Interdisciplinary spatial modeling of terrain, soils, and productivity: new tools for forest management

CFRU Maine Project Update

CAFS Meeting
Jun 22

WHO AM I?

NM STATE

Associate Professor of Soil Science
Digital Soil Mapping

Environmental Soil Consulting LLC

Owner and Operator

Outline

- Overview
- Why this project?
- Study Area
- What is digital soil mapping?
- Results
- Chris Hennigar - digital soil mapping + site productivity
- Summary and next steps

Overall Project Goals

- Integrate Digital Soil Maps into forest productivity, forest management interpretations, and wet areas mapping
- Develop new digital soil maps (DSM)

Why?

- Forest management can benefit from more precise and higher spatial resolution site and soil information
- Use DSM to help match forest planning activities to site and soil potentials and limitations

Why?

- Advance the CFRU mission of sustainable forest management
  - By increasing the ability to anticipate site accessibility and productivity

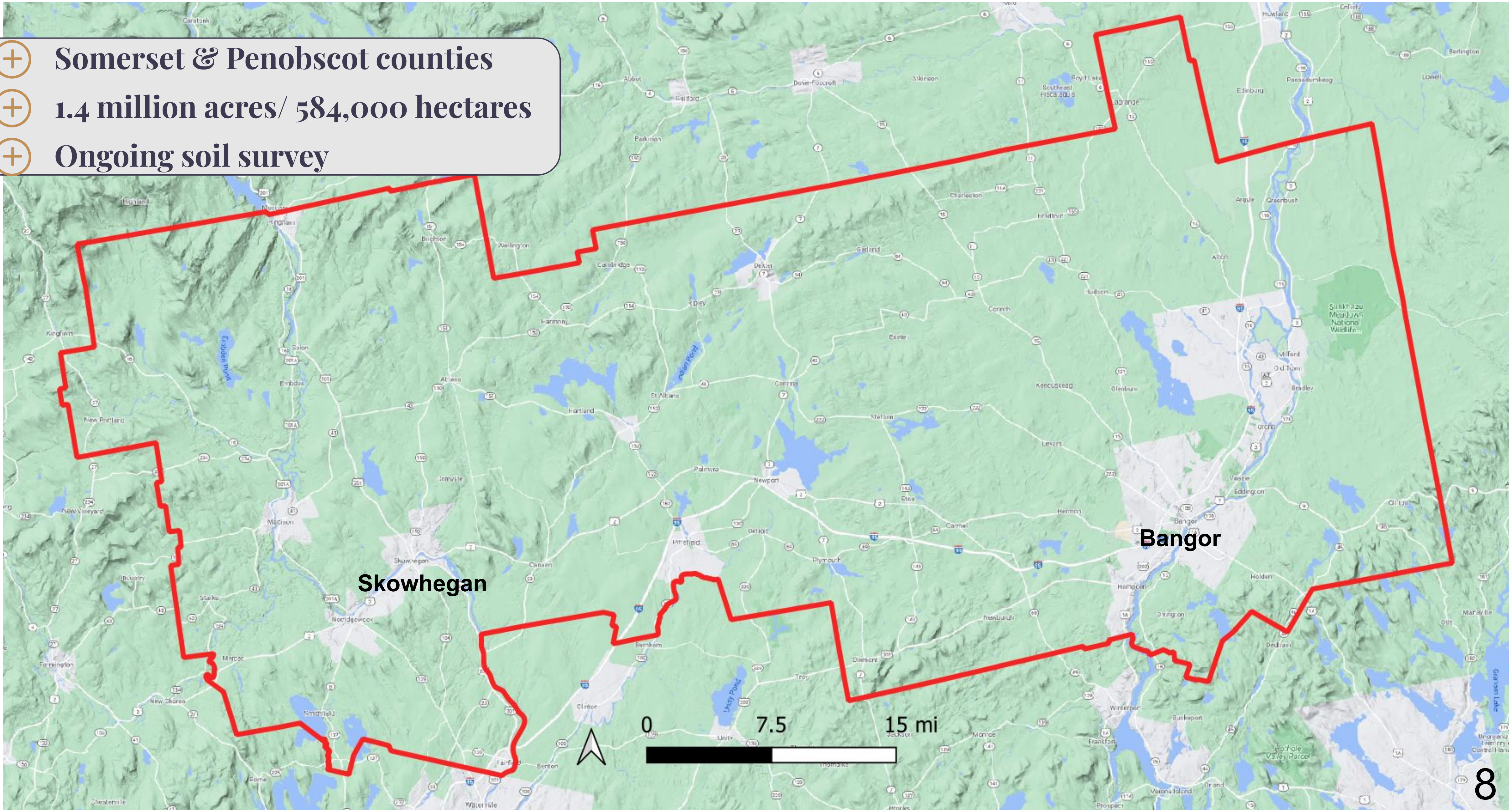
- The proposed methods are at the forefront of research

What?

- Produced Digital Soil Maps (DSM) of key soil properties
- Used DSM as input to harvest suitability interpretations
- Used DSM as input into a Biomass Growth Index & Site Index

Study Area

- Somerset & Penobscot counties
- 1.4 million acres/ 584,000 hectares
- Ongoing soil survey



What is Digital Soil Mapping?

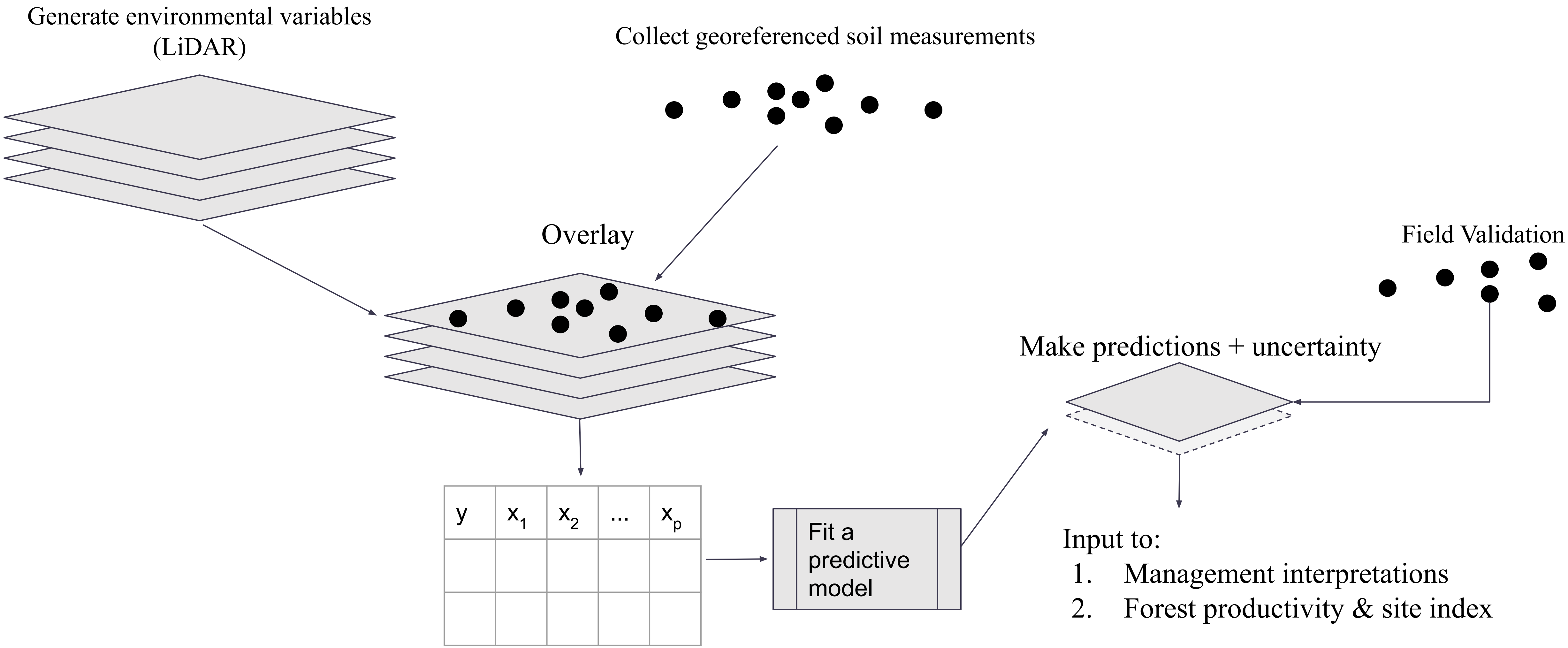
Spatial predictions of high-resolution gridded soil properties

1. Similar to Species Distribution Modeling
2. Quantitatively integrates
    a. Environmental variable data layers
    b. Georeferenced soil profile measurements

Benefits

1. Gridded (raster)
    a. Higher resolution
    b. Easier to integrate than NRCS soil maps
2. Transparent uncertainty
3. Easier to update

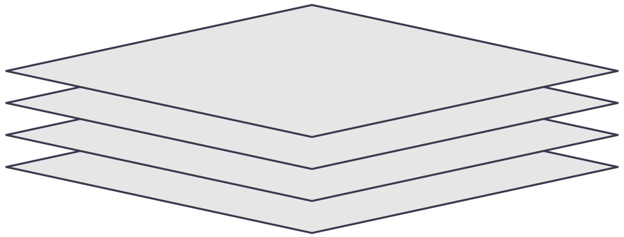
How does Digital Soil Mapping work?

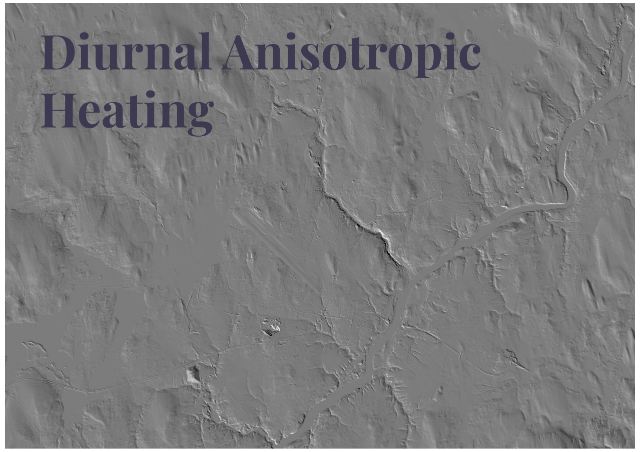


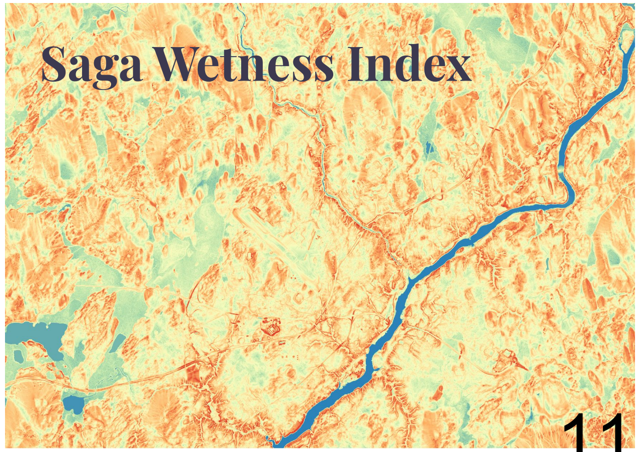
Environmental Variables

- 141 variables
- LIDAR Digtial Elevation Model (5 m)
- Landsat image

Generate environmental variables (LiDAR)

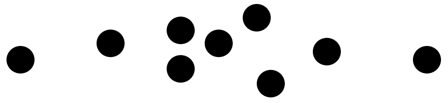




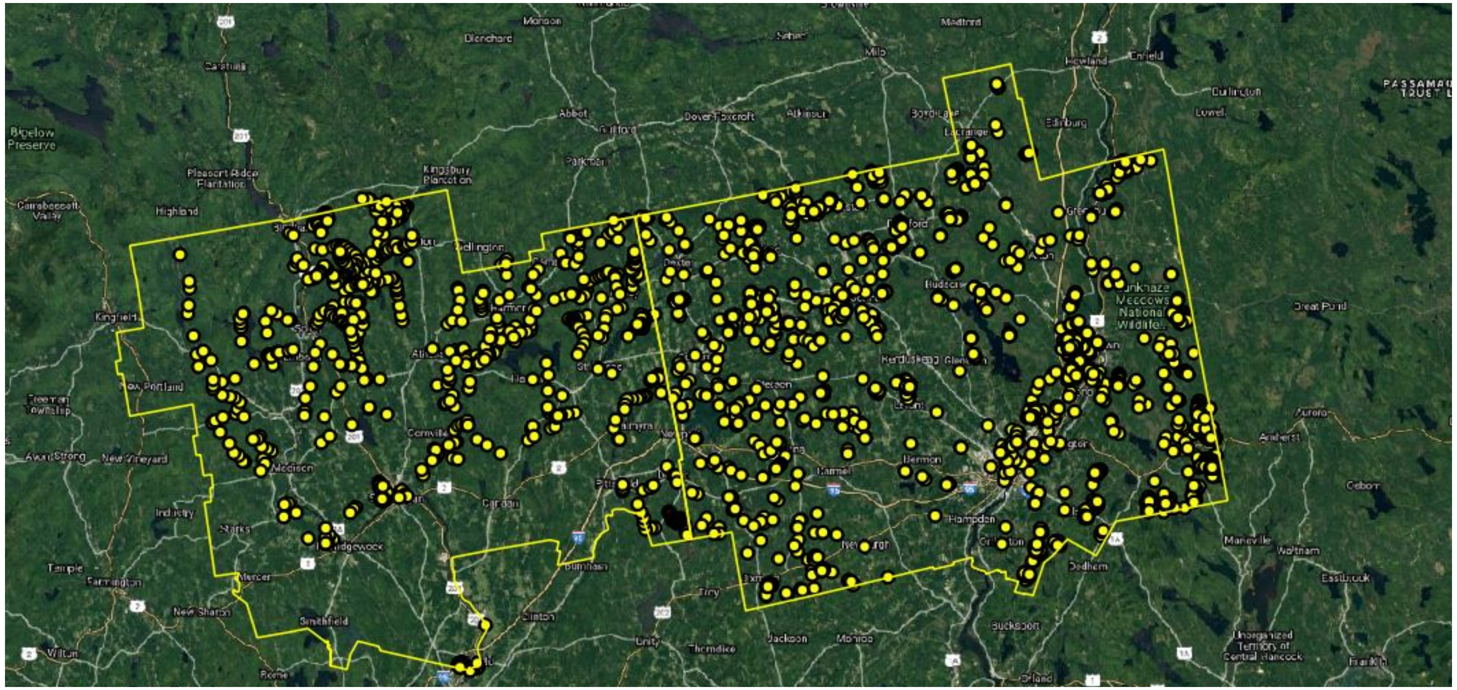


Soil Measurements

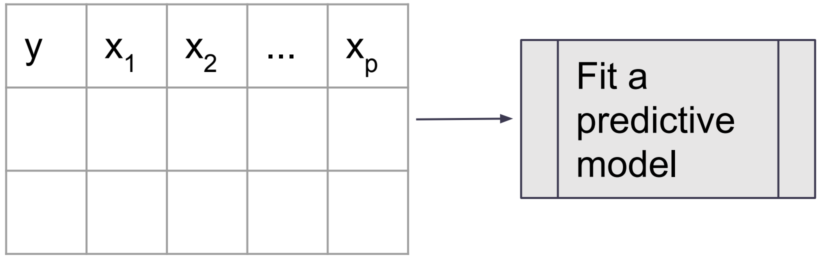
Collect georeferenced soil measurements



- 2,666 observations - training
  - NRCS Dover-Foxcroft Soil Survey Office
  - 15 measured soil properties
- 46 observations - validation
  - Stratified random sample



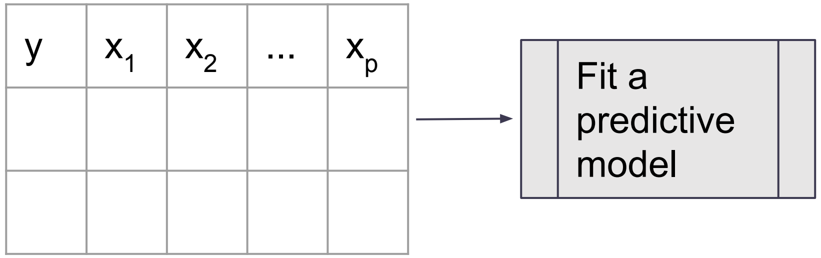
Predictive Modeling



Soil properties modeled (so far)

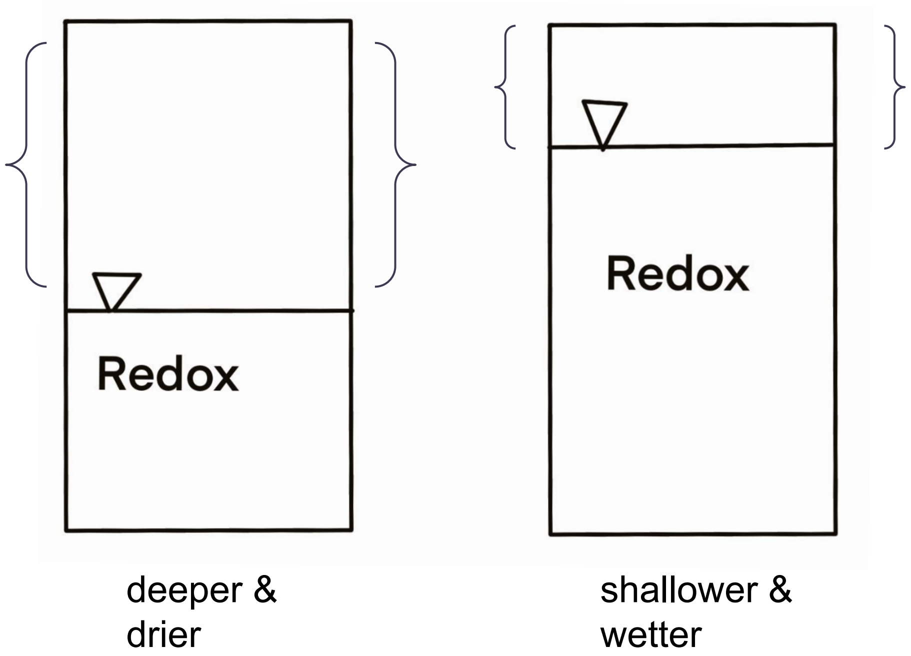
- Depth to seasonal wetness
- Depth to root restricting layer
- Depth to bedrock
- Organic horizon thickness

Predictive Modeling Steps



For each soil property

1. Presence/absence
2. Numerical values
   a. 7 models + variable selection
      i. Linear Regression
      ii. Regression Tree
      iii. Elastic Net
      iv. Multivariate Adaptive Regression Splines
      v. Gradient Boosting Machines
      vi. Random Forests
      vii. Cubist
   b. Ensemble modeling
   c. Spatial prediction + uncertainty
3. Validated predictive accuracy



Depth to Reduction-Oxidation (redox)

Indicates seasonal wetness

https://www.soils.org/news/media-releases/releases/2018/0601/1003/

Modeling Results

Linear Regression
Gradient Boosting Machines
Random Forests
Multivariate Adaptive Regression Splines

Ensemble Modeling

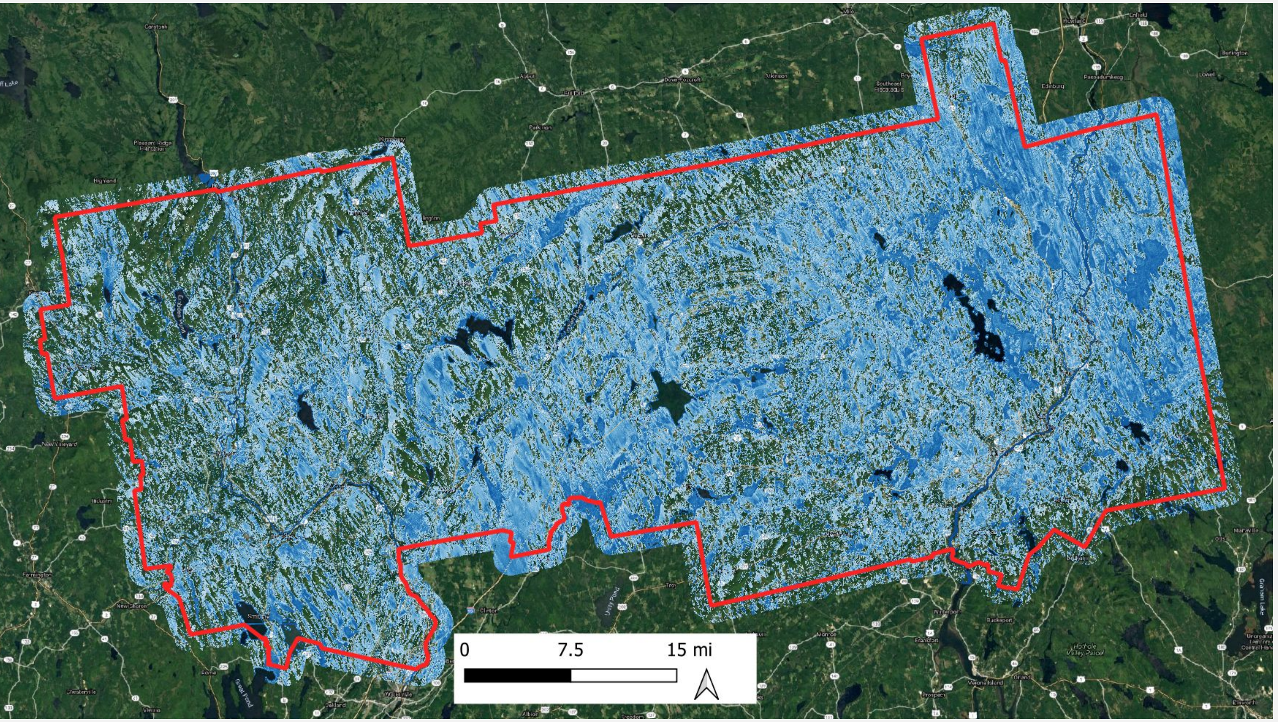
Validation metrics

Model	Mean Absolute Error (cm)	Root Mean Square Error (cm)
Gradient Boosting Machines	14.3	19.0
Random Forests	13.0	19.0
Multivariate Adaptive Regression Splines	14.4	19.3
Linear Regression	14.5	18.9
Ensemble Model	**13.4**	**15.4**

All models had similar metrics

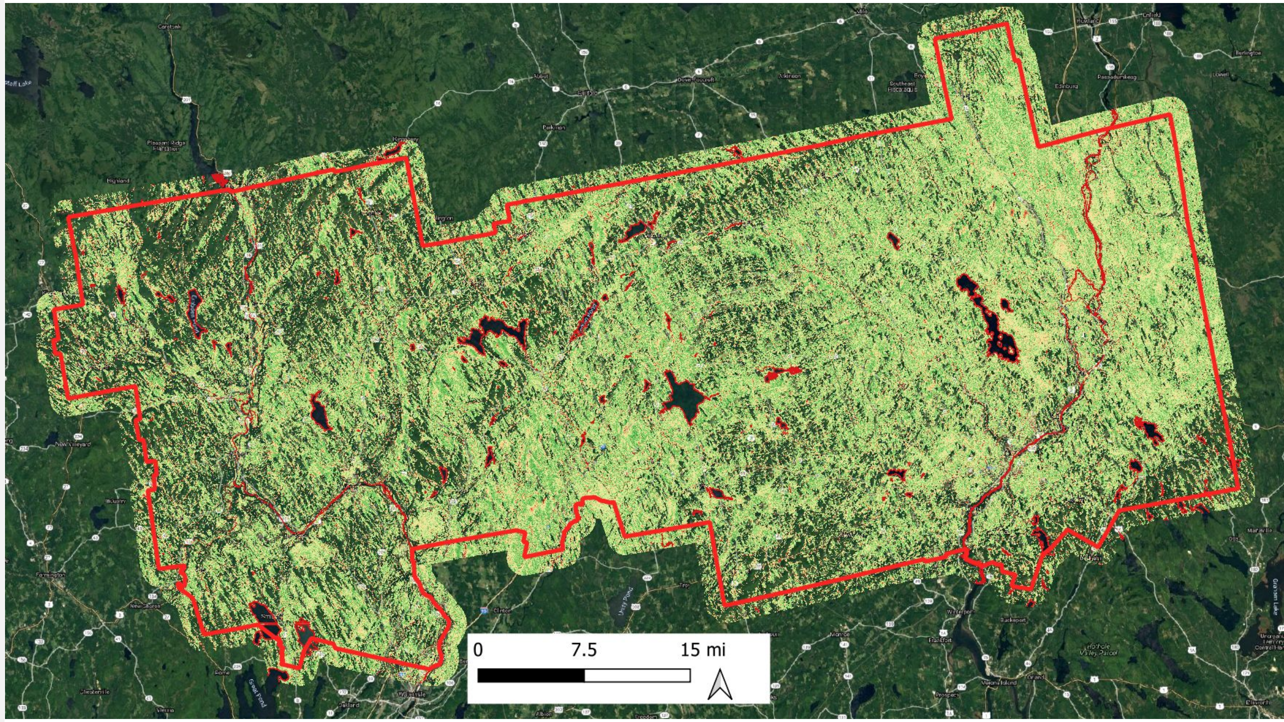
Ensemble

Spatial Prediction

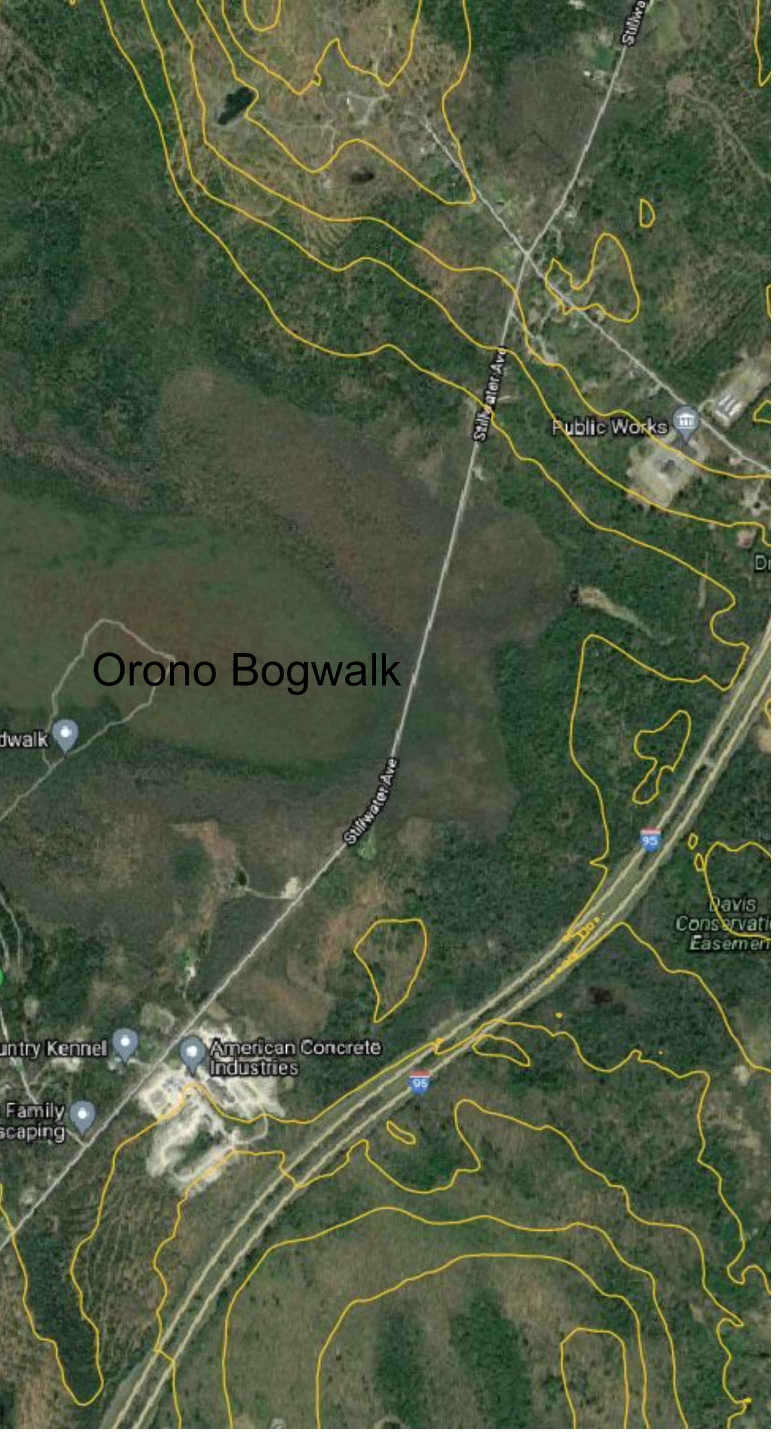


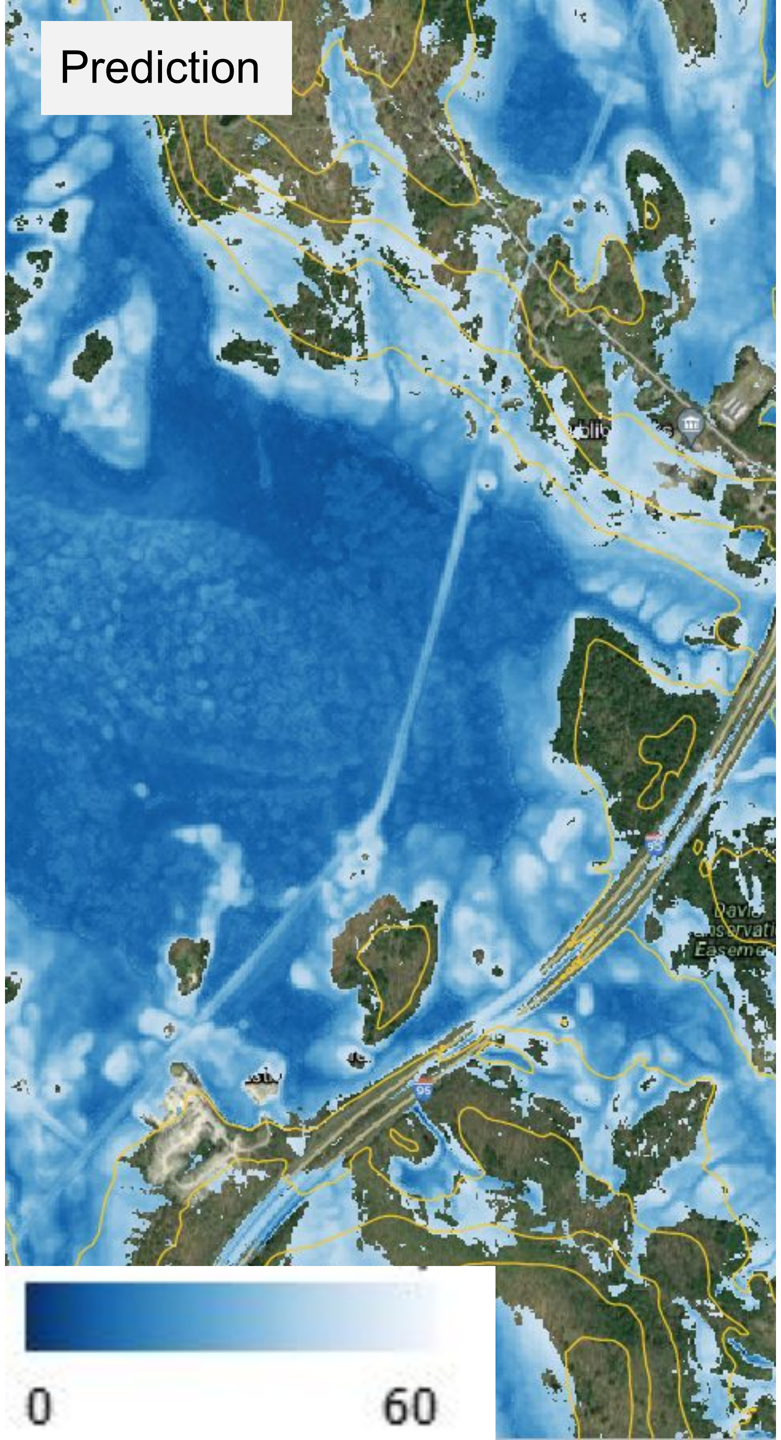
Darker values (closer to 0) are shallower ‘depth-to-redox’ and indicate shallower rooting depths (i.e. seasonal wetness closer to the soil surface).

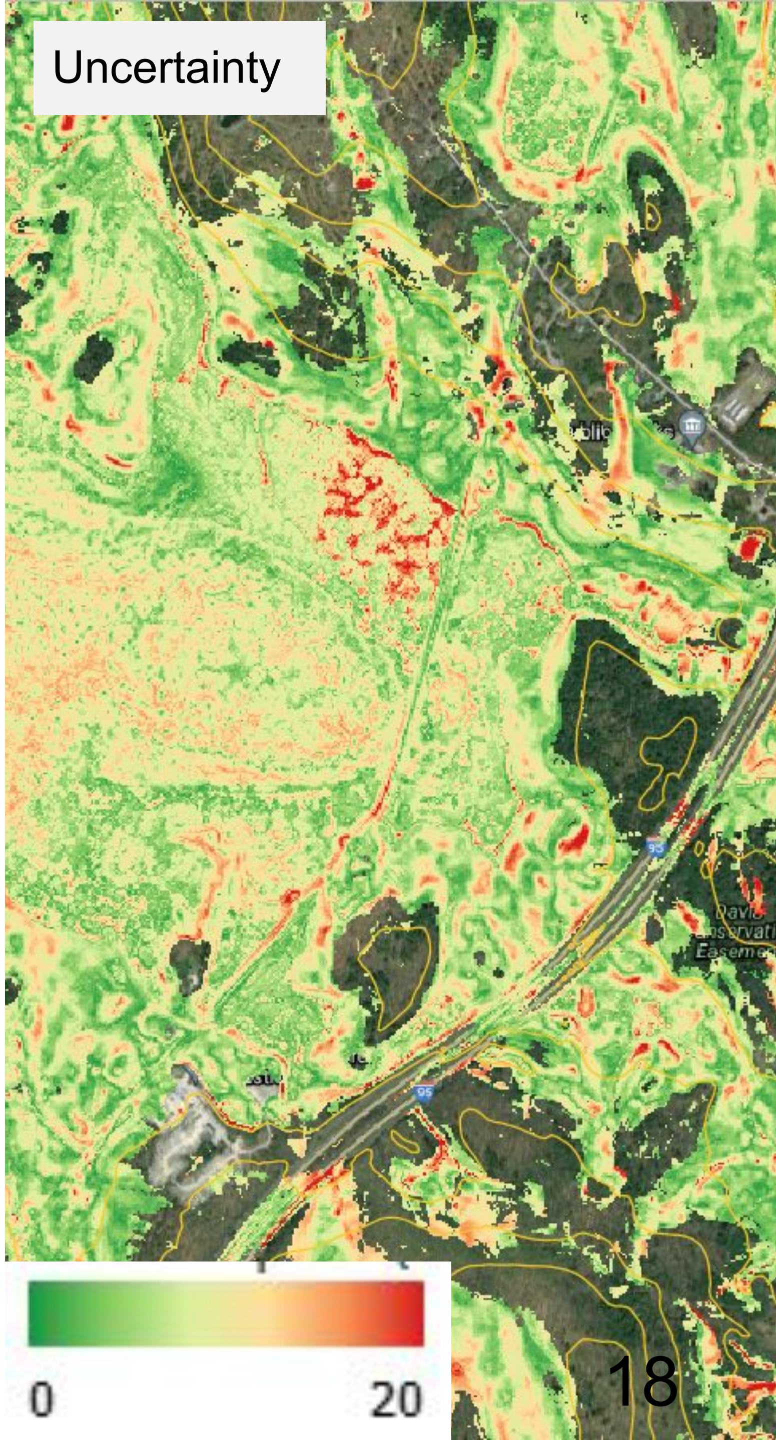
Uncertainty



Darker values (larger values) are wider prediction intervals and indicate more uncertainty in the predictions.

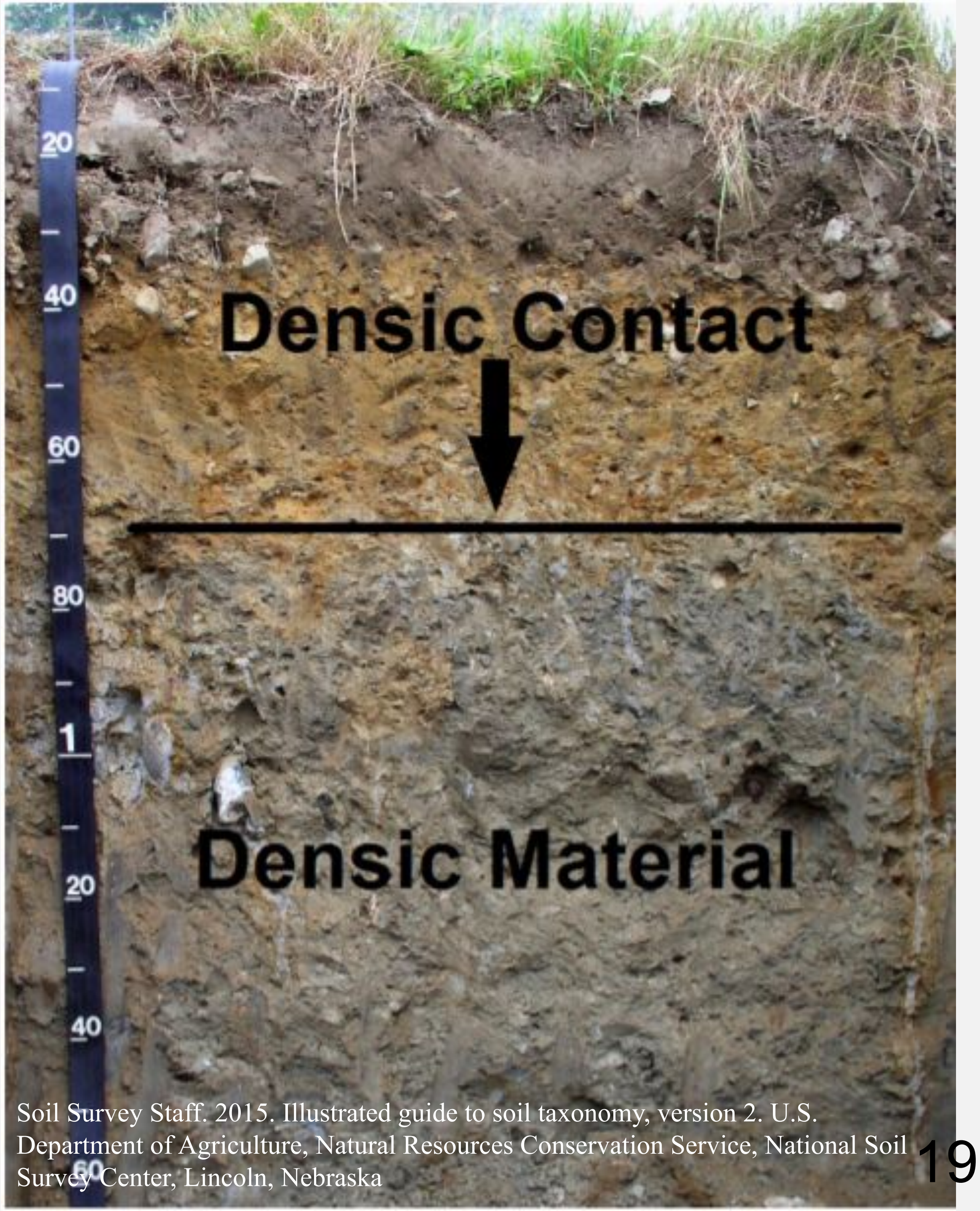

Orono Bogwalk
Public Works
Stillwater Ave
American Concrete Industries


Prediction
0
60


Uncertainty
0
20

Densic Horizon

Restricts rooting depth



Soil Survey Staff. 2015. Illustrated guide to soil taxonomy, version 2. U.S. Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, Nebraska

Modeling Results

Validation metrics

Model	Mean Absolute Error (cm)	Root Mean Square Error (cm)
Gradient Boosting Machines	7.0	7.8
Random Forests	9.3	9.9
Cubist	4.0	5.1
Elastic Net	5.1	7.2
Ensemble Model	**5.6**	**6.7**

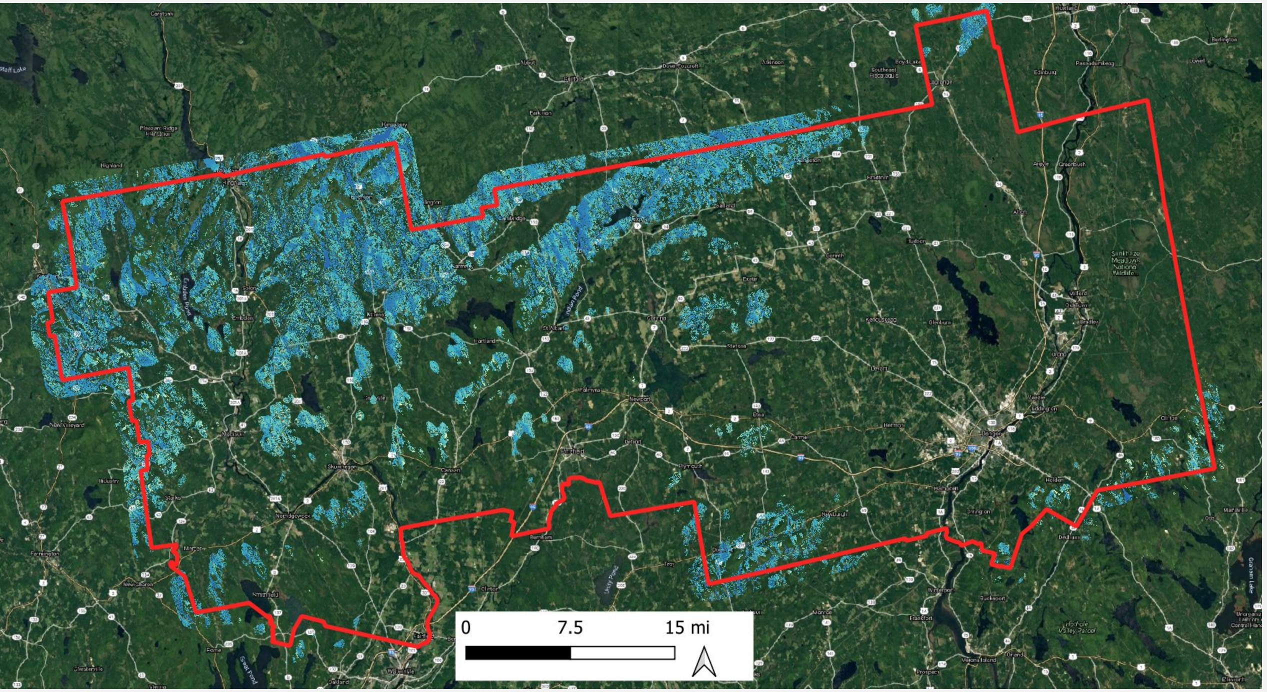
based on 7 validation locations that had densic contacts

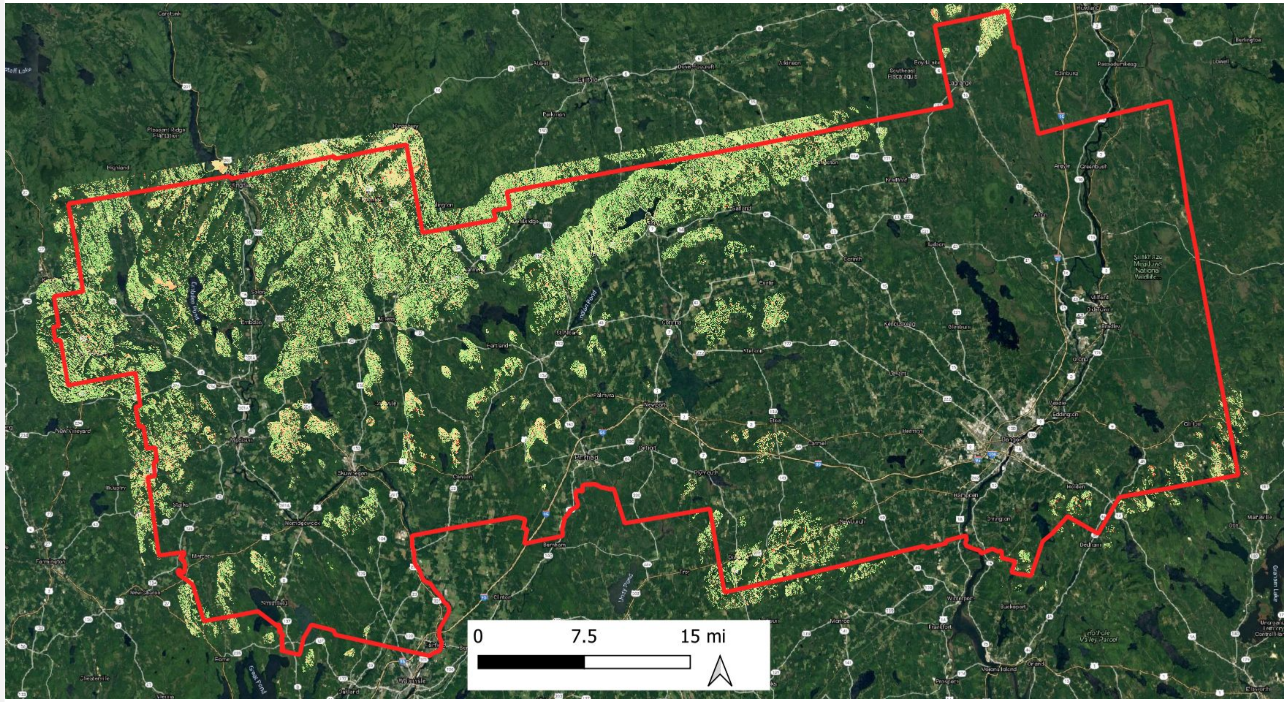
All models had similar metrics

Gradient Boosting Machines
Random Forests
Cubist
Elastic Net
Ensemble Modeling

Spatial Prediction

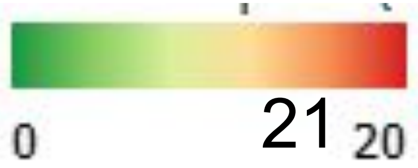
Uncertainty





Darker values (closer to 0) are shallower ‘depth-to-densic’ and indicate shallower rooting depths.

Darker values (larger values) are wider prediction intervals and indicate more uncertainty in the predictions.



Depth to bedrock (lithic contact)

Restricts rooting depth

Soil Survey Staff. 2015. Illustrated guide to soil taxonomy, version 2. U.S. Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, Nebraska

Modeling Results

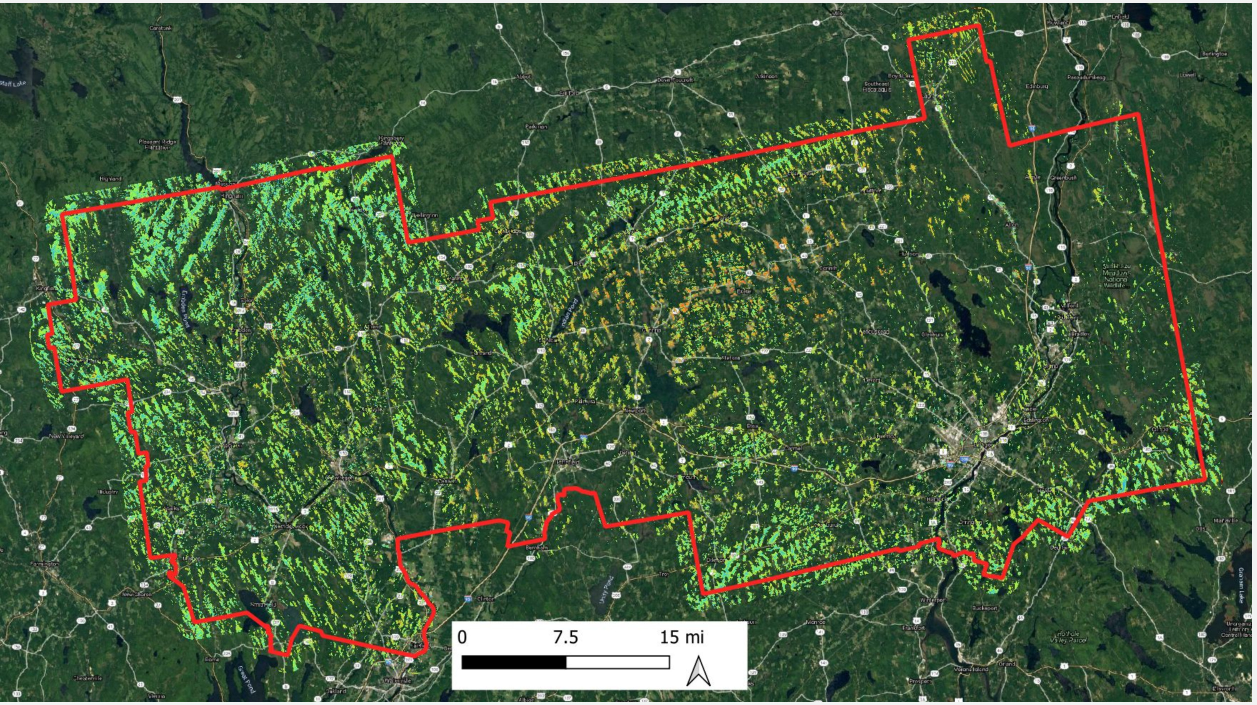
Validation metrics

Model	Mean Absolute Error (cm)	Root Mean Square Error (cm)
Gradient Boosting Machines	23.6	24.1
Random Forests	21.6	25.5
Cubist	20.3	24.2
Elastic Net	23.9	26.2
Linear Regression	32.1	34.2
Ensemble Model	**23.8**	**24.3**

All models had roughly similar metrics except linear regression

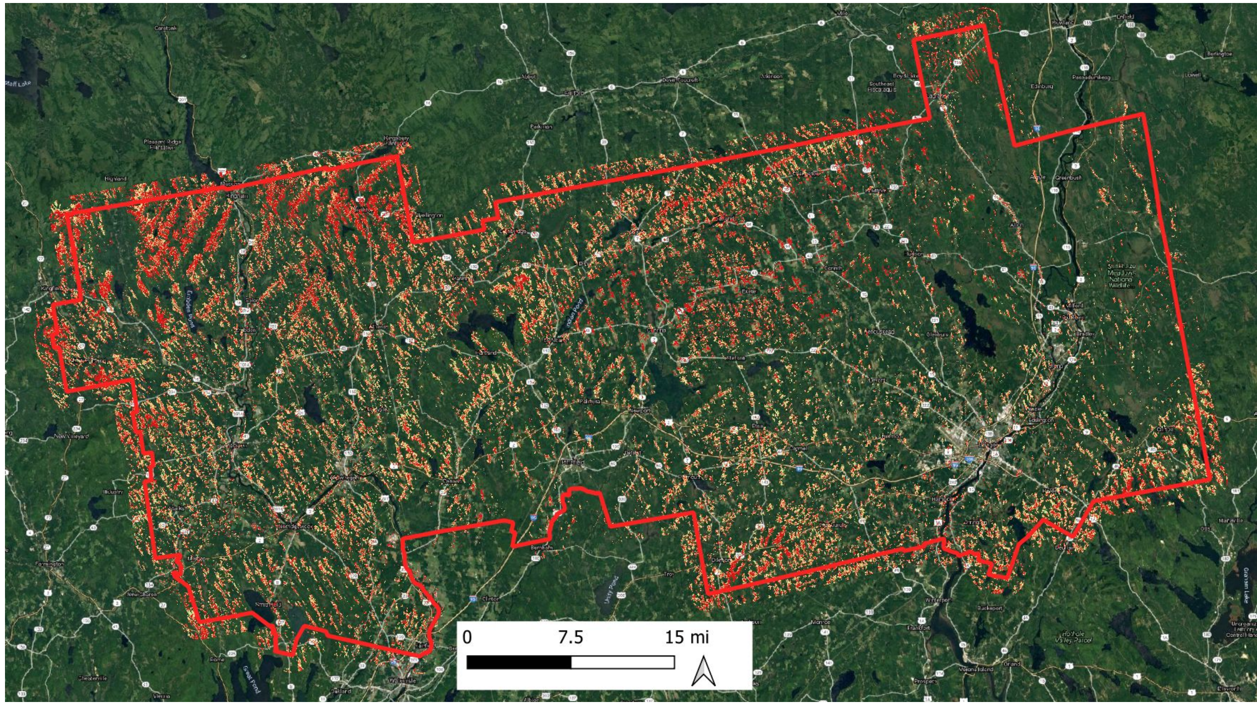
Gradient Boosting Machines
Random Forests
Cubist
Elastic Net
Linear Regression Ensemble Modeling

Spatial Prediction



Darker values (closer to 0) are shallower and indicate shallower rooting depths (i.e. bedrock closer to the soil surface).

Uncertainty



Darker values (larger values) are wider prediction intervals and indicate more uncertainty in the predictions.

Organic horizon thickness

Modeling Results

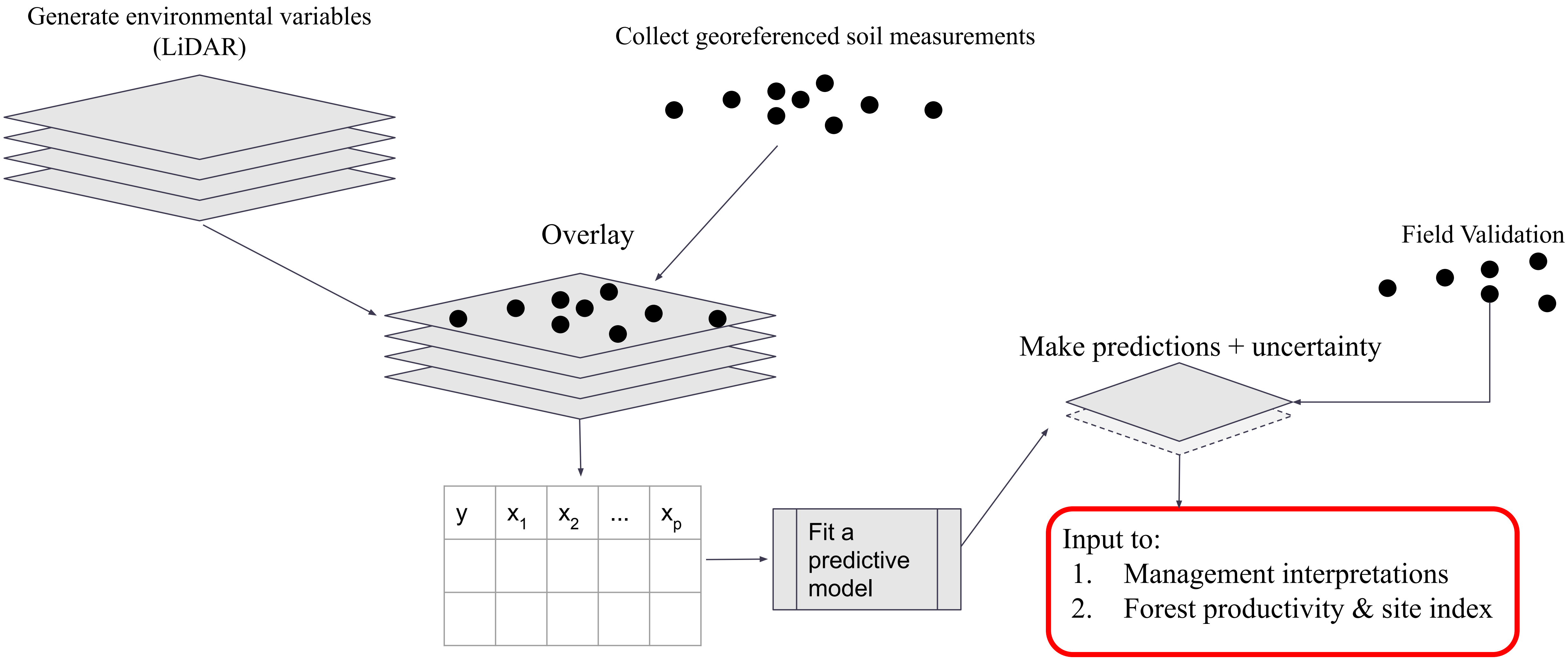
Validation metrics

Model	Mean Absolute Error (cm)	Root Mean Square Error (cm)
Gradient Boosting Machines	42.9	47.2
Random Forests	42.7	46.5
Cubist	43.8	47.6
Elastic Net	37.8	40.9
Classification Tree	42.7	46.5
Linear Regression	40.4	44.0

No model was accurate - did not predict

Gradient Boosting Machines
Random Forests
Cubist
Elastic Net
Classification Tree
Linear Regression

How does Digital Soil Mapping work?



Interpretations

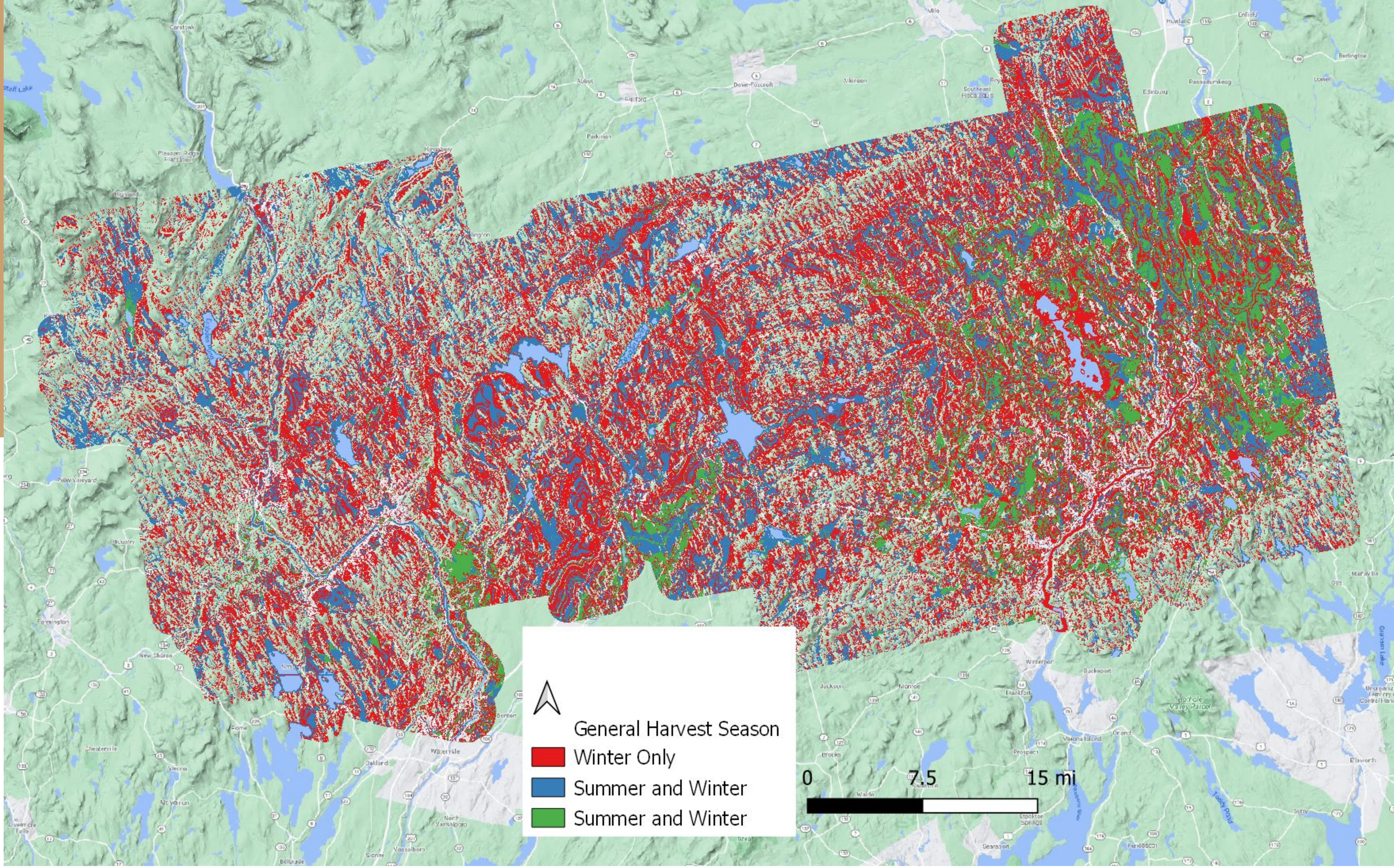
- Soil-based Management Interpretations
  - General Harvest Season for logging.
  - Harvest Equipment Operability Limitations
  - Rutting Hazard

- Expert-derived numerical and/or categorical ratings for specific uses

- Series of yes/no, threshold, and algebraic expressions
  - All inputs from DSM products

General Harvest Season

Version 1.0



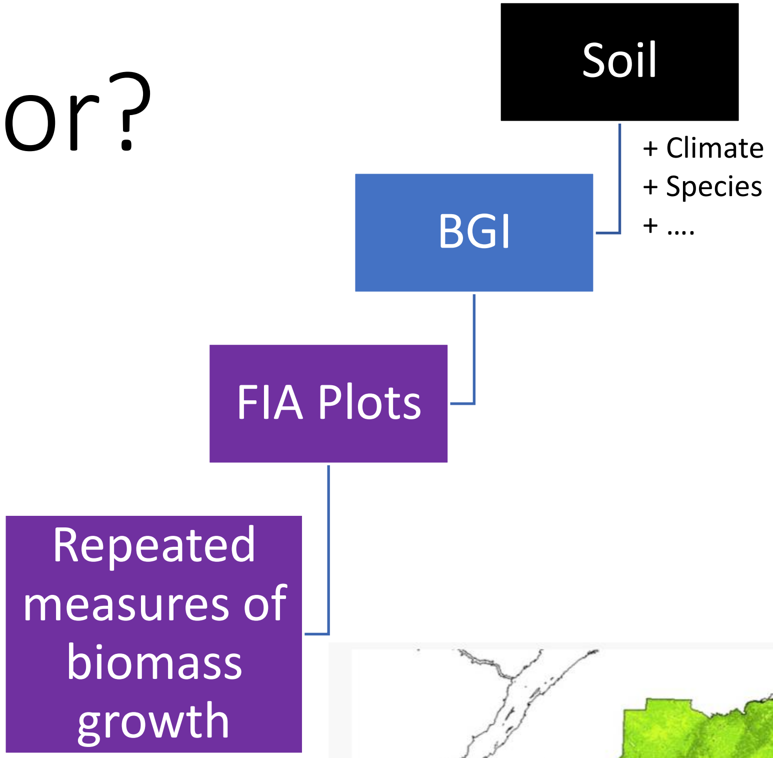
Based on water table depth, hydric rating, and parent material

DSM + Forest Productivity & Site Index Models

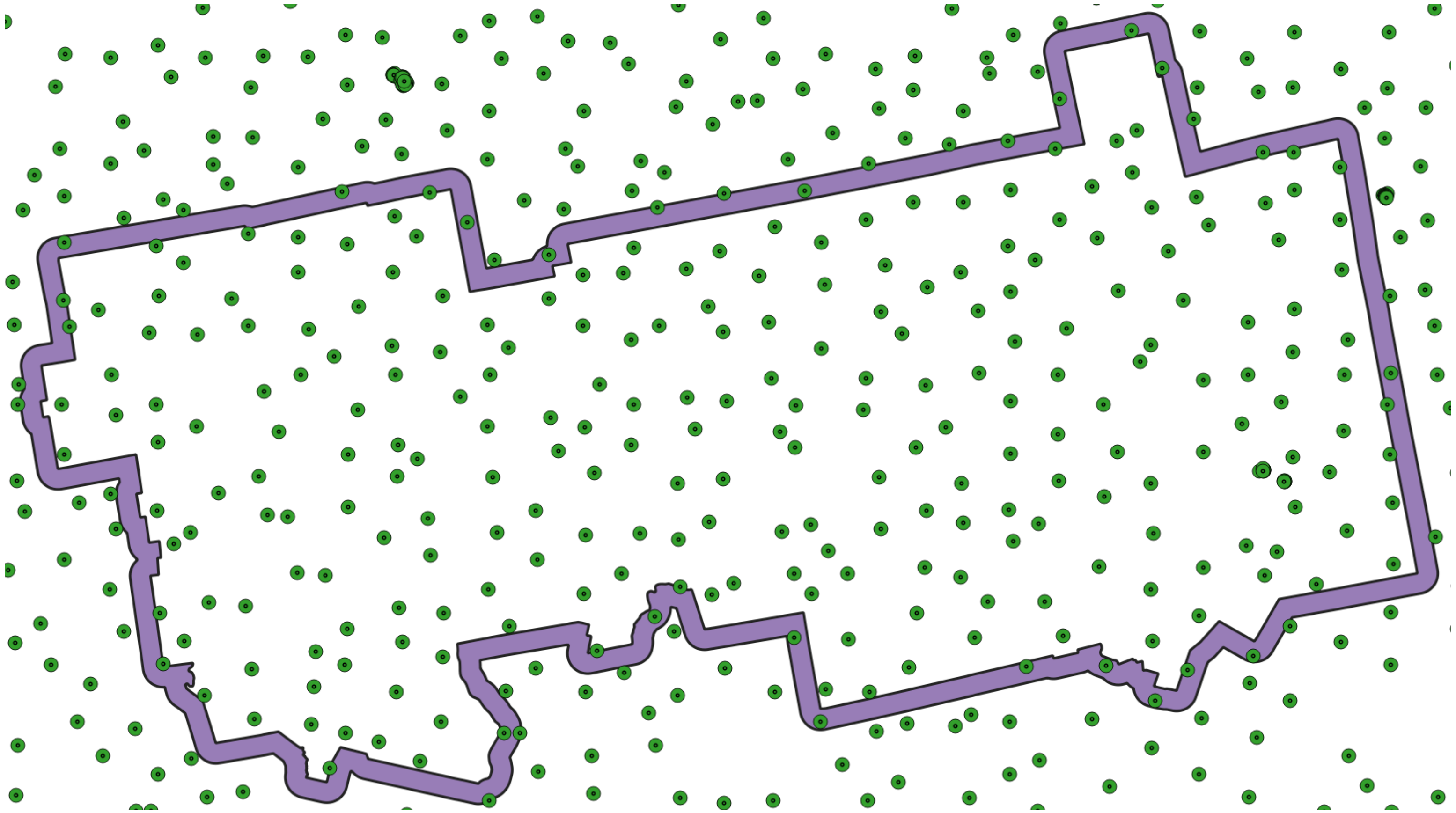
Chris Henniger

FORUS Research

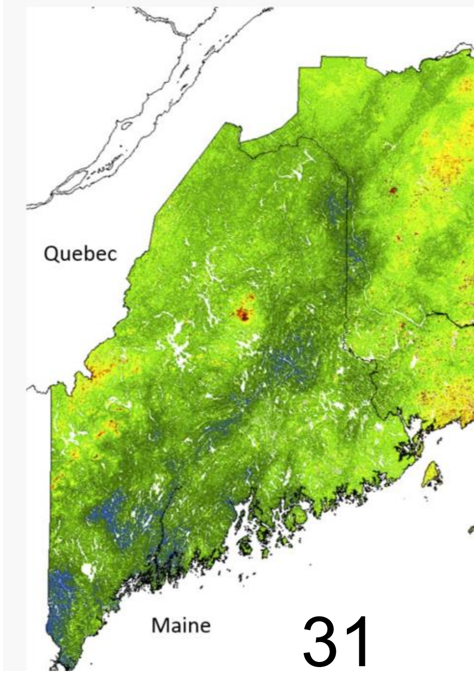
Can DSM explain BGI Residual Error?



If so, then likelihood of existing BGI model improvement



177 FIA Plots in Study Area



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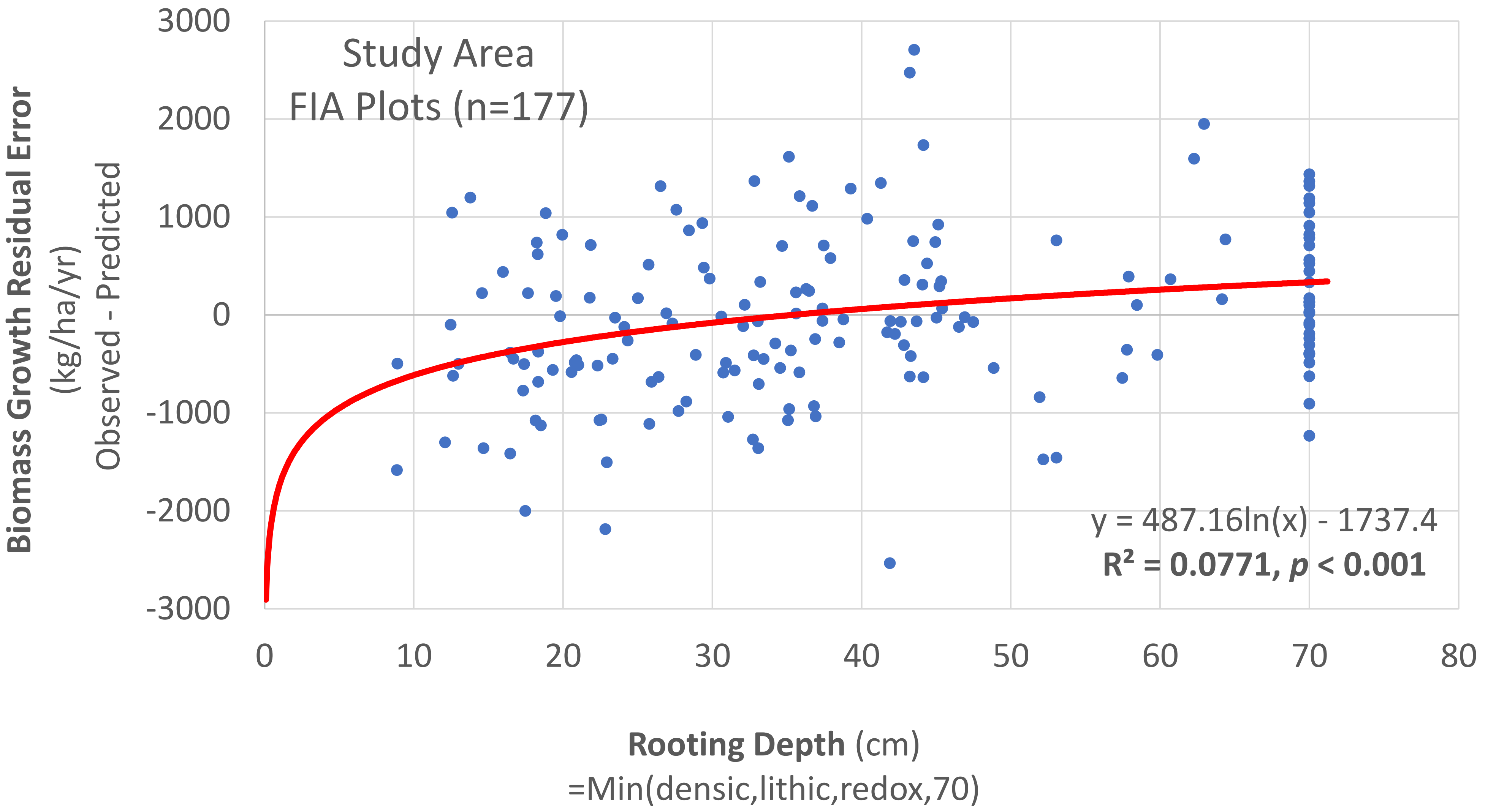


Key Messages

- There is evidence the DSM is outperforming earlier soil and depth-to-water variables used in the BGI model
  - Depth to Redox best so far
  - Few growth observations in shallow densic and lithic layers in study area

Next Steps

REFINE MODELS

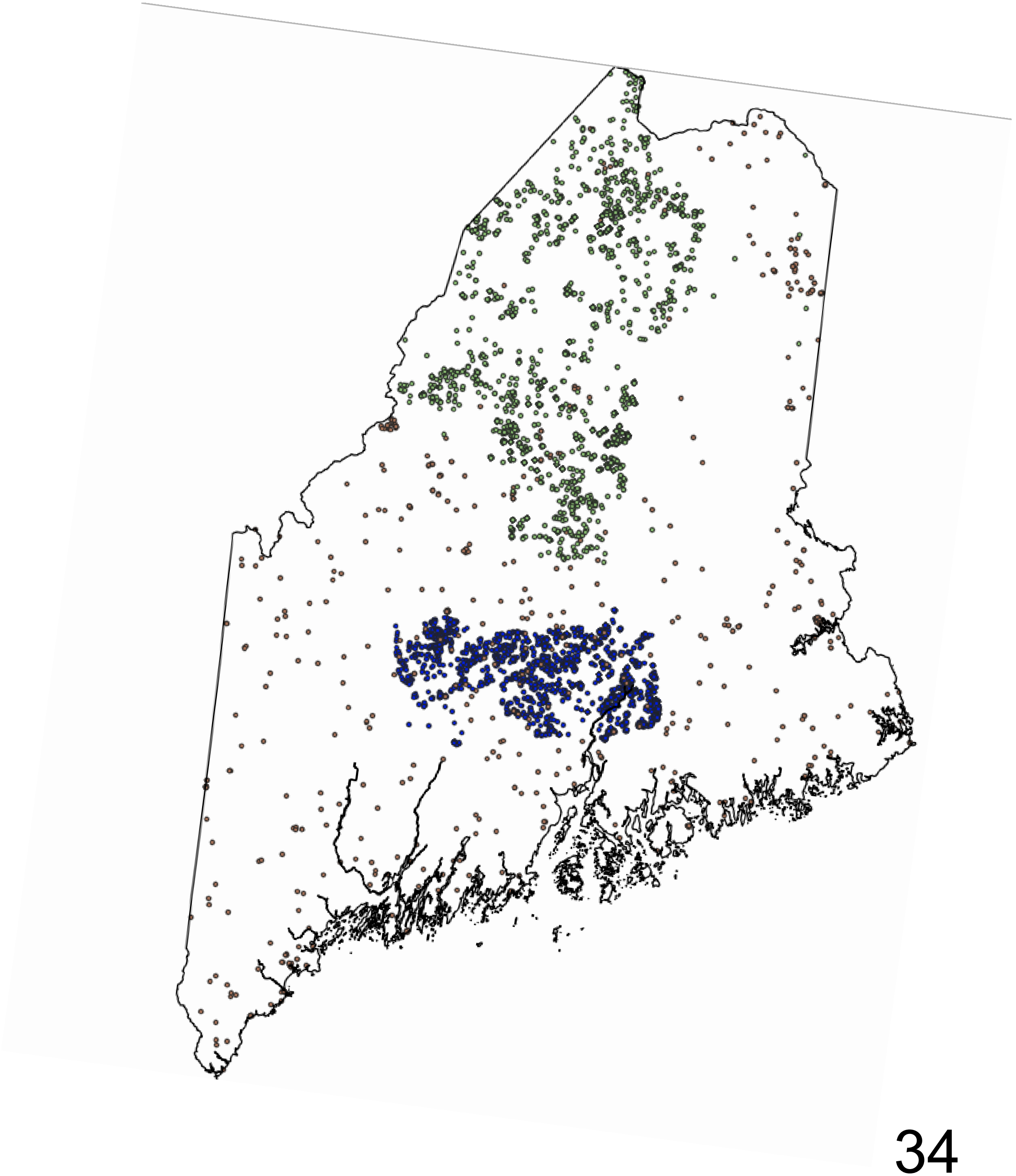
- A few additional properties and methods

ADDITIONAL INTERPRETATIONS

- Harvest Equipment Operability
- Rutting Hazard

EXTEND TO ALL OF MAINE

- Environmental Variables
- ~ 5600 observations



Conclusions

Digital Soil Mapping

DSM Accurate

- Predictions within 10 - 50 cm
- Spatial patterns make sense
- Uncertainty is generally low

Interpretations promising

- Forefront of DSM research

How do you currently use soil/terrain data
How can gridded soil data/information be most useful to you?

Thank You

Environmental Soil Consulting