (LiDAR) Data and Processing
- Small Area Based Modeling
- Local Study
  - Imputation
  - Results
  - Conclusions
- Regional Study
  - Regression
  - Results
  - Conclusions



Airborne Laser Scanning

- LiDAR instrument actively emits laser pulses

- Three-dimensional data are recorded through a simple calculation:



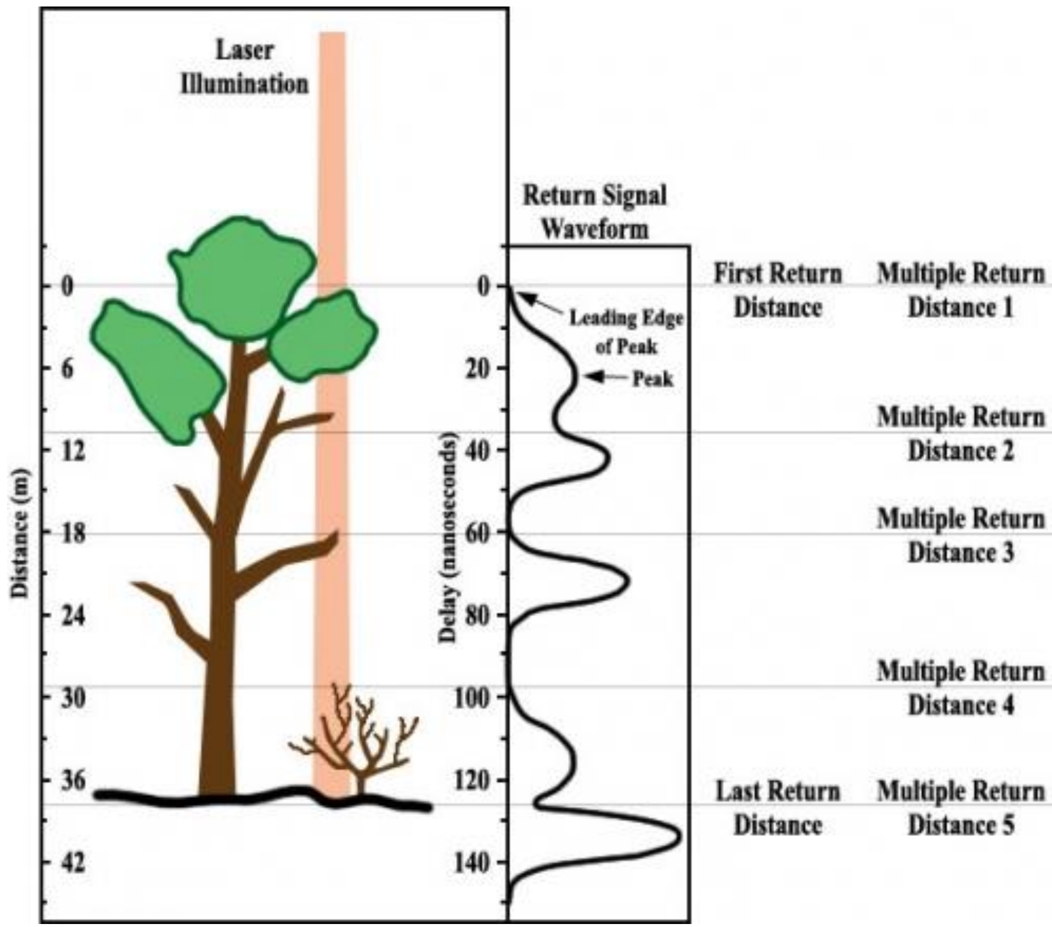
Distance = Rate * Time

Rate = speed of light (299,792,458 m/s)

Time -> measured by the LiDAR sensor

Distance = (Rate * Time) / 2

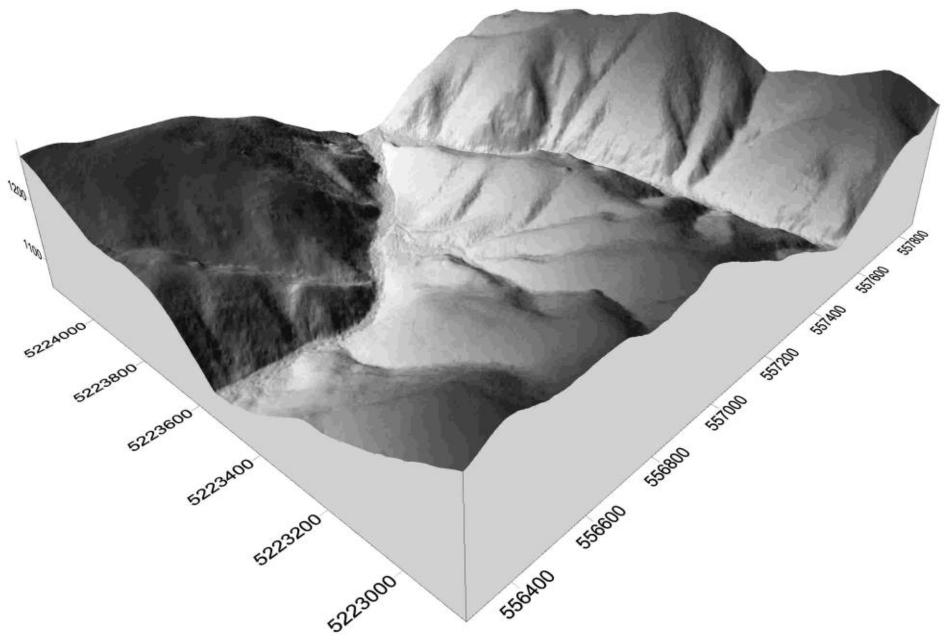
LiDAR Pulse Hits an Object



Source: Lefsky *et al.*, 2002

Topographic Metrics from Digital Terrain Model

Topography



ELEV – Elevation (m)

SLP – Slope (degrees)

SPS – Slope position

SCOSA – Slope * cos(Aspect)

SSINA – Slope * sin(Aspect)

INSOL – Solar Insolation

TRASP – Transformed Aspect

TRI – Topographic Ruggedness Index

TRMI – Topographic Relative Moisture Index

HLI – Hierarchical Landscape Index

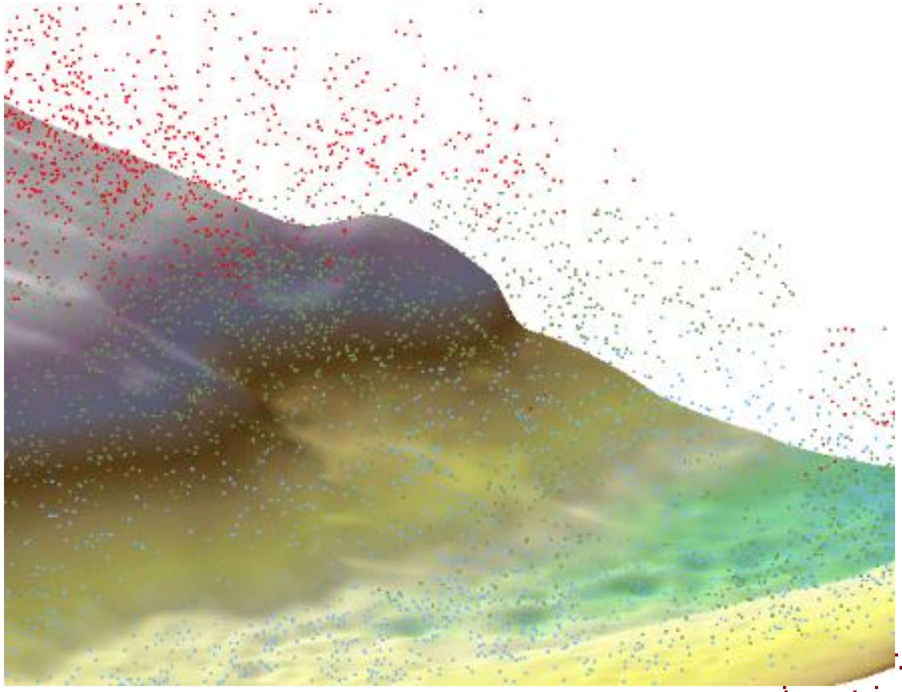
HSP – Hierarchical slope position

CTI – Compound Topographic Index

DIS – Dissection Coefficient

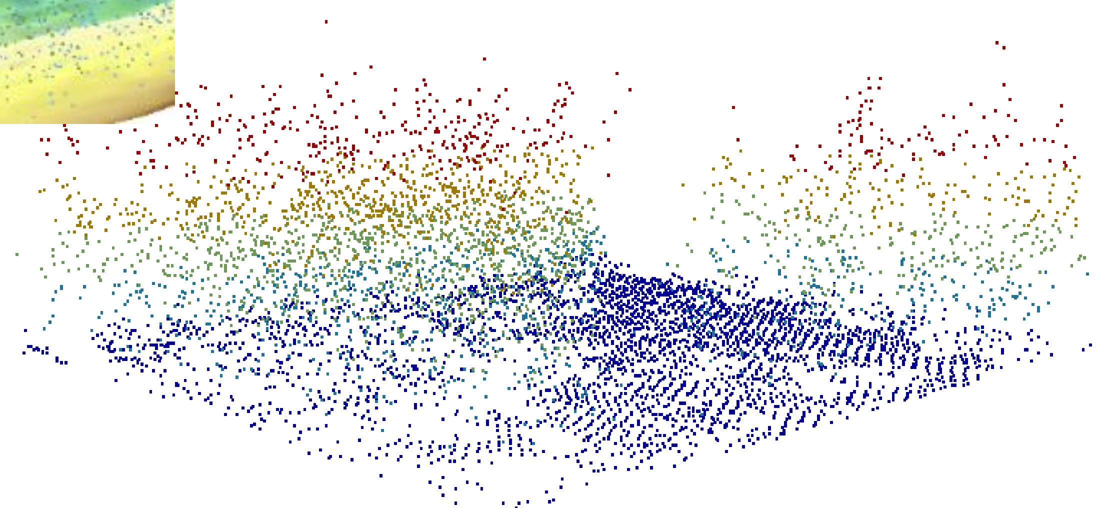
ERR – Elevation Relief Ratio

Calculating Canopy Height

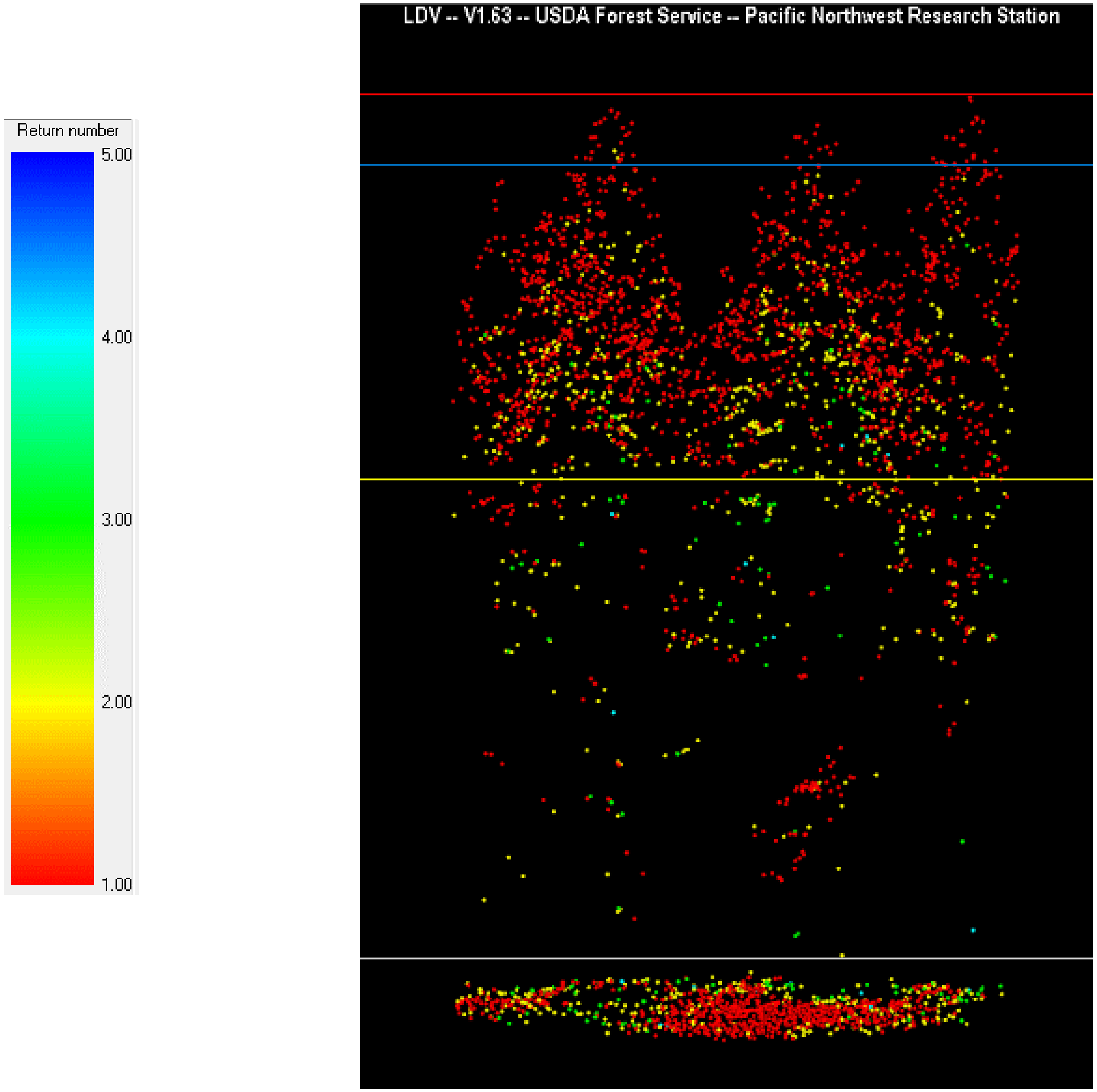


Subtract DEM ground surface from the elevation of LiDAR returns to normalize Z values for canopy height

- Removes the effect of topography



Lidar Height Metrics



Maximum Canopy Height

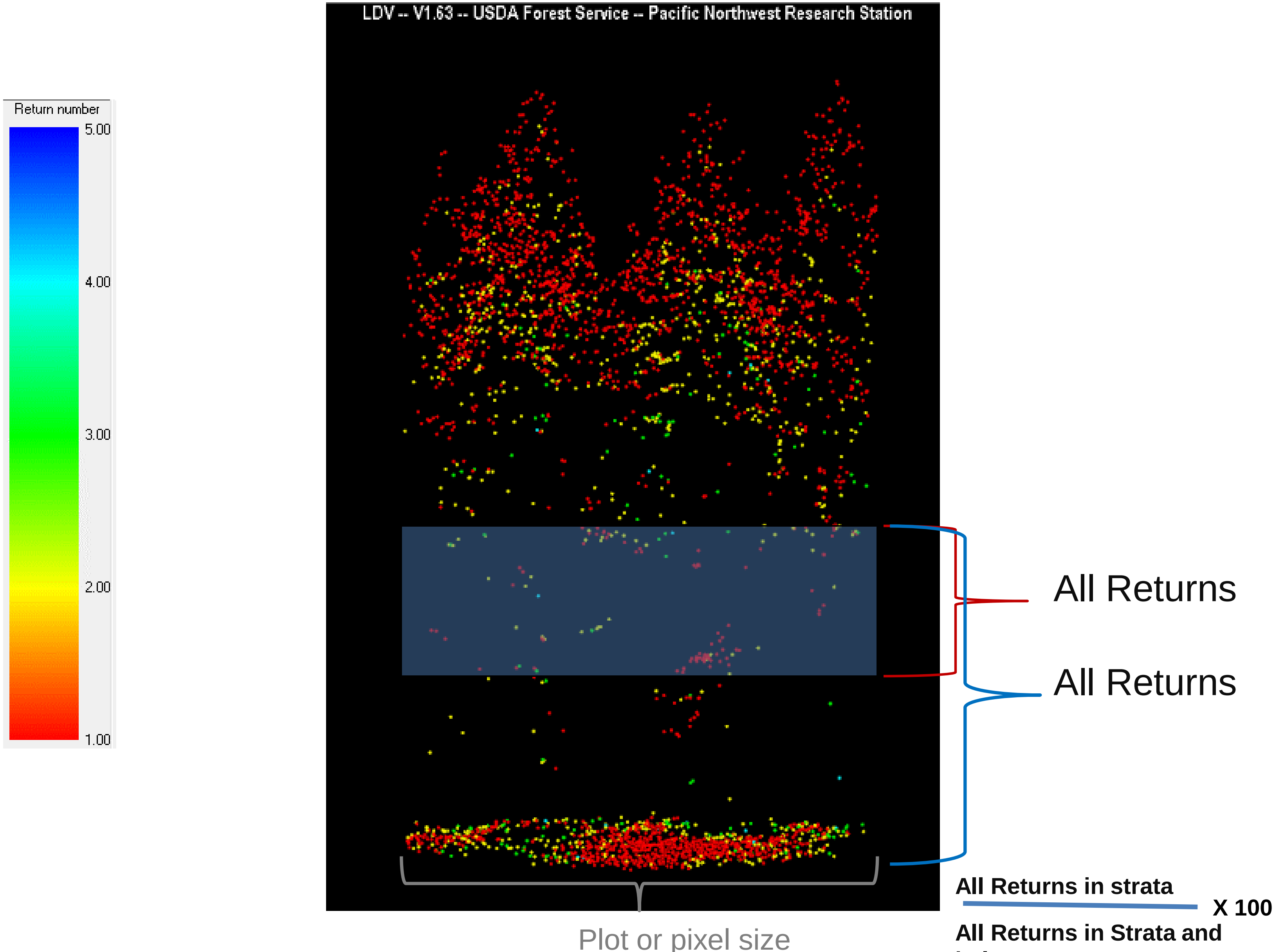
95th percentile

Mean Canopy Height

Height Cutoff (1.37 m)

USDA Forest Service, Remote Sensing Applications Center, http://fsweb.rsac.fs.fed.us

Lidar Mid-story Density Metrics

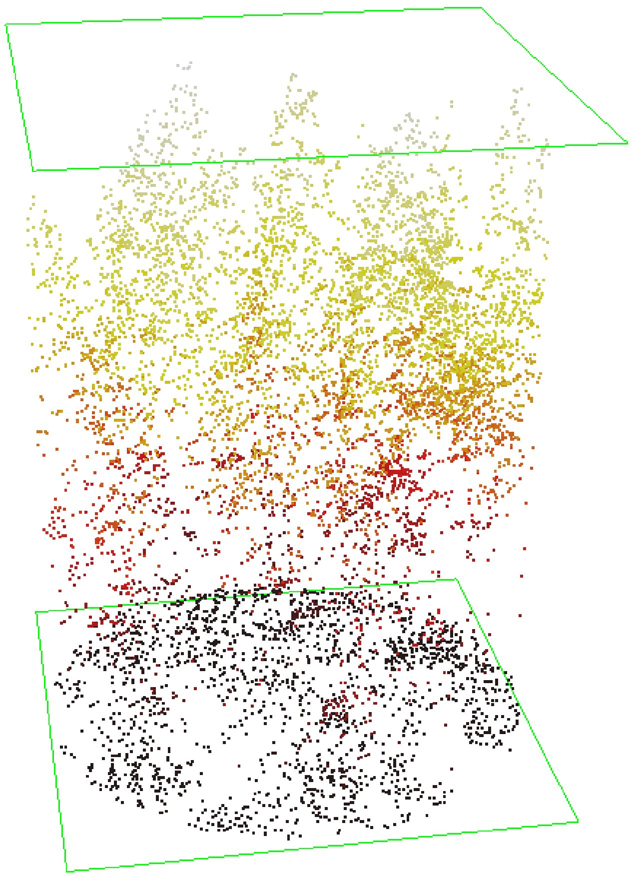


$$\frac{\textbf{All Returns in strata}}{\textbf{All Returns in Strata and below Strata}} \times 100$$

USDA Forest Service, Remote Sensing Applications Center, http://fsweb.rsac.fs.fed.us

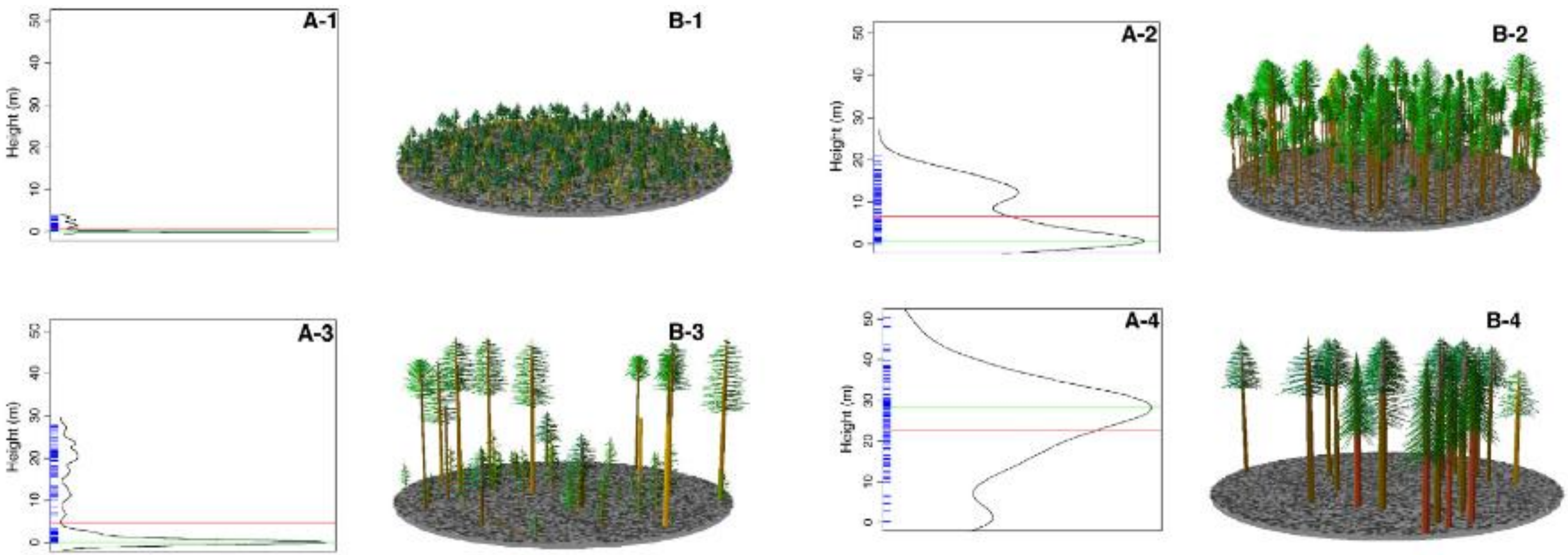
Predictor (x) and Response (y) Variables

- Predictor Variables (from lidar measures):
  - LiDAR metrics
  - Topographic metrics
- Response variables (from tree measures):
  - Above ground biomass (AGB)
  - Basal area (BA)
  - Crown competion factor(CCF)
  - Quadratic mean diameter (QMD)
  - Stand density index (SDI)
  - Average top height (TopHt)
  - Tree density (Tpa)
  - Volume – merch (MCuFt)
  - Volume – total (TCuFt)



Example point cloud in a 0.1 acre plot

Build a Database of Reference Plots



Important ABCs for LiDAR-based forest inventory:

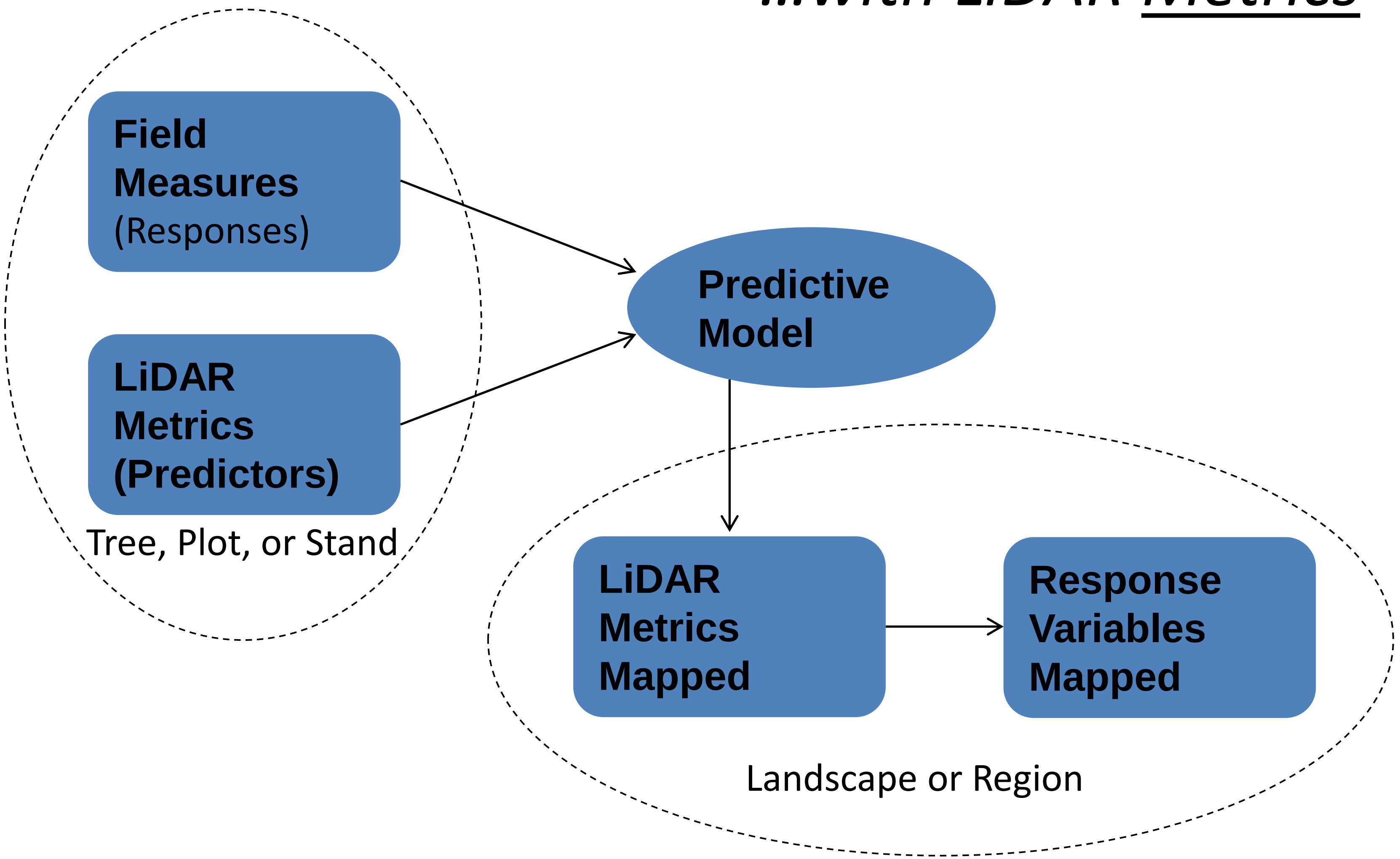
A. Stratify landscape of interest and apply a stratified random design to place field plots for efficient, unbiased sampling

B. Use fixed-radius, not variable-radius plots

C. Accurately geolocate plot centers using resource-grade (or better) GPS with differential correction capability

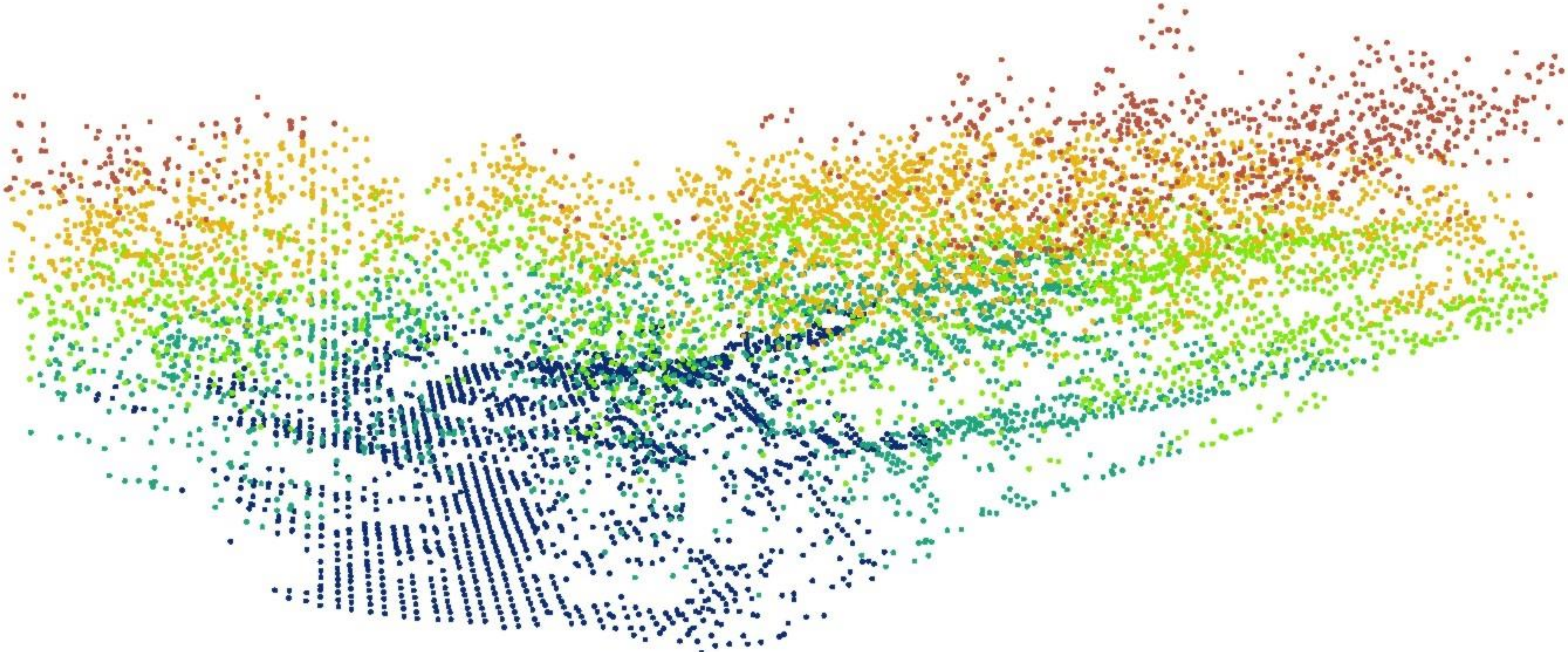
Model and Map Vegetation Attributes

...with LiDAR Metrics

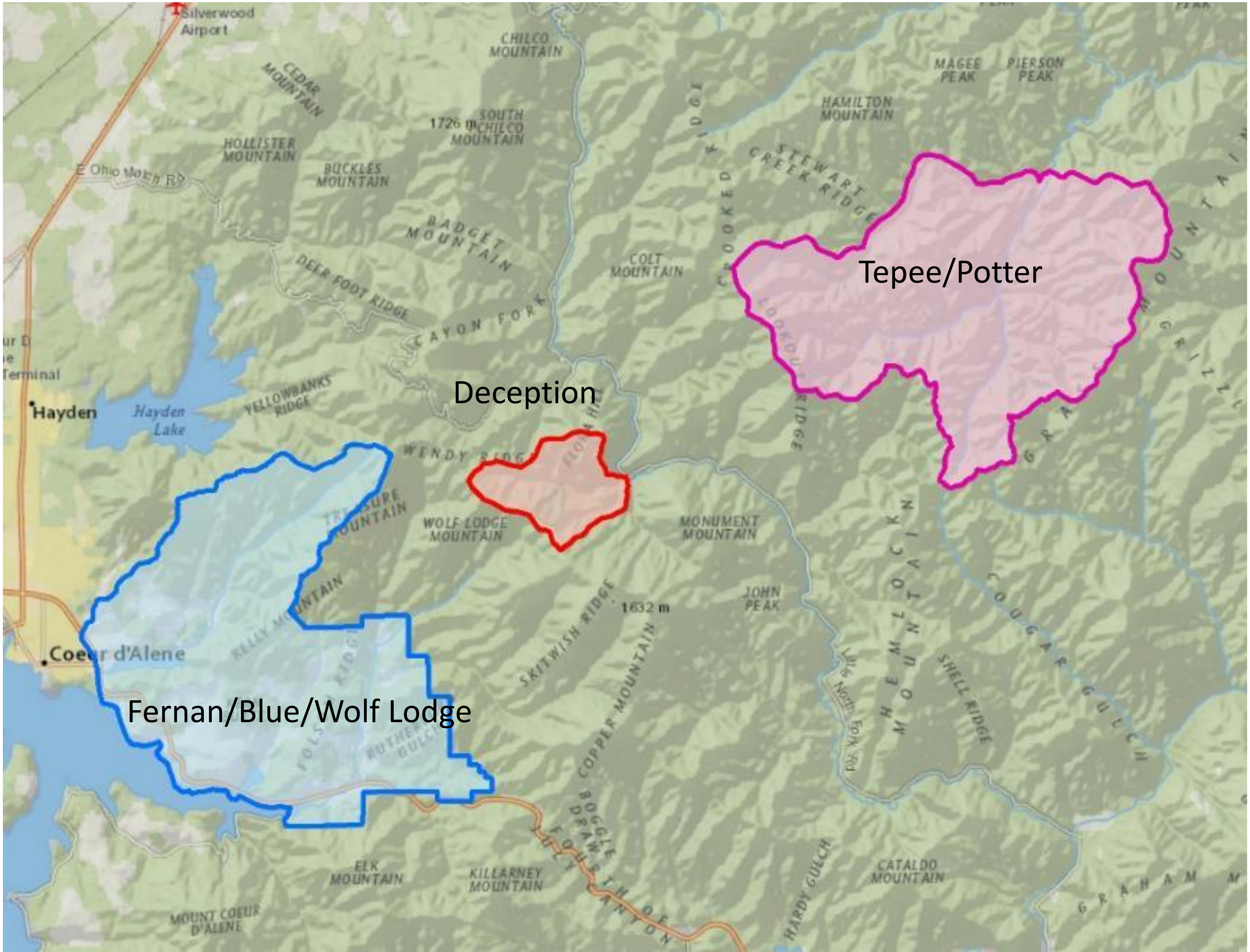


Predictive modeling approaches include:
multiple linear regression, generalized linear models, machine learning algorithms (e.g., Random Forests), neural networks, imputation, etc.

Local Study



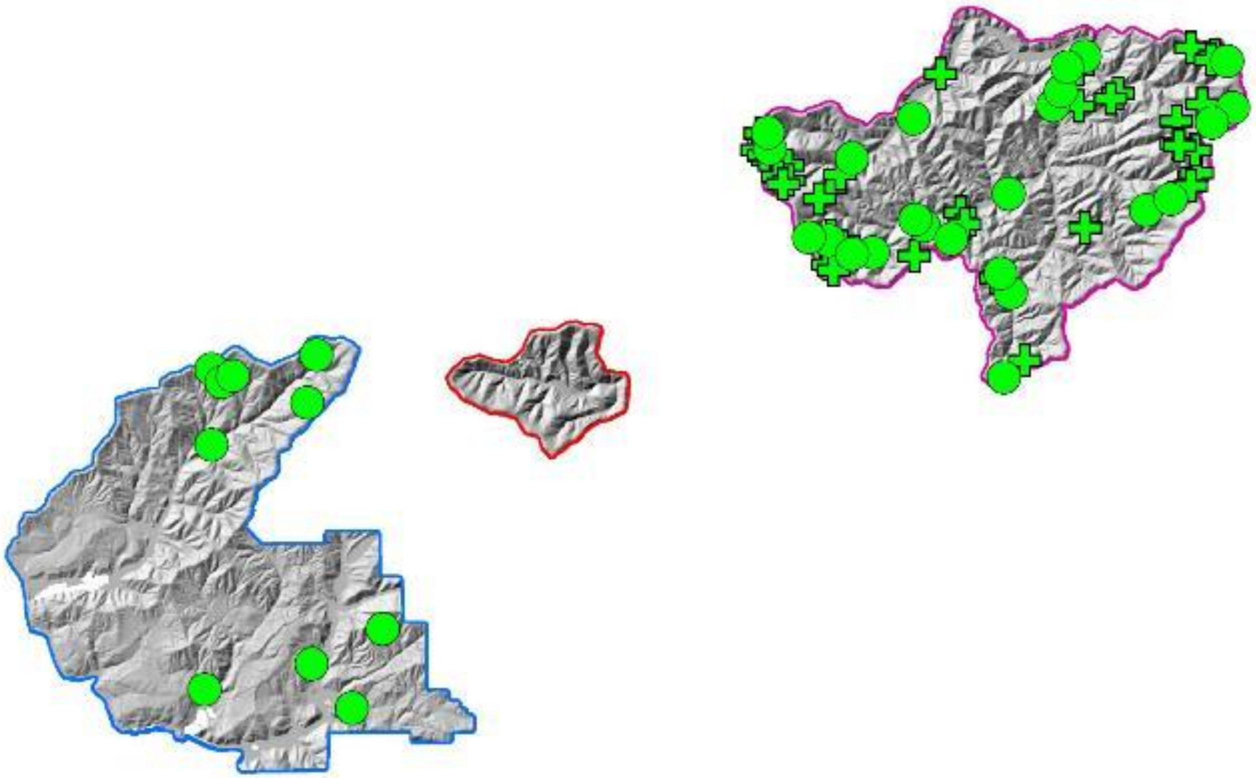
Local Study LiDAR collections



Local Study Data Description

- Data
  - Fernan, Blue, and Wolf Lodge Creeks:
    - LiDAR flown winter 2014-2015 (leaf-off)
    - 10 plots, 1/10 acre, characterized 2015
  - Tepee and Potter Creeks:
    - LiDAR flown spring (24-29 May) 2015 (leaf-on)
    - 24 plots, 1/10 acre, characterized 2015
    - 39 USFS plots , 1/10 acre, characterized 2014

Field Plots Placed Per Stratified Random Sampling Designs



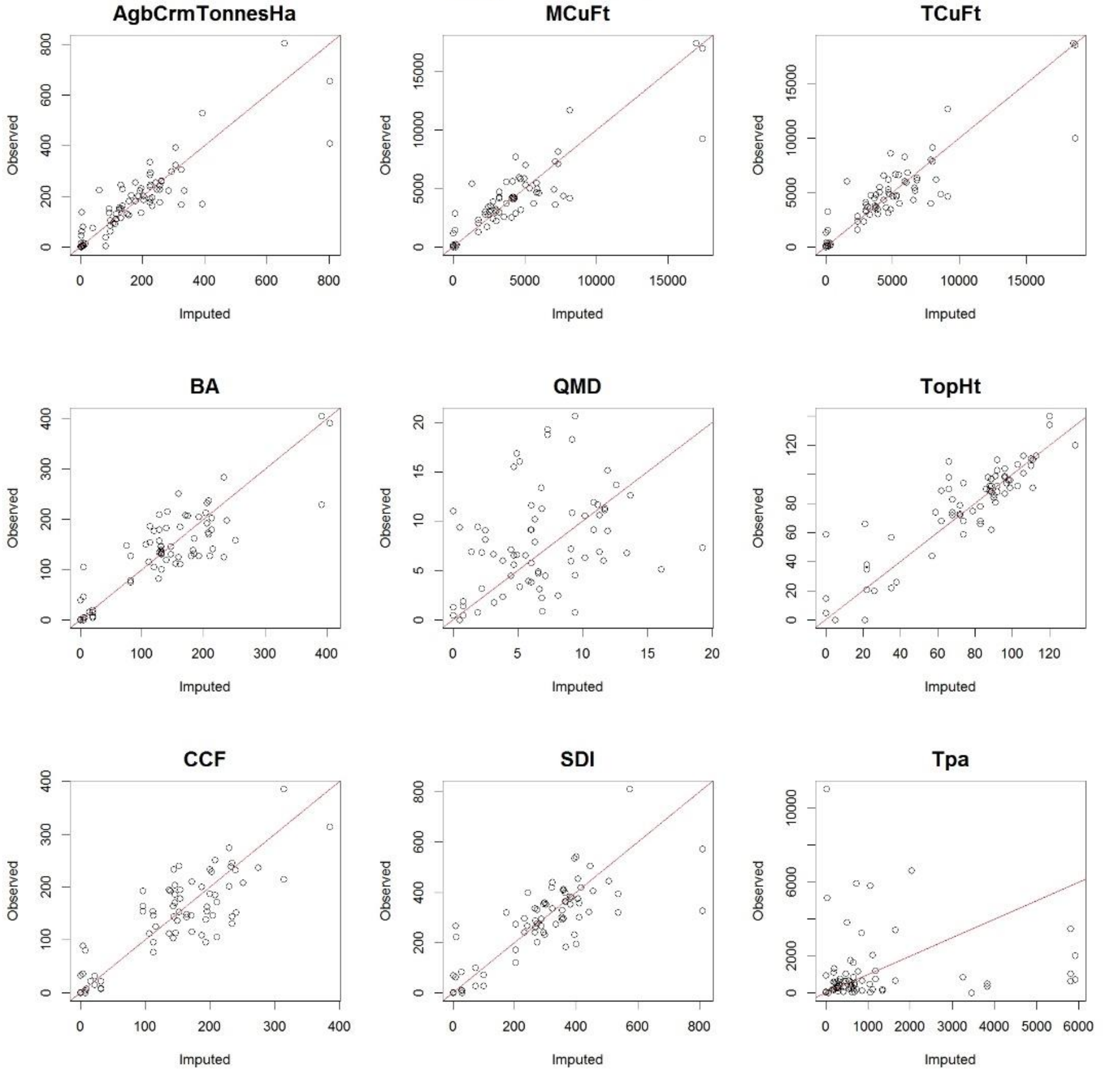
Imputation

- Imputation is 1 of numerous modeling techniques
- Multiple response variables can be predicted simultaneously
- Imputation is weighted by the relationship between multiple response variables and multiple predictors
- The model matches unknown response variables with the ‘nearest neighbor’ set of known response variables, based on ‘most similar’ set of known predictor variables

Predictor Variables

Description of explanatory variables	AGB	BA	CCF	QMD	SDI	Top Ht	TPA	Vol - Merch	Vol - Total
H05PCT - Height 5th percentile			x	x	x	x	x		
H25PCT - Height 25th percentile									
H50PCT - Height 50th percentile	x	x	x	x	x	x		x	x
H75PCT - Height 75th percentile									
H95PCT - Height 95th percentile				x		x		x	x
Hmean - Height mean									
Hmode - Height mode									
Hstdv - Height standard deviation				x			x		
Hiq - Height interquartile range									
Hskew - Height skewness									
Hkurt - Height kurtosis									
CRR - Canopy relief ratio									
Stratum 1 - Percentage returns > 0.15 m and < 1.37 m				x					
Stratum 2 - Percentage returns > 1.37 m and < 5.0 m							x		
Stratum 3 - Percentage returns > 5 m and < 10 m									
Stratum 4 - Percentage returns > 10 m and < 20 m			x	x	x	x			
Stratum 5 - Percentage of returns > 20 m and ≤ 30 m	x			x		x		x	
Stratum 6 - Percentage of returns > 30 m	x	x	x	x	x	x		x	x
Pct1Rtn_1.37 - Percentage first returns above 1.37 m					x				
Pct1Rtn_mean - Percentage first returns above height mean	x	x	x	x	x	x		x	x
Pct1Rtn_mode - Percentage first returns above height mode									
Elev - DTM elevation				x					
Slope				x					
TrAsp - Transformed aspect									
SCOSA - Slope cosine aspect transformation (Evans 2003)									
SSINA - Slope sine aspect transformation (Evans 2003)									

Model Results



Strong correlations when imputing AGB & BA

Poor correlations when imputing QMD and tree density (Tpa)

Imputation model fit statistics

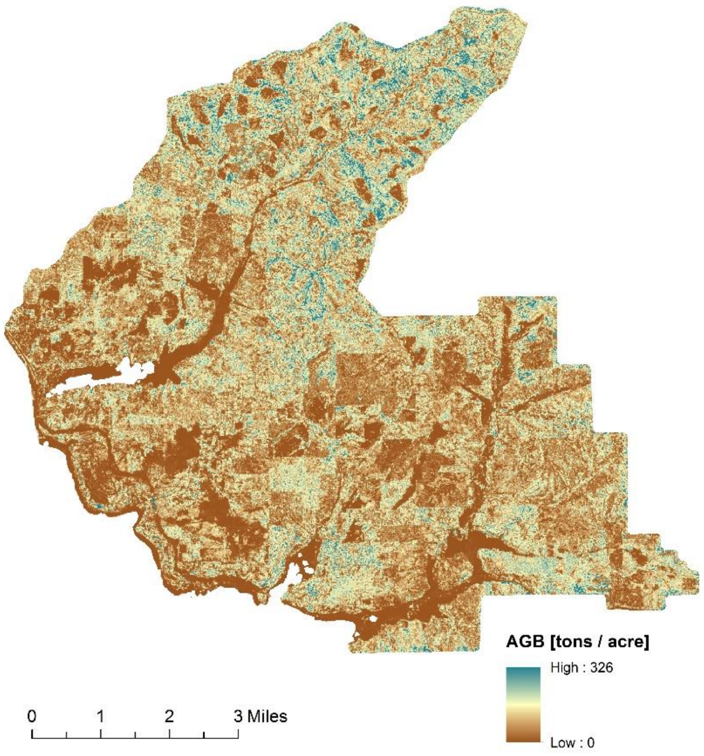
RMSD – Root Mean Square Difference

RMSD

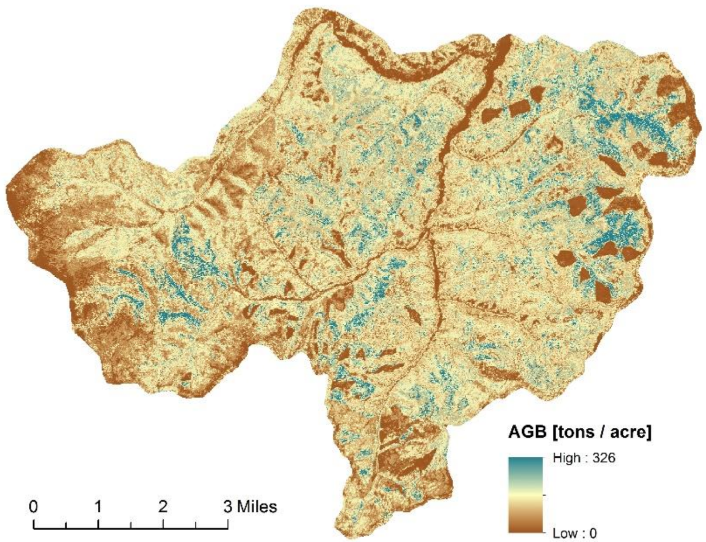
Response Variable	Units	RMSD	%
AGB	tons / ac	49	66
BA	sq-ft / ac	62	46
CCF		67	47
QMD	in	5.7	75
SDI		131	46
Average top height	ft	17	21
Tpa	trees / ac	2163	191
Volume - merch	cubic ft / ac	2834	73
Volume - total	cubic ft / ac	3049	68

Biomass Estimates Under Different Management Regimes

Fernan



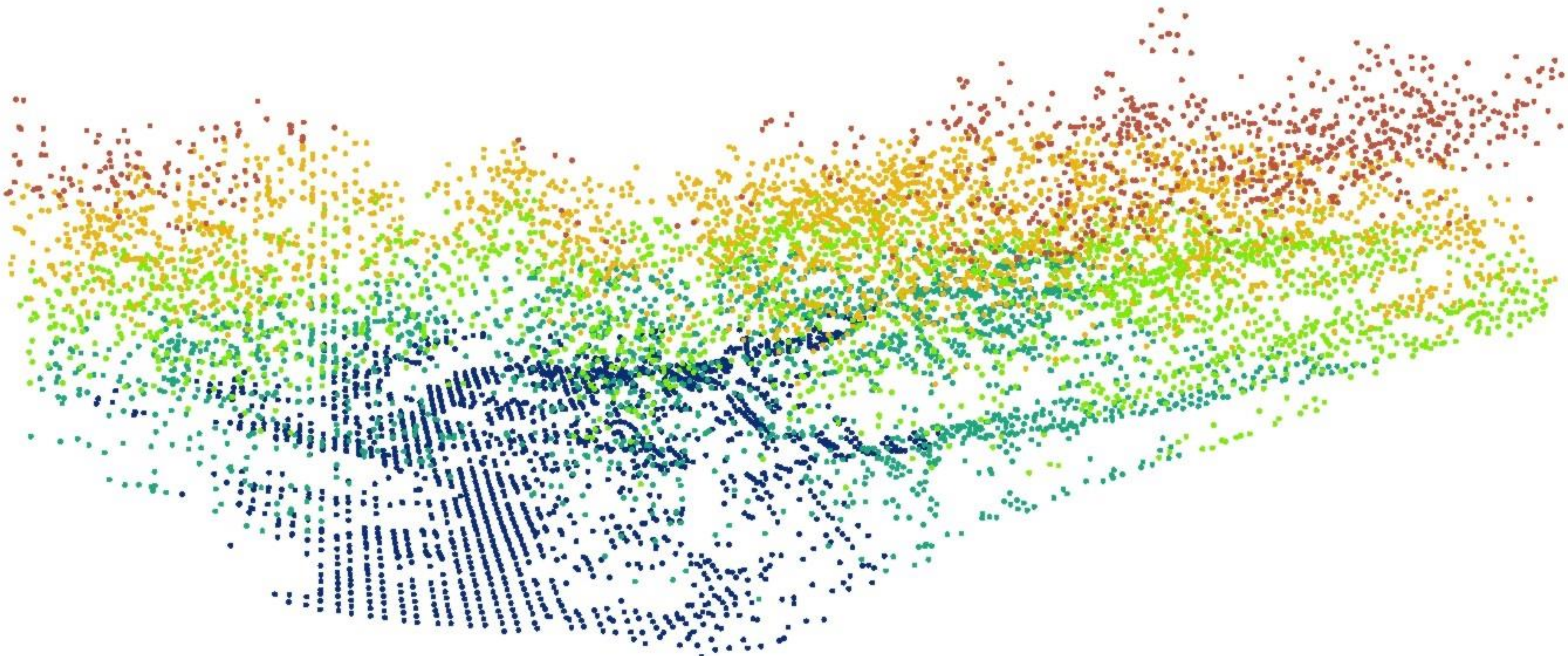
Tepee Creek



Private land: harvests follow property boundaries
USFS: harvests have 'soft' edges

USFS: less harvesting;
effects of topography on biomass

Regional Study



Fekety, P.A., M.J. Falkowski, A.T. Hudak, T.B. Jain and J.S. Evans. (2018) Transferability of lidar-derived basal area and stem density models within a northern Idaho ecoregion. *Canadian Journal of Remote Sensing* 44(2): 131-143.

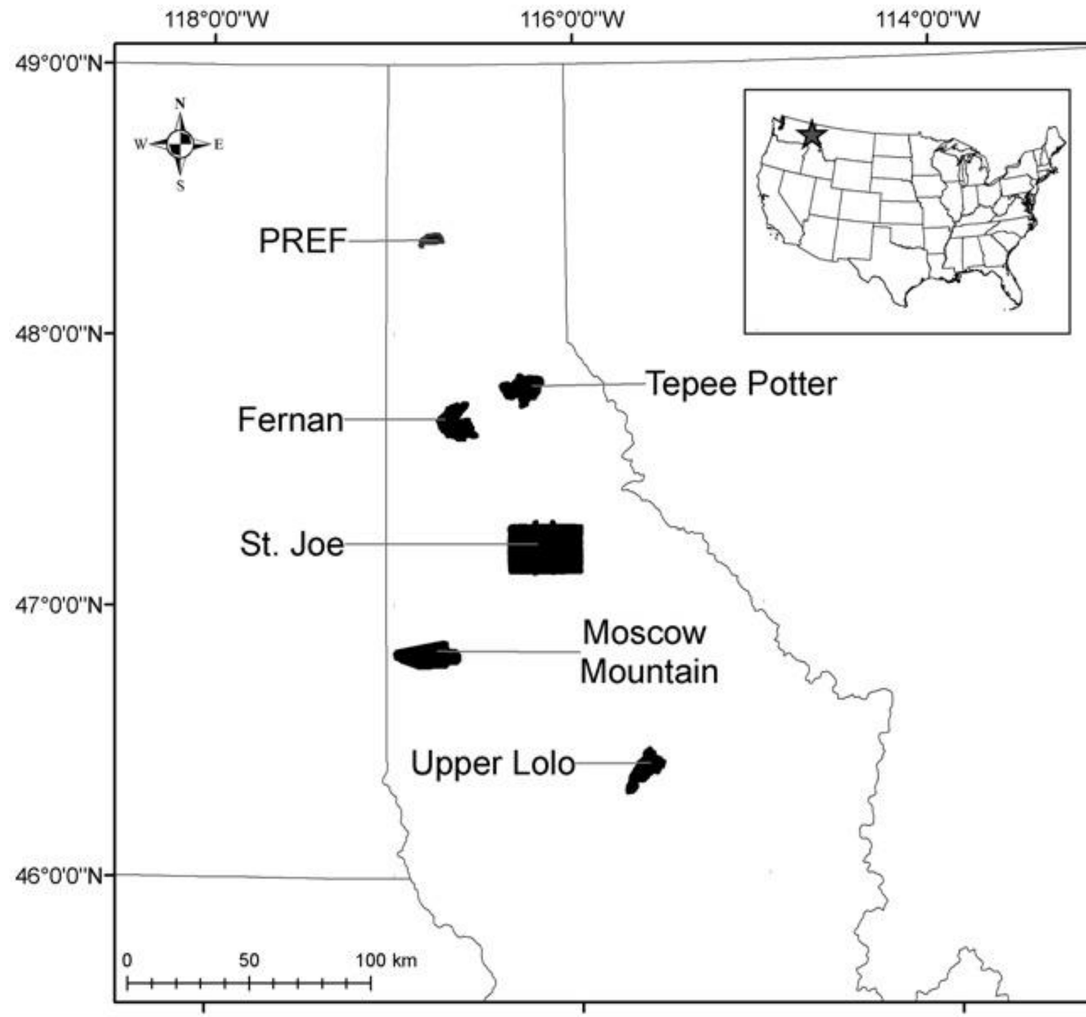


Table 1. Field data collection parameters.

Field dataset	n	Year	Lidar unit	Plot Area (m^2)	Plot design	Sampling design
CdA-East	24	2015	Tepee Potter	400	Fixed radius	Stratified by elevation, transformed aspect, and wetness
CdA-West	10	2015	Fernan	400	Fixed radius	Stratified by elevation, transformed aspect, and wetness
Moscow Mtn.	85	2009	Moscow Mtn.	400	Fixed radius	Stratified by elevation, solar insolation, and NDVIc
PREF	96	2011	PREF	400	Fixed radius	Stratified by forest type and canopy cover
St. Joe	79	2003-2004	St. Joe	400	Fixed radius	Stratified by elevation and solar insolation
Tepee Potter	39	2014	Tepee Potter	400	Fixed radius	Stratified by elevation, solar insolation, and NDVI
Upper Lolo	27	2007	Upper Lolo Creek	400	Fixed radius	Stratified by elevation, transformed aspect, and NDVIc

Note: CDA-East and CDA-West were part of the same data collection exercise. Both Tepee Potter and Fernan lidar units were combined for the stratification.

Imputation vs Regression Models

- Regression generates unique predictions based on the best model fit to a single response variable
- Imputation is weighted by the relationship between multiple response variables and multiple predictors.
- Imputations are the values observed at the reference plots assigned to unsampled locations.
- Regression predictions have a better fit to observations than imputations
- An advantage of imputation is the ability to predict ancillary variables.

Table 4. Potential explanatory variables.

Description of explanatory variables	Data source	
H05Pct: Height 5th percentile	FUSION	Height
H25Pct: Height 25th percentile	FUSION	
H50Pct: Height 50th percentile	FUSION	
H75Pct: Height 75th percentile	FUSION	
H95Pct: Height 95th percentile	FUSION	
Hmean: Height mean	FUSION	
Hstdv: Height standard deviation	FUSION	
Hskew: Height skewness	FUSION	
Hkurt: Height kurtosis	FUSION	
CRR: Canopy relief ratio (McGaughey 2016)	FUSION	
Stratum 0: Percentage lidar returns <0.15 m	FUSION	Density
Stratum 1: Percentage lidar returns >0.15 m and <1.37 m	FUSION	
Stratum 2: Percentage lidar returns >1.37 m and <5.0 m	FUSION	
Stratum 3: Percentage lidar returns >5 m and <10 m	FUSION	
Stratum 4: Percentage lidar returns >10 m and <20 m	FUSION	
Stratum 5: Percentage lidar of returns >20 m and ≤0 m	FUSION	
Stratum 6: Percentage lidar of returns >30 m	FUSION	
Pct1Rtn_1.37: Percentage lidar first returns above 1.37 m	FUSION	
Pct1Rtn_mean: Percentage lidar first returns above height mean	FUSION	
Elev: DTM elevation at 20 m resolution	FUSION	Topographic
Slope: Percent slope at 20 m resolution	FUSION	
TrAsp: Transformed aspect at 20 m resolution	Calculated in R	
SCOSA: Slope cosine aspect transformation	Calculated in R	
SSINA: Slope sine aspect transformation	Calculated in R	
GlobRadEquinox: Radiance estimate on 23 Sept	GRASS	
accumulation: Hydrologic flow accumulation	GRASS	
tci: Topographic convergence index	GRASS	
twi: Topographic wetness index	GRASS	

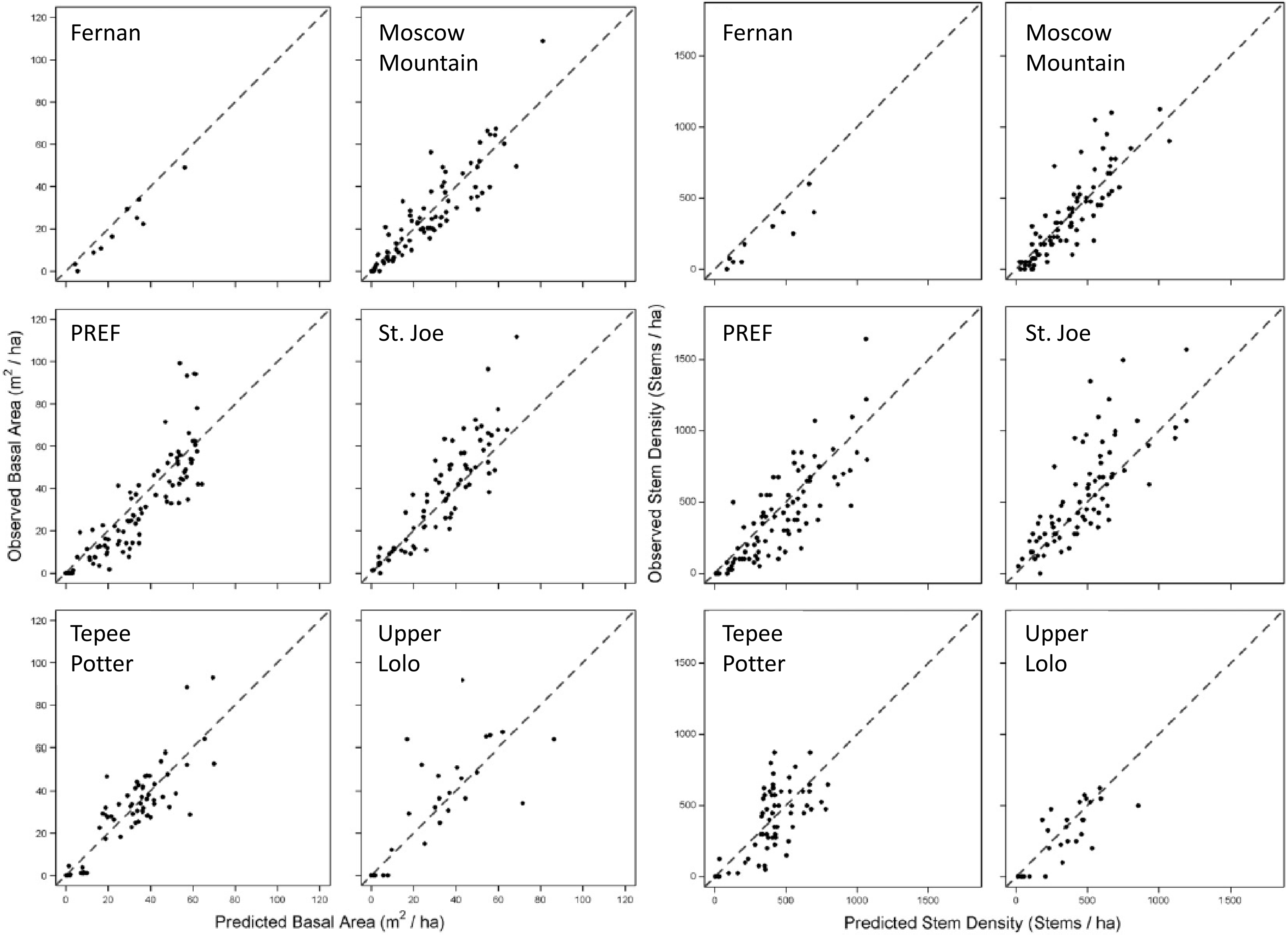
Table 5. Explanatory variables used in basal area and stem density random forests models.[a]

	Basal Area						Stem Density					
Explanatory Variable	Fernan	Moscow Mtn.	PREF	St. Joe	Tepee Potter	Upper Lolo	Fernan	Moscow Mtn.	PREF	St. Joe	Tepee Potter	Upper Lolo
H05Pct	X		X	X	X	X	X	X	X	X	X	X
H95Pct	X		X	X	X	X						
Hmean		X										
Pct1Rtn_mean	X	X	X	X	X	X	X	X	X	X	X	X
Stratum 0								X			X	
Stratum 1	X			X	X		X	X	X	X	X	X
Stratum 2			X									
Stratum 3										X		
Stratum 4	X	X	X	X	X		X	X	X	X	X	X
Stratum 5	X	X	X	X	X	X	X	X	X		X	X
Stratum 6		X										

Note: X: selected variable. [a]See Table 4 for description of explanatory variables.

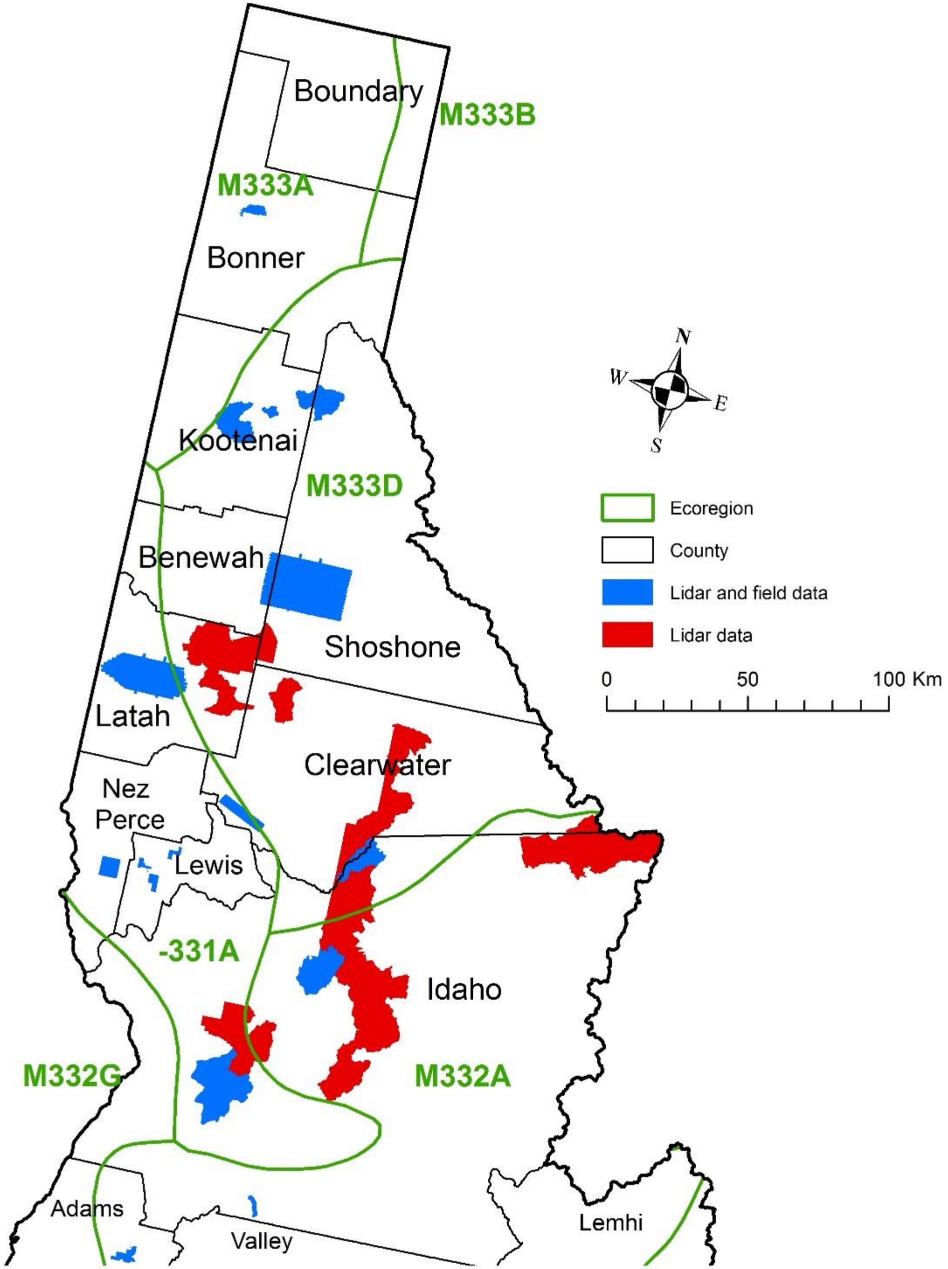
Table 6. Median cross-validated model fit statistics (and standard deviation) for basal area and stem-density models.

Response	Model	Variance Explained (%)	SD (%)	RMSE% (%)	SD (%)
Basal area	Fernan	76.9	(1.0)	35.2	(5.6)
	Moscow Mountain	73.3	(1.1)	34.9	(6.8)
	PREF	76.7	(0.9)	32.0	(6.7)
	St. Joe	76.8	(1.2)	35.2	(6.9)
	Tepee Potter	76.7	(1.0)	36.9	(6.4)
	Upper Lolo	79.1	(0.8)	32.5	(5.0)
Stem density	Fernan	65.6	(1.3)	42.5	(5.5)
	Moscow Mountain	64.4	(1.4)	43.7	(7.1)
	PREF	61.8	(1.5)	44.7	(6.9)
	St. Joe	65.5	(1.0)	43.8	(8.4)
	Tepee Potter	69.1	(1.1)	42.4	(7.7)
	Upper Lolo	65.6	(1.3)	43.9	(6.6)

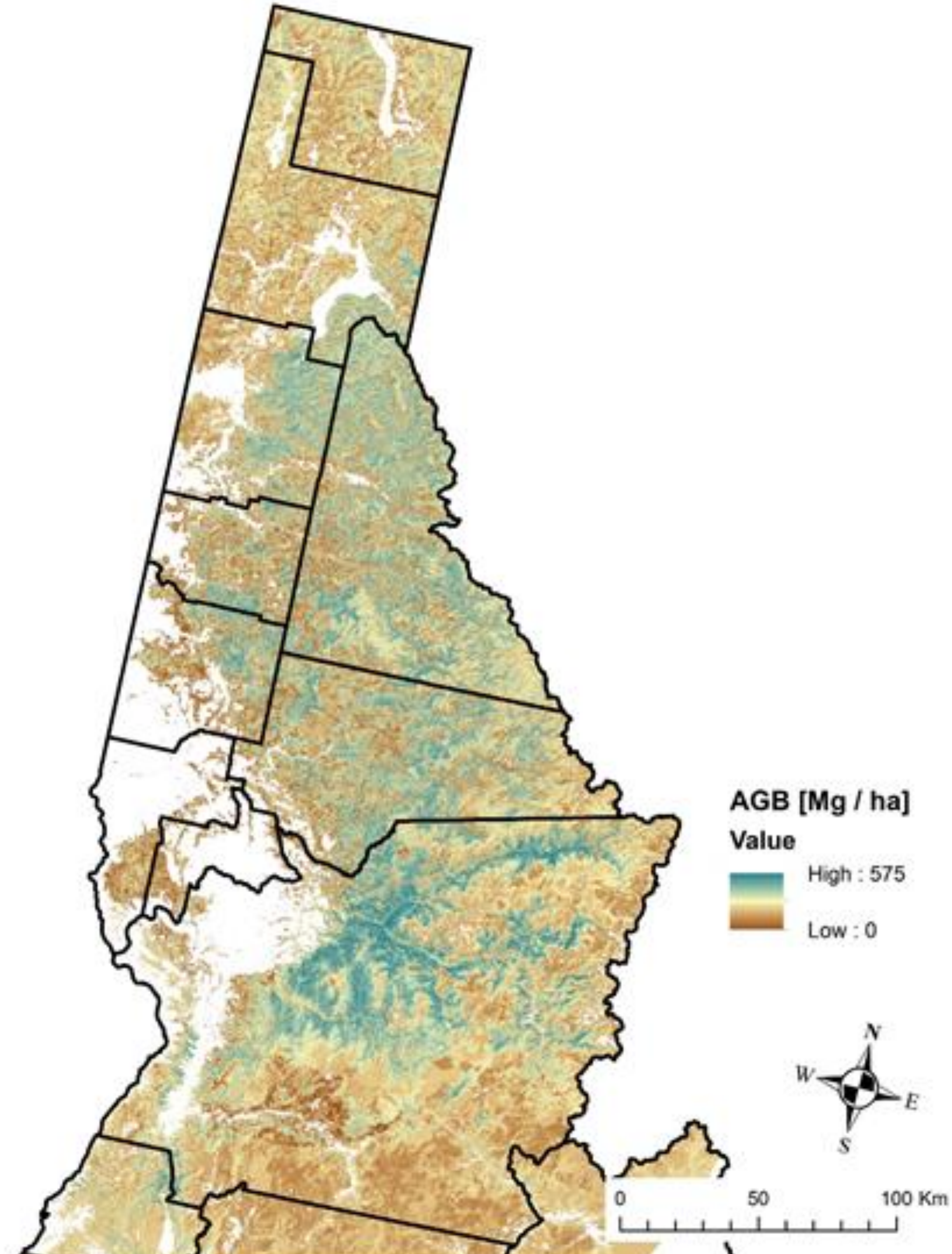


Fekety et al. (2018) *Canadian Journal of Remote Sensing* 44(2): 131-143.

Expanding LiDAR Coverages



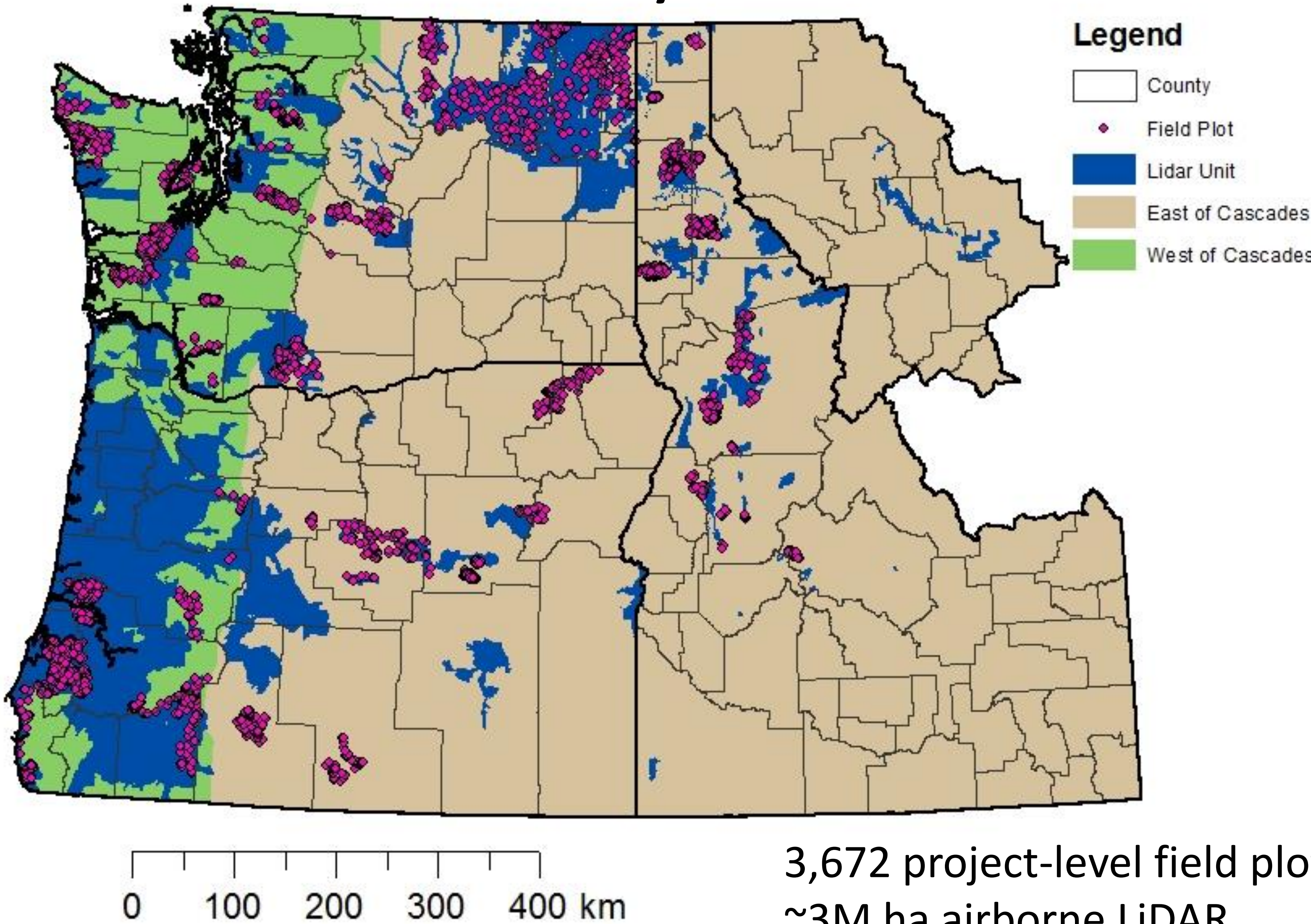
Regional Forestry Study



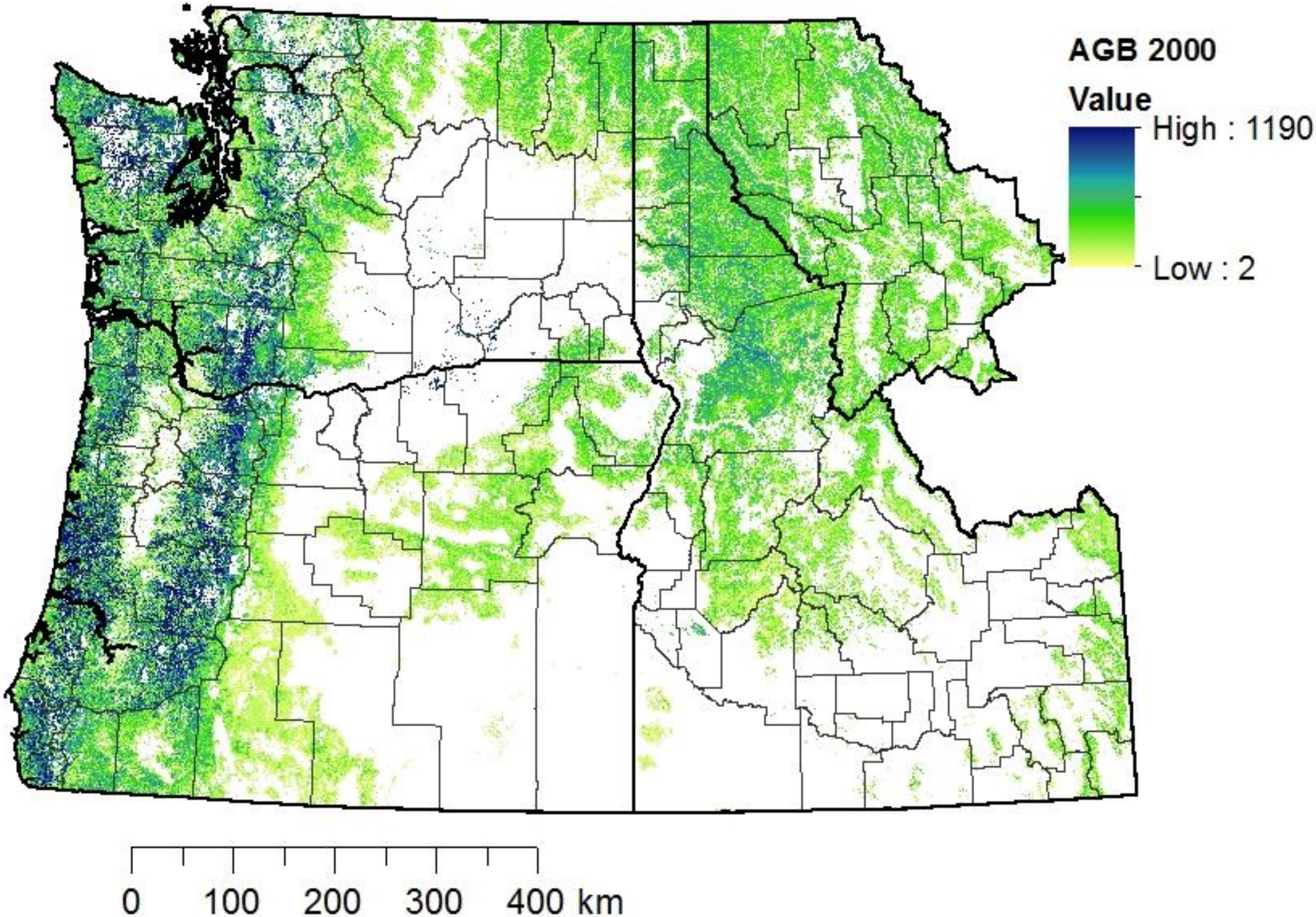
Current Work

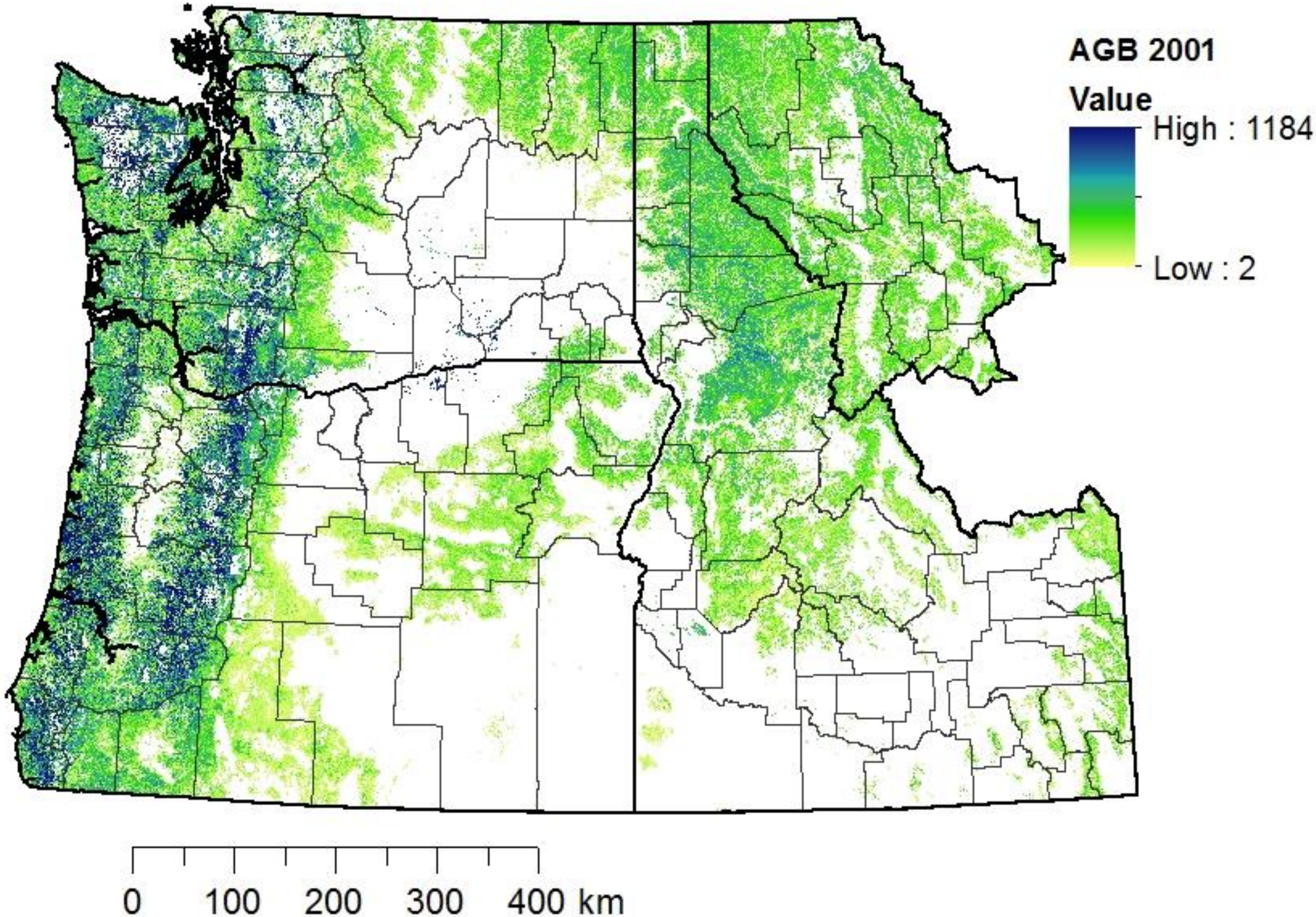
- Predicting AGB across large spatial extents from annual Landsat image time series
  - Use LiDAR-mapped 30m AGB pixels as reference data
  - Use 30m Landsat pixels without lidar as target data
- Instead of topographic predictors, using climate predictors
  - To capture regional environmental gradients that drive productivity across the Inland and Pacific Northwest
  - To allow for future AGB projections under climate change scenarios

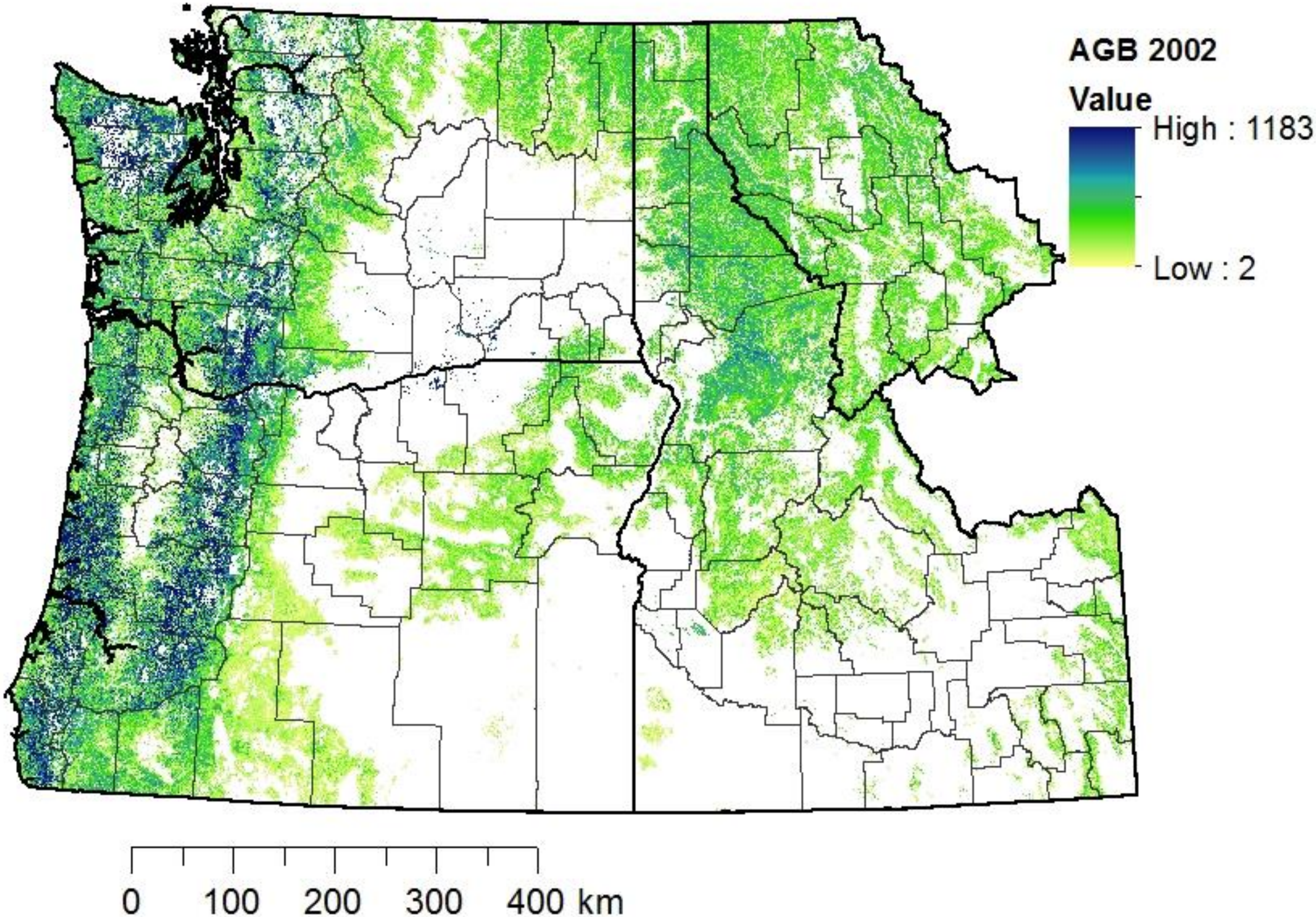
Study Area



3,672 project-level field plots
~3M ha airborne LiDAR


AGB 2000
Value
High : 1190
Low : 2
0
100
200
300
400 km


AGB 2001
Value
High : 1184
Low : 2
0
100
200
300
400 km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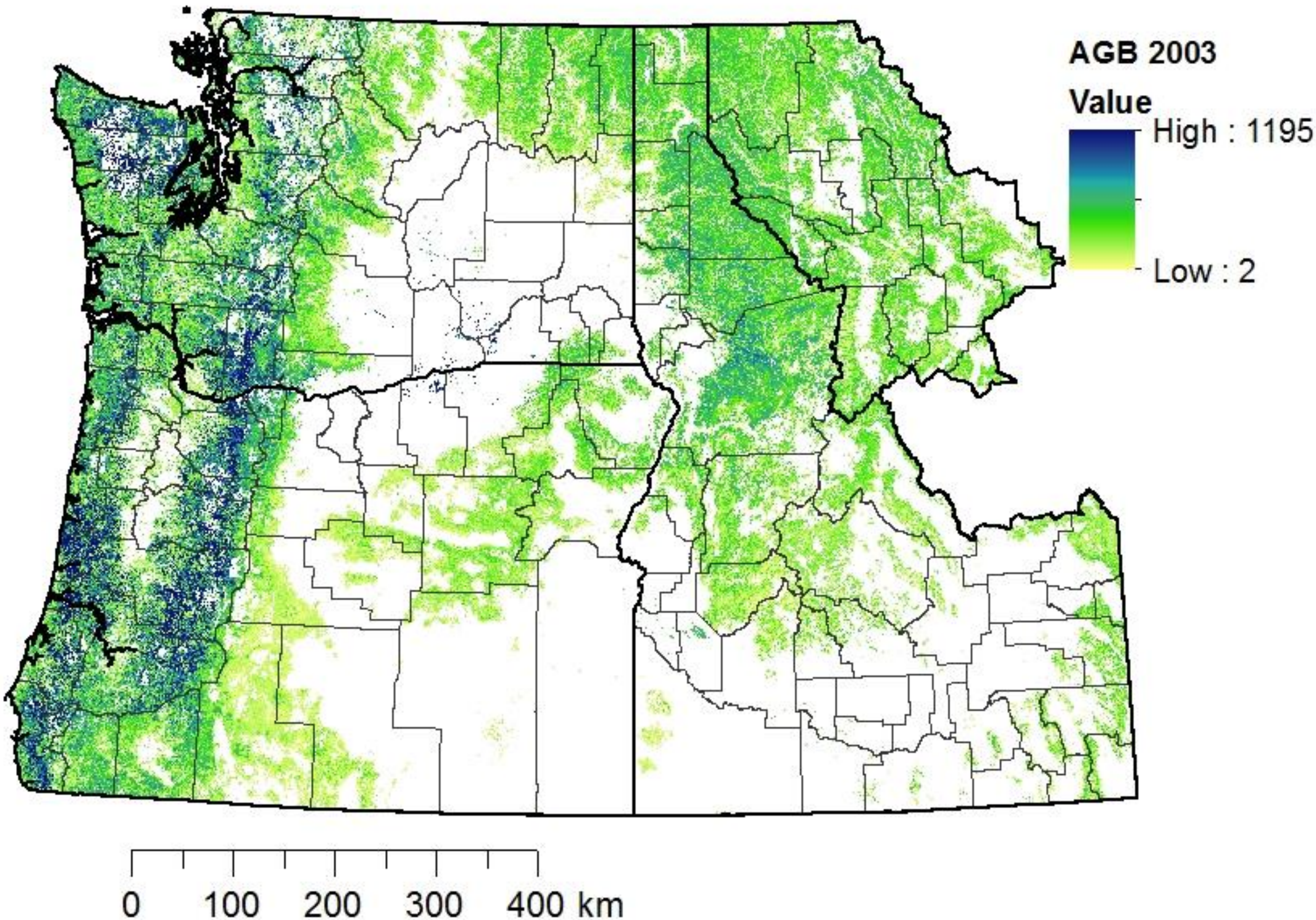
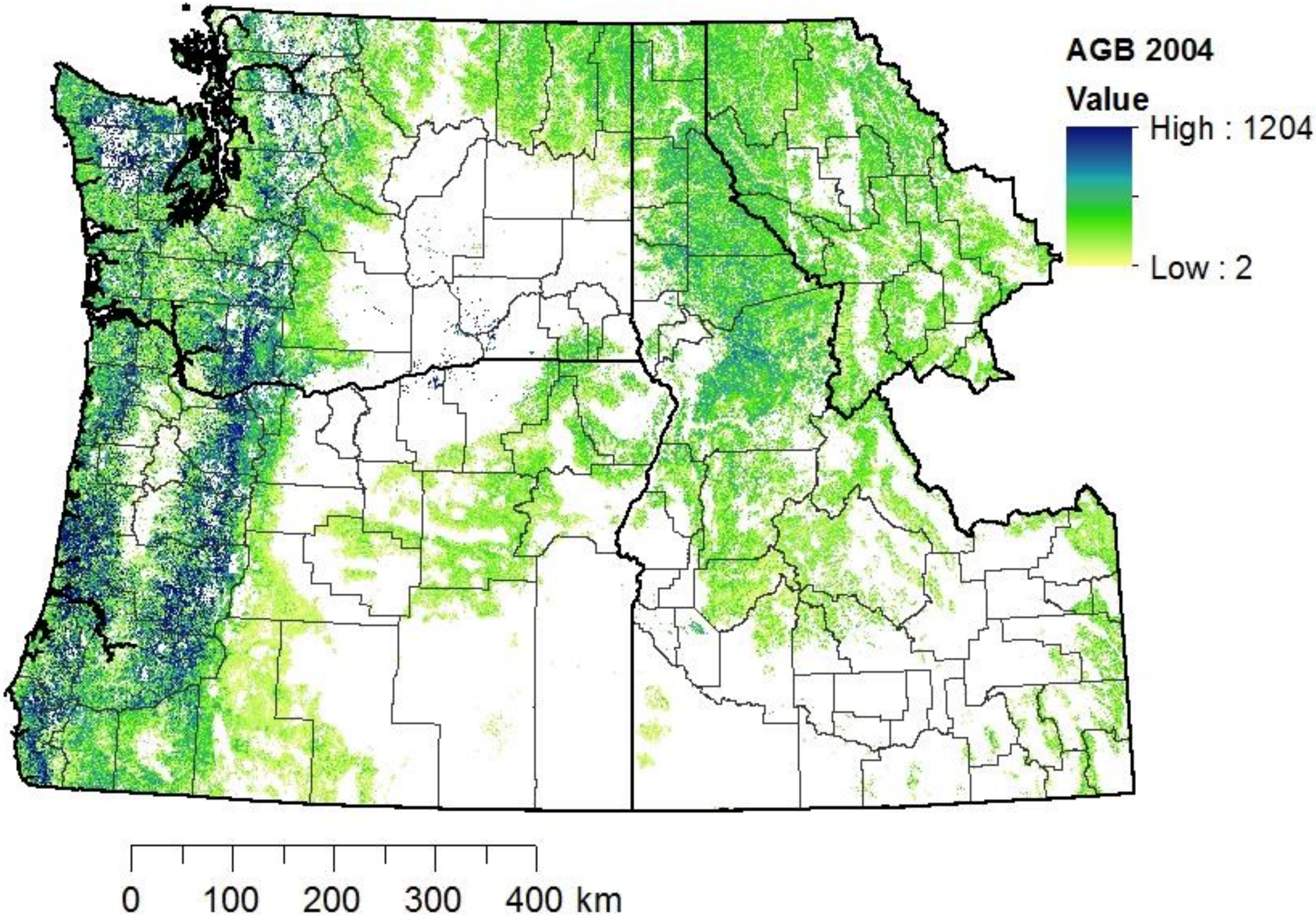
Value
High : 1183
Low : 2
0
100
200
300
400 km



AGB 2003
Value
High : 1195
Low : 2
0
100
200
300
400 km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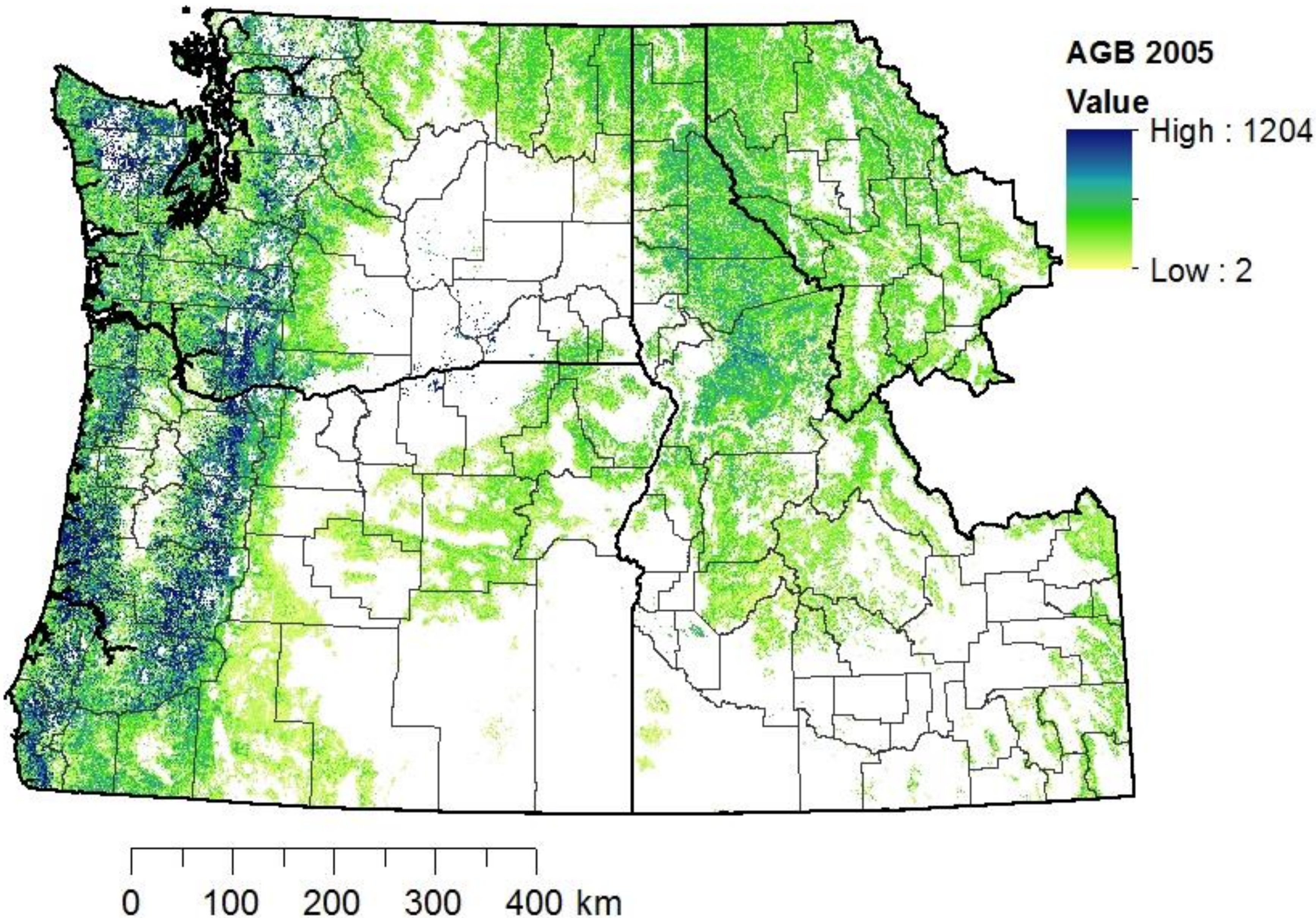
Value
High : 1204
Low : 2
0
100
200
300
400 km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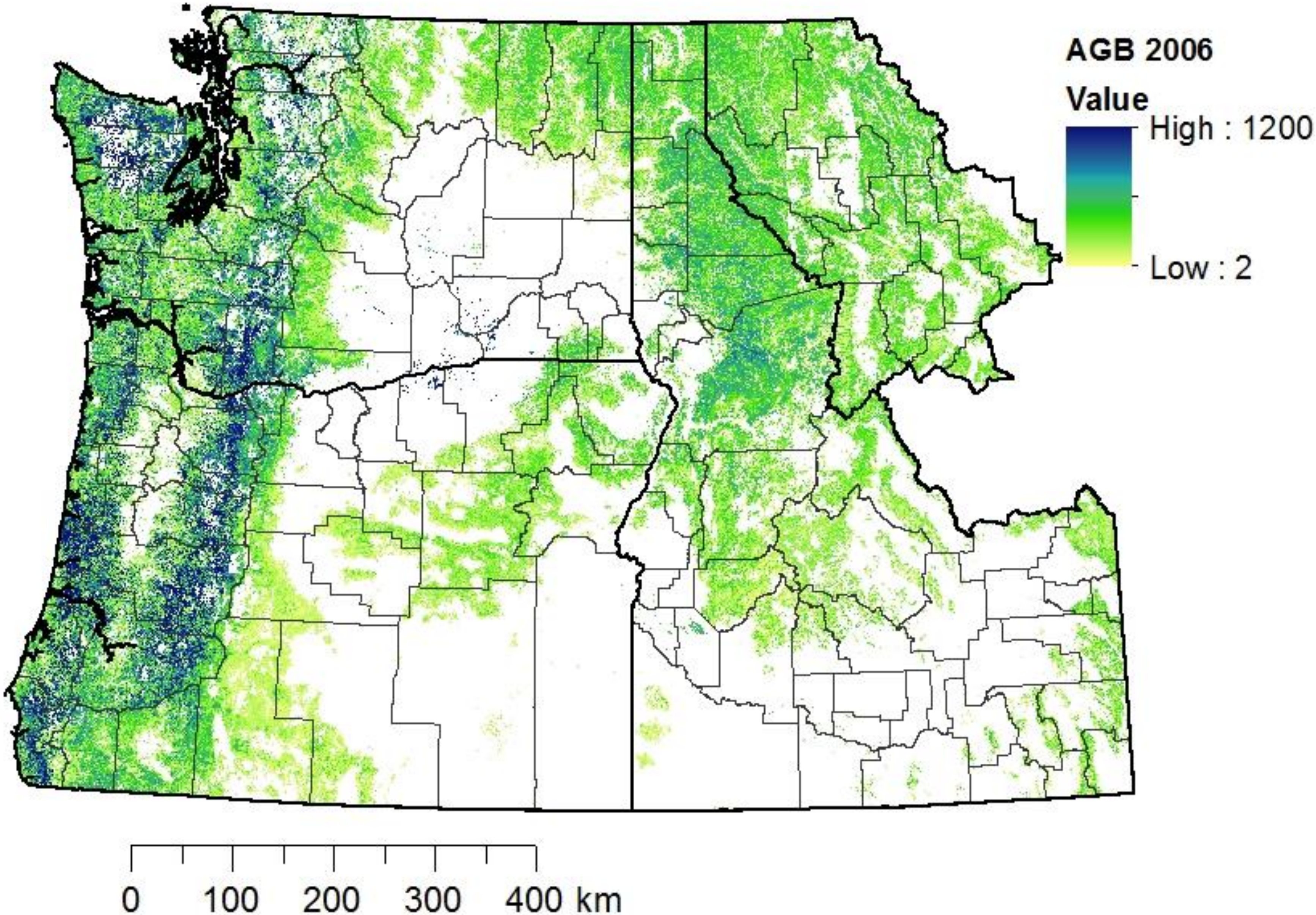
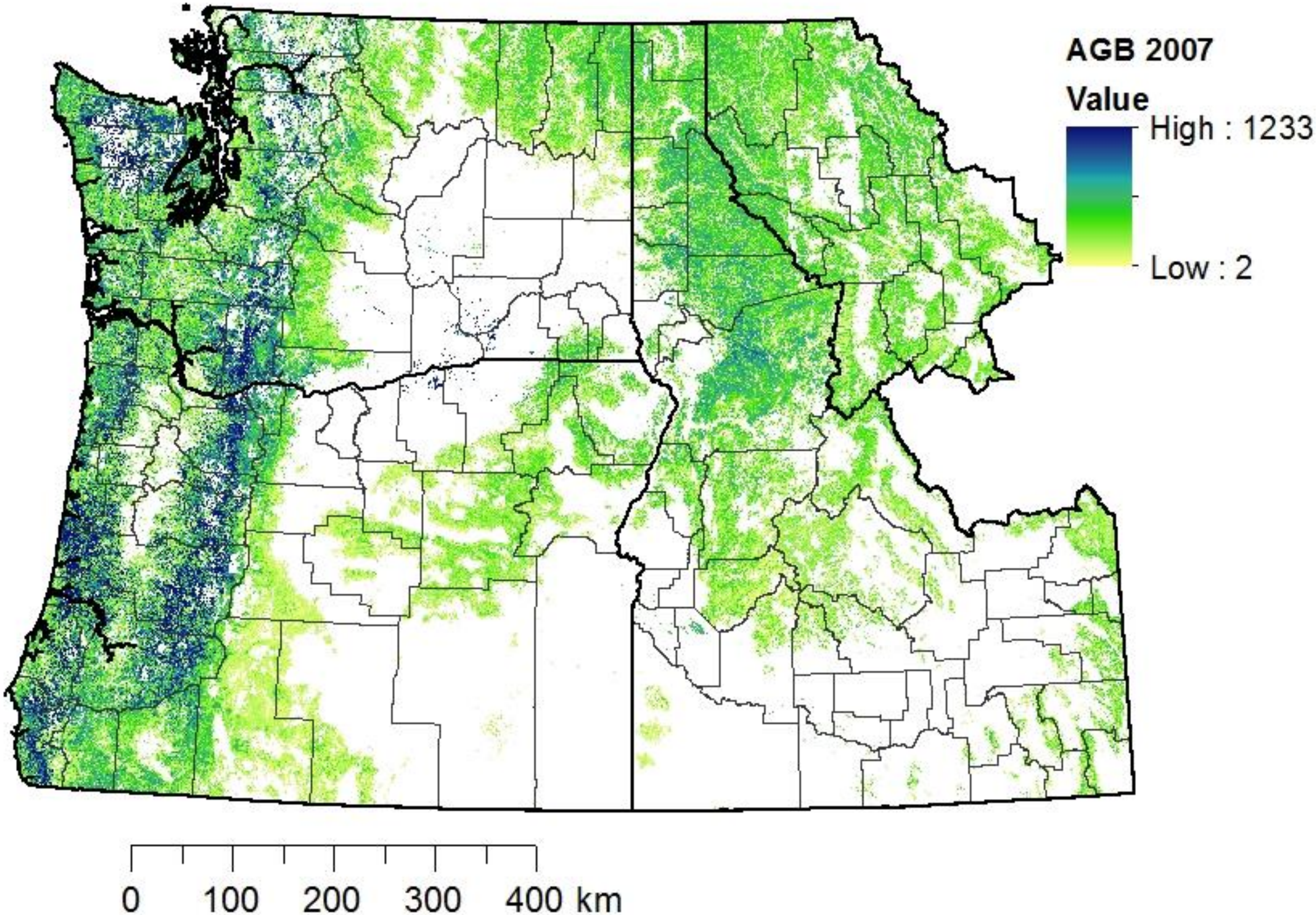
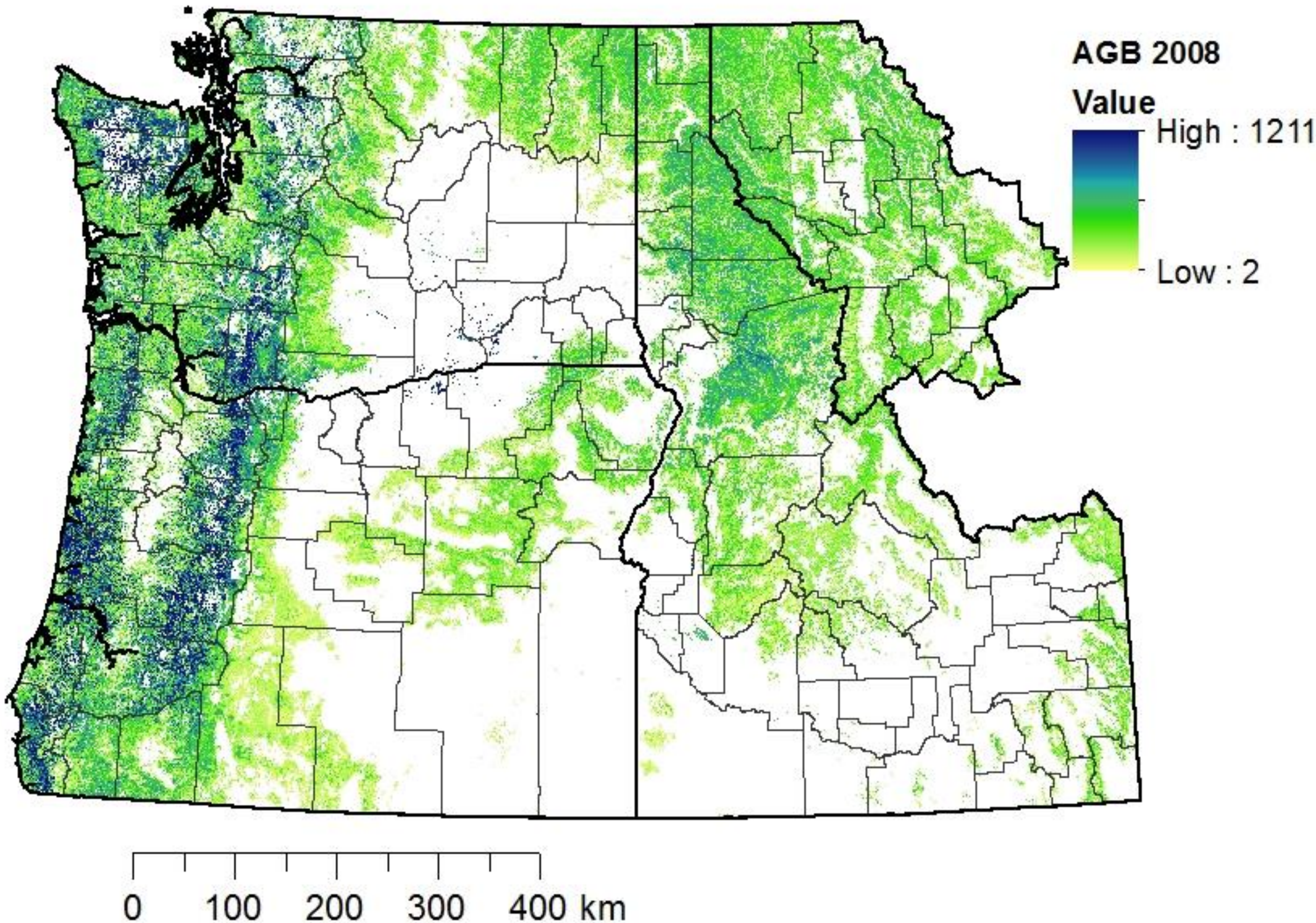
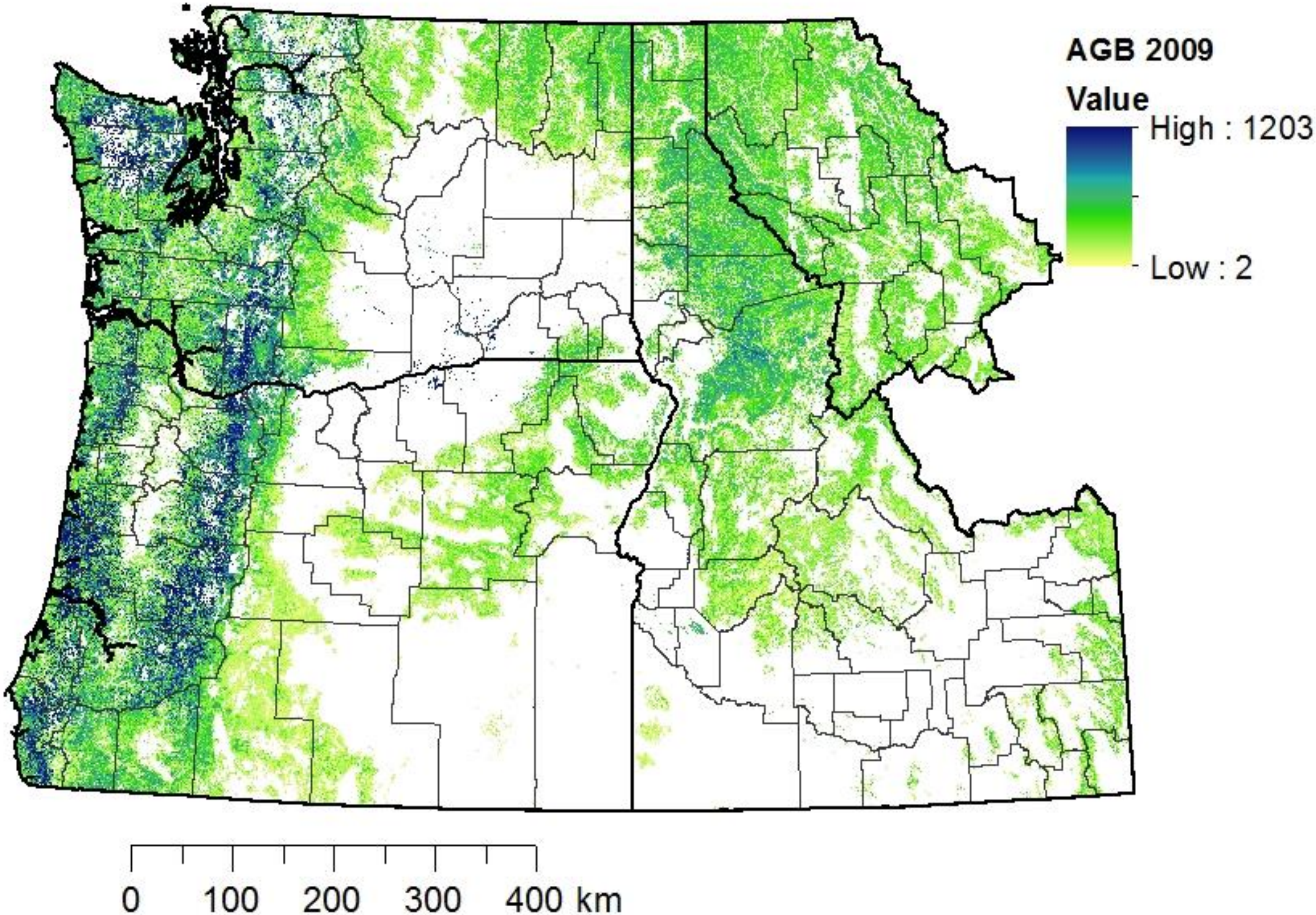
Value
High : 1204
Low : 2
0
100
200
300
400 km


AGB 2006
Value
High : 1200
Low : 2
0
100
200
300
400 km


AGB 2007
Value
High : 1233
Low : 2
0
100
200
300
400 km


AGB 2008
Value
High : 1211
Low : 2
0
100
200
300
400 km


AGB 2009
Value
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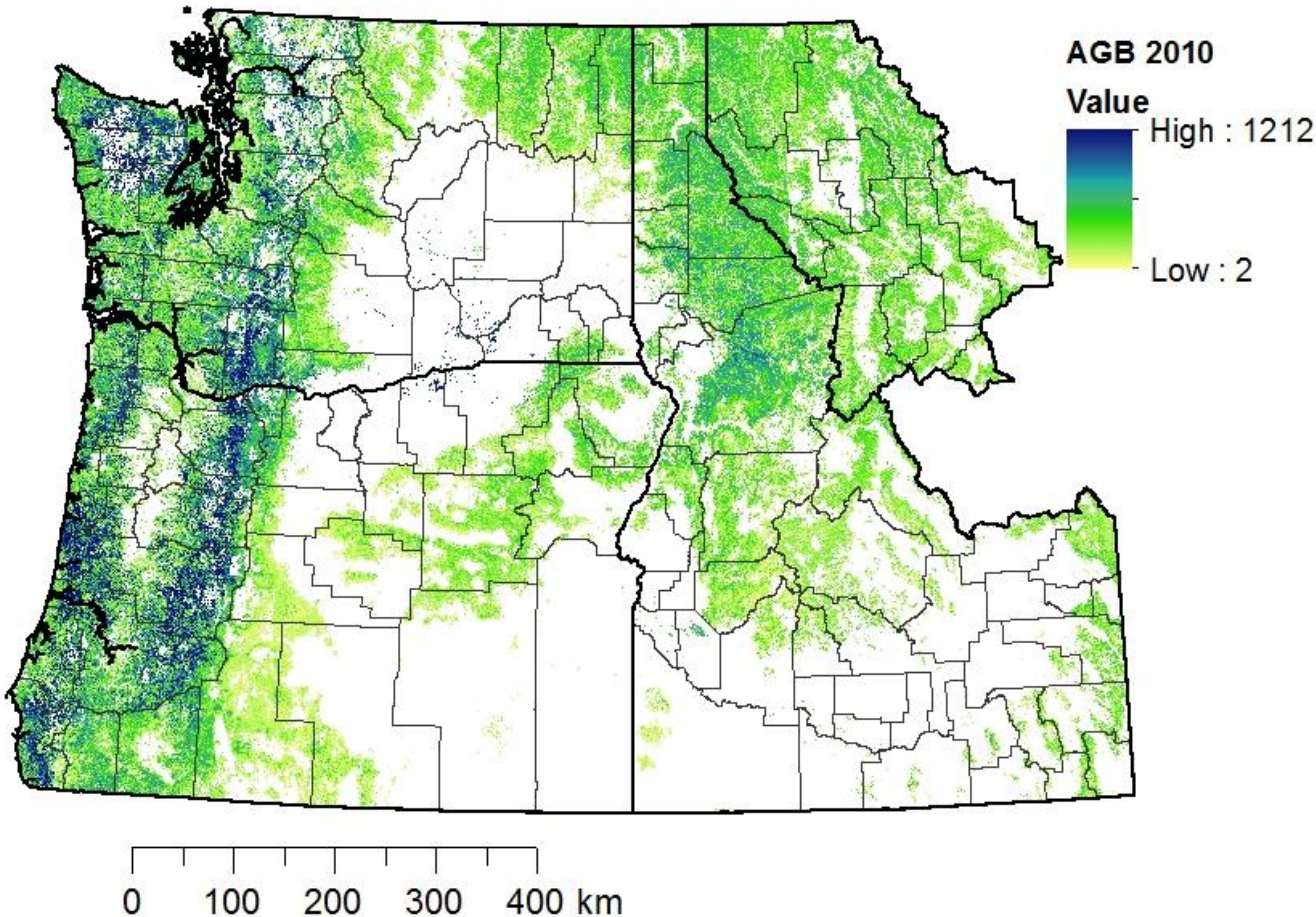
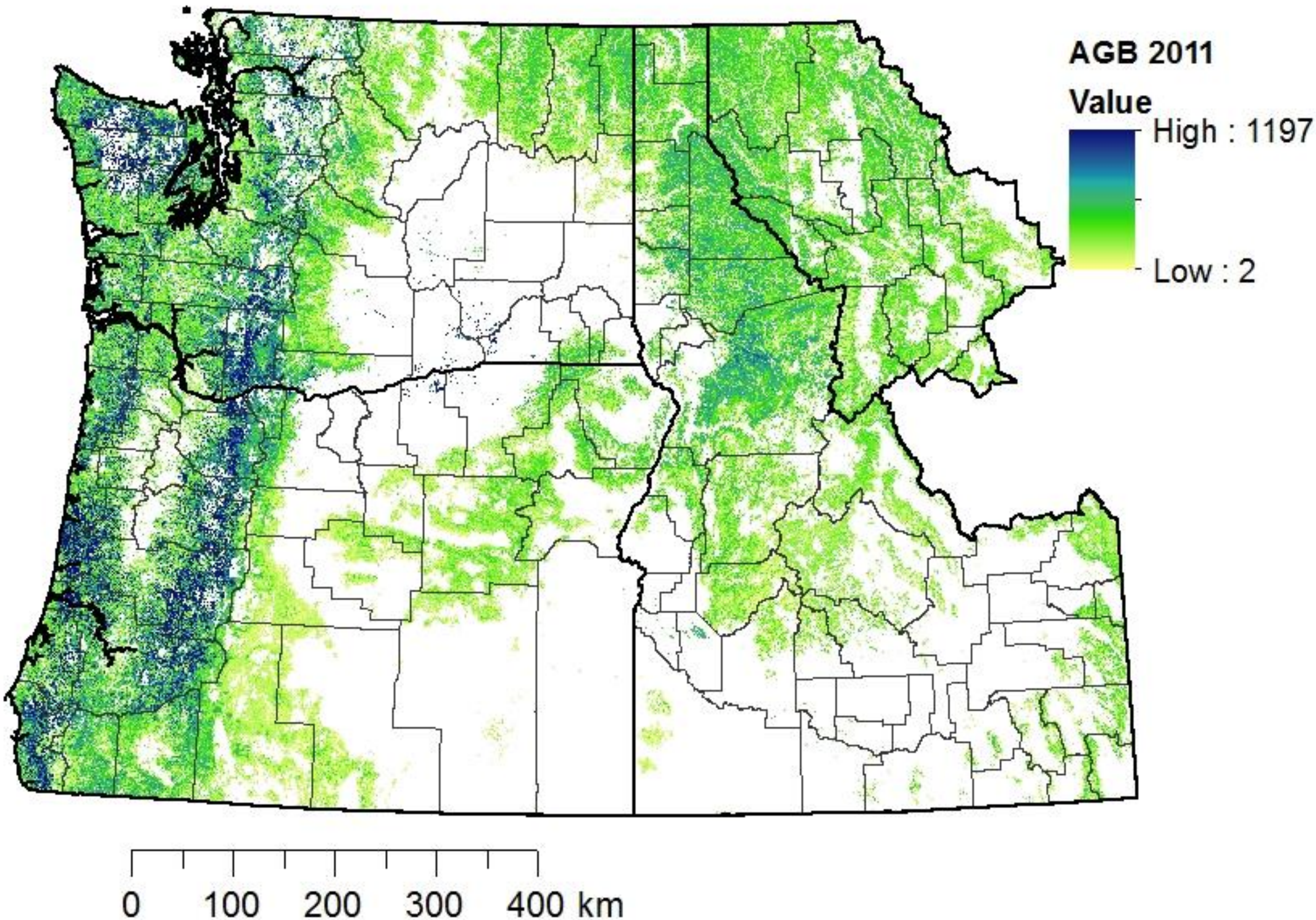
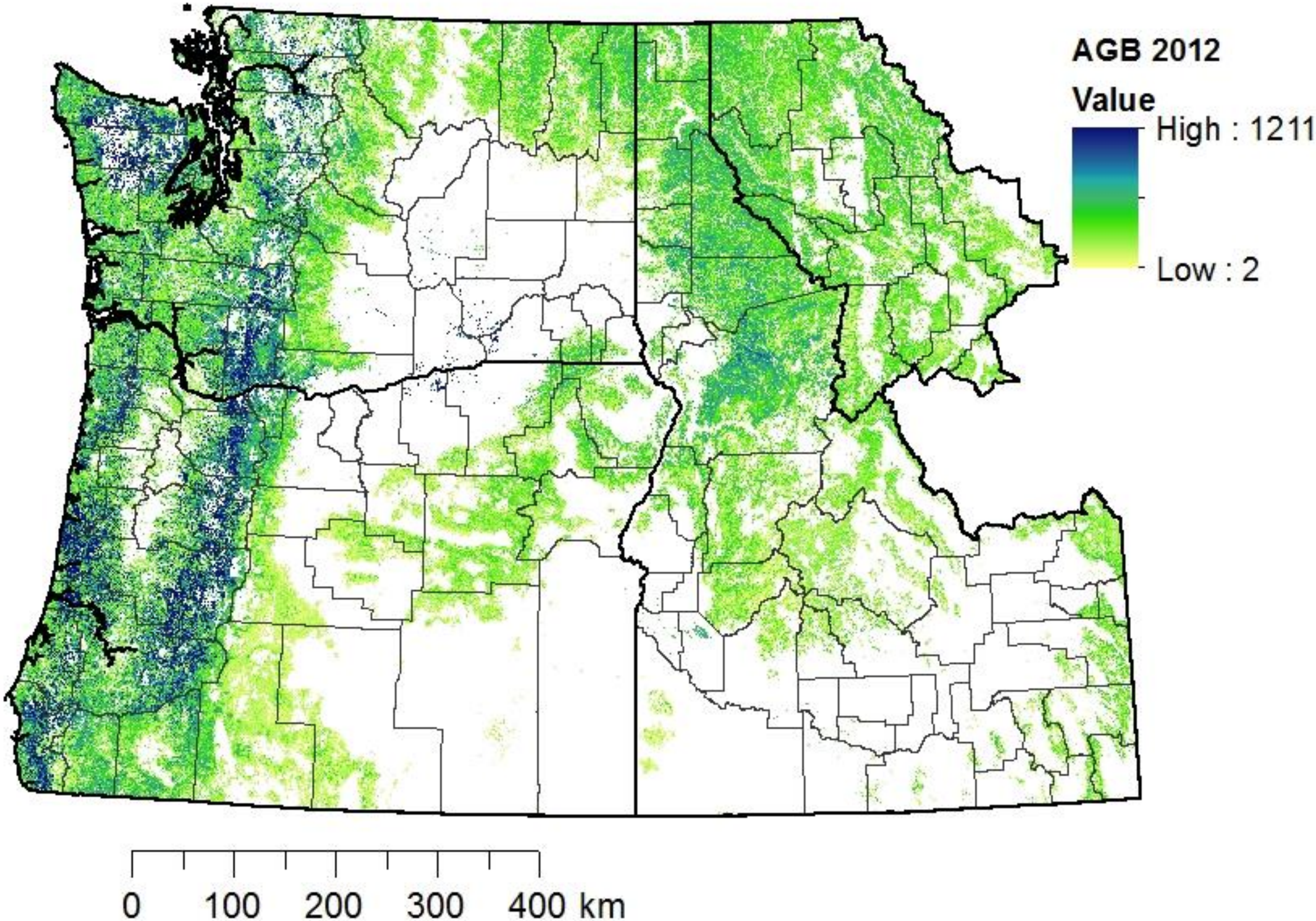
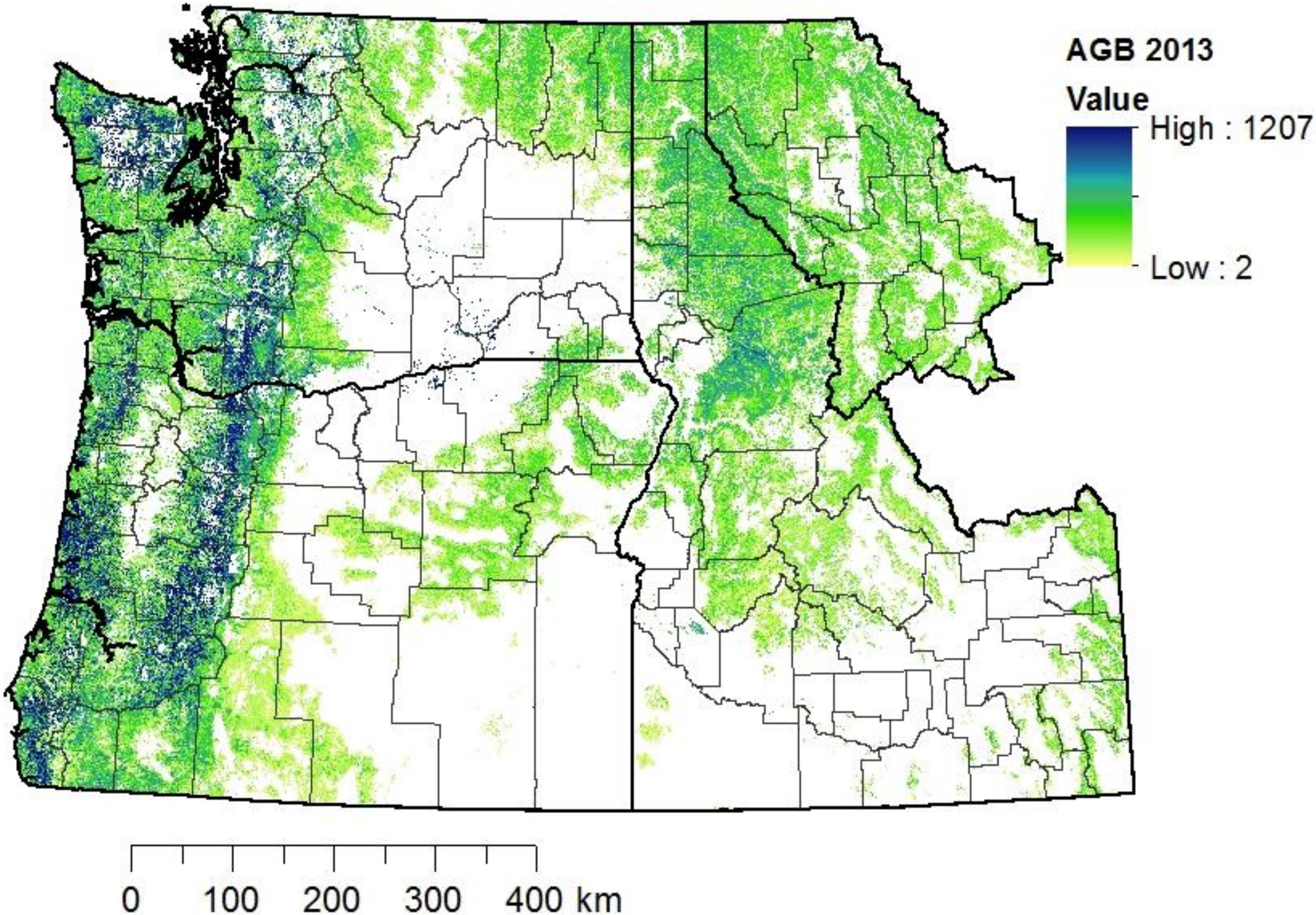
Low : 2
0
100
200
300
400 km

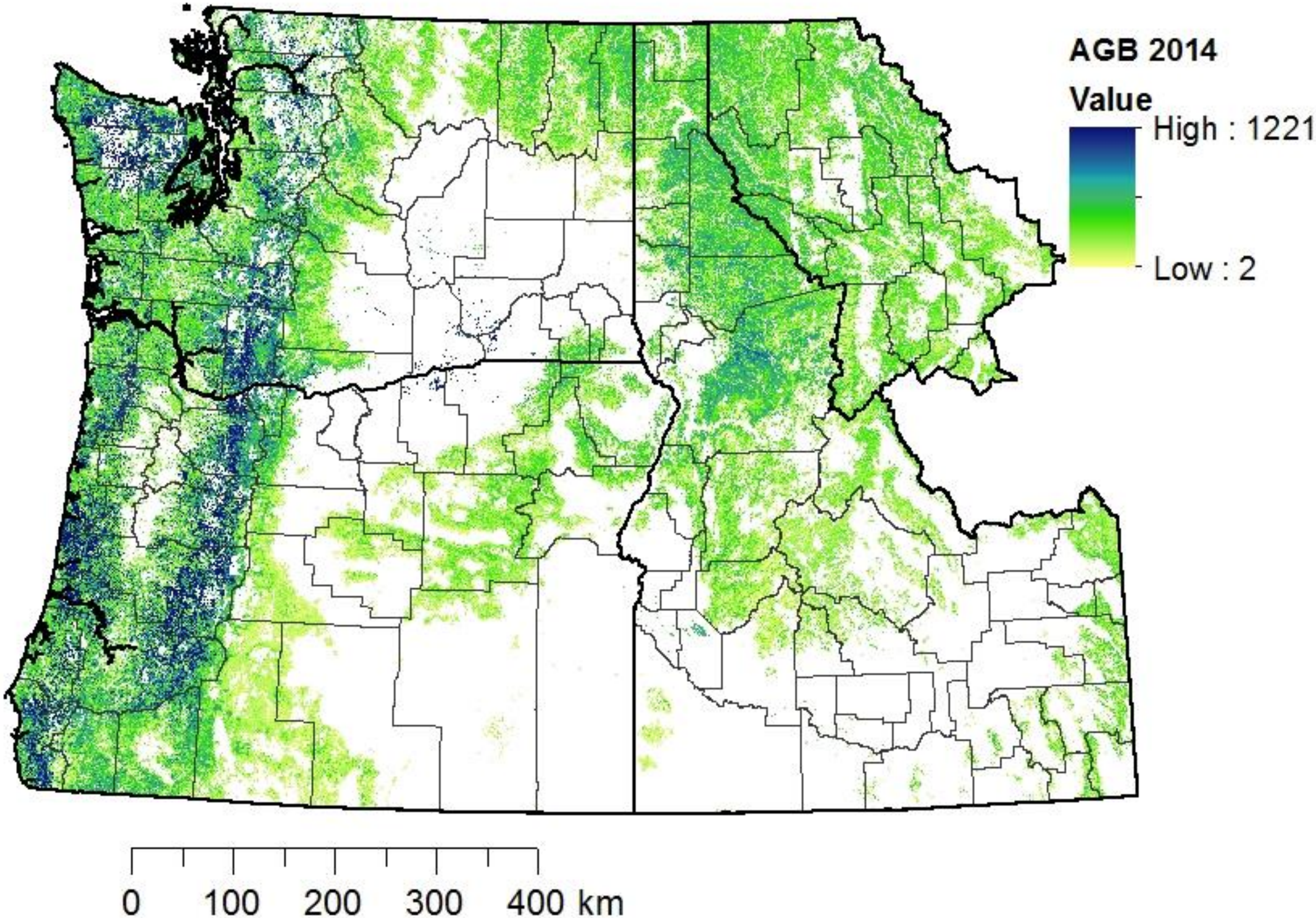

AGB 2010
Value
High : 1212
Low : 2
0
100
200
300
400 km

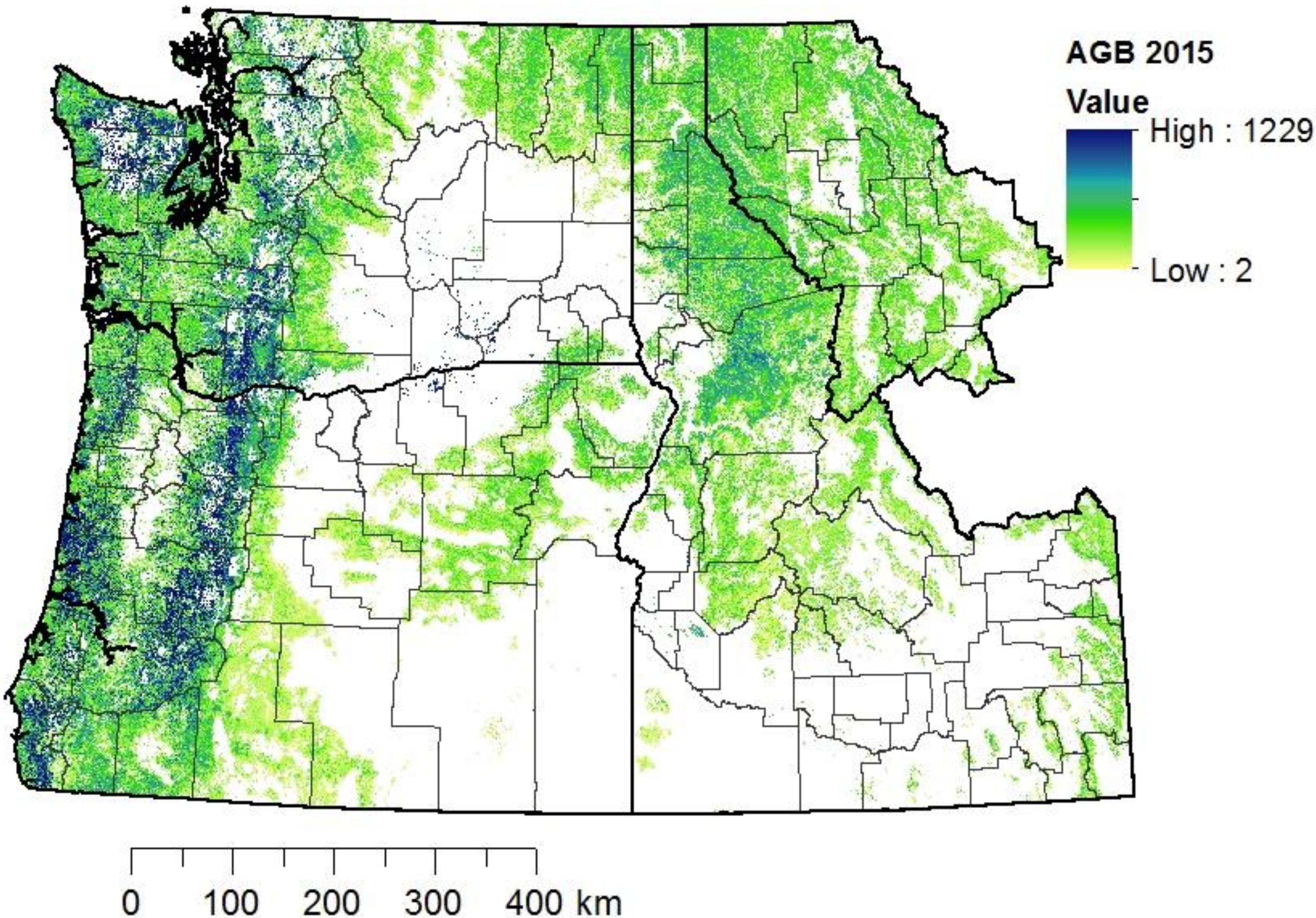

AGB 2011
Value
High : 1197
Low : 2
0
100
200
300
400 km

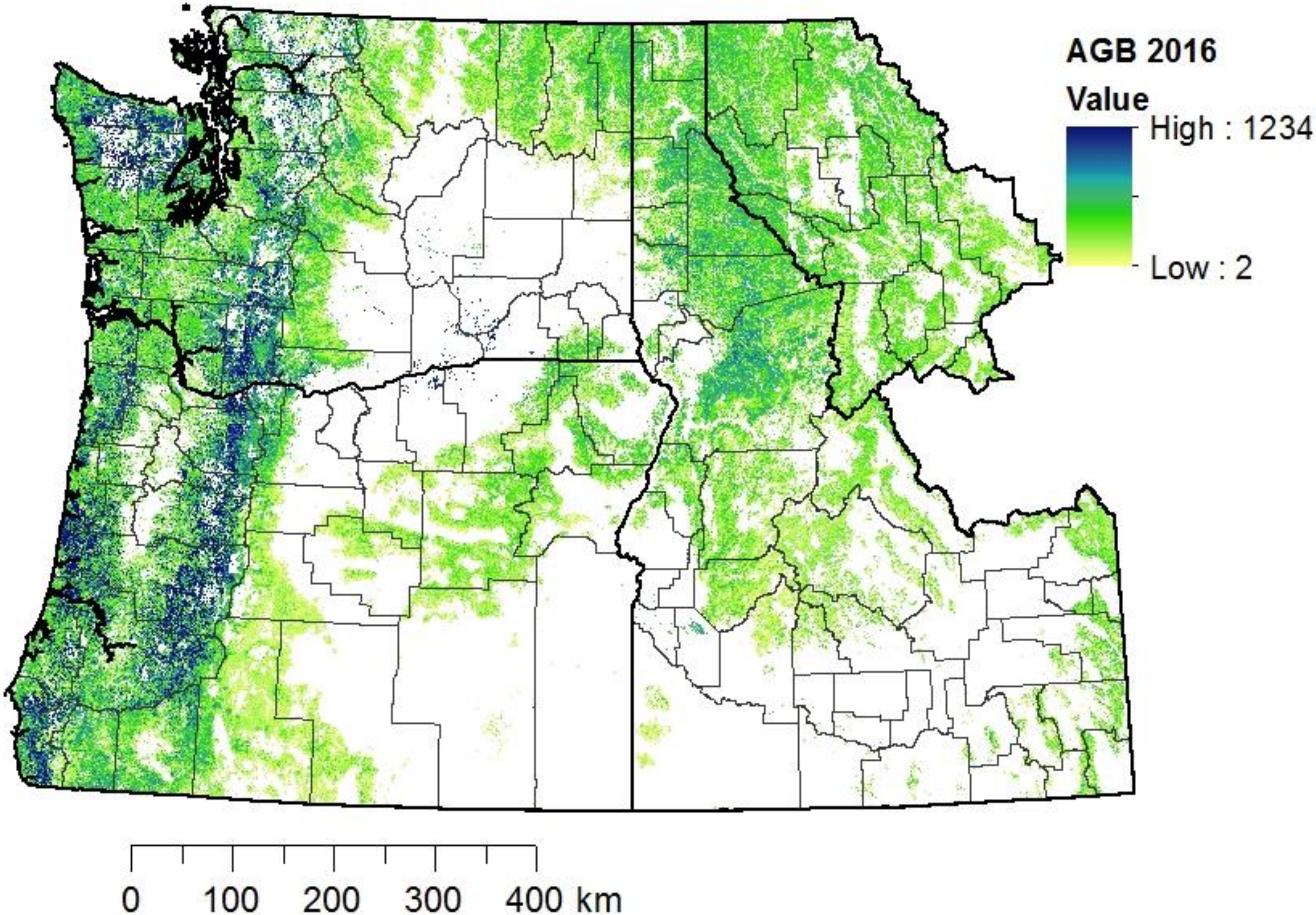

AGB 2012
Value
High : 1211
Low : 2
0
100
200
300
400 km



AGB 2013
Value
High : 1207
Low : 2
0
100
200
300
400 km


AGB 2014
Value
High : 1221
Low : 2
0
100
200
300
400 km


AGB 2015
Value
High : 1229
Low : 2
0
100
200
300
400 km


AGB 2016
Value
High : 1234
Low : 2
0 100 200 300 400 km

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Questions?