Soil Survey of the Boundary Waters Canoe Area Wilderness -
A Collaborative Project between USFS and NRCS
11.30.17 | Joseph Brennan, Tom D’Avello, Suzann Kienast-Brown, Jessica Philippe
Soil Survey of the Boundary Waters Canoe Area Wilderness

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nrcresearch.gov/
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BACKGROUND

- August 2012 – kick-off DSM project
- 1.1 million-acre Wilderness area established in 1978 within the Superior National Forest in Northeastern Minnesota
- Soil Survey Region 10 in St. Paul MN
  - Soil Survey staff in Duluth MN
- Managed by USFS and well known for recreational activities
  - Fishing, hunting, camping, canoeing, dog sledding, swimming, hiking, skiing
- Very limited access
  - No vehicles
  - Foot and paddle only with few exceptions
  - No cell phone service
- Wildlife!
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MATERIALS AND METHODS

Soil = f (s, c, o, r, p, a, n)

- c – frigid MAAT=1.5C (34.75F) Precip=685mm (27″)
- o – boreal forest
- r – ~relation to depth and drainage
- p – drift over Precambrian BR
- a – ~12000 BP
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MATERIALS AND METHODS

- Many covariates created and explored
- Covariate selection
  - Optimum Index Factor
  - Random Forests Variable Importance
- Covariate predictor set

Terrain Derivatives (5m LiDAR)
- slope
- minimum curvature
- depression cost surface
- downslope distance gradient
- surface area factor
- relative position (@ 2 neighborhoods)
- canopy height (from 1m LiDAR)
- landforms (geomorphons)

Spectral Derivatives (Landsat 5)
- Landsat bands 1, 5
- NDVI
- brightness, greenness
- principle component 6
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MATERIALS AND METHODS

Legend

- Developed a data driven stratification/pre-map via unsupervised and supervised classification prior to field sampling
  - Determined number of classes data (covariates) would support
- Initial observations and tacit knowledge yielded upwards of 45 soil series/classes
- Exploratory pre-map process thinned to ~16 classes based on parent material, depth, and wetness
- Further refinement to 11 broad classes after field data collected, inclusive of water
  1. Very shallow dry till
  2. Shallow dry till
  3. Deep dry till
  4. Moderately deep dry till
  5. Deep wet till
  6. Moderately deep and shallow wet till
  7. Dysic organic
  8. Euic organic
  9. Lacustrine
  10. Eskers
  11. Water
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MATERIALS AND METHODS

- Where to sample?
- Training points selected using conditioned Latin Hypercube Sampling
  - Insure objective, representative sampling of covariate space
  - Access extremely limited
  - 214 training points collected
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MATERIALS AND METHODS

- **Classification methods**
  - **Rule-based** (ArcSIE) – knowledge-based inference to develop 9 classes
  - **Unsupervised** (ERDAS Imagine) – ISODATA clustering for dysic/euic organic soils
  - **Maximum Likelihood – Supervised** (ERDAS Imagine) – applying training data in two runs; 11 and 9 classes
  - **Heads-up** (ArcGIS) – automated identification of eskers tested - abandoned in favor of heads-up digitization
  - **Pre-defined class** (ArcGIS) – water, as defined by break lines from LiDAR data used as “water”
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MATERIALS AND METHODS

- Classification methods continued
  - Classification tree (R) – standard classification tree
  - Logistic regression (R) – primarily for modeling extent of lacustrine
    - Modeled class using a binary approach
    - Used probability to assign class to final map
  - Random forests (R)
    - Separability analysis & class collapsing
    - Modeled all 11 classes simultaneously
    - Modeled classes using binary approach
      » Used probability surfaces to assign classes to final map
RESULTS AND DISCUSSION

Classification methods

- Local experts qualitatively evaluated results from all classification methods
  - Each method independently
  - Each class, independent of method
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RESULTS AND DISCUSSION

- Logistic regression – Lacustrine
  - Nagelkerke’s "pseudo R squared" = 0.53
  - Refined using rules defined by local experts according to Land Type Association Strata

1  411m and below
2a 442m and below
2b 460m and below
2c 469m and below
3 Incidentally <= 442m
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RESULTS AND DISCUSSION

- Rule-based
  - Documented “what we think we know” from local soil scientists
  - Translated into rules for selected terrain covariates
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RESULTS AND DISCUSSION

– Rule-based
  • ArcSIE extension used to create rules and a fuzzy membership layer for each class
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RESULTS AND DISCUSSION

- Rule-based
  - Very shallow dry till and shallow dry till class results favored by local experts
  - Ideally, the rule-based process would include many iterations, using knowledge gained in the field to improve the model
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RESULTS AND DISCUSSION

- Random forests
  - Class collapsing

<table>
<thead>
<tr>
<th>Original classes</th>
<th># observations</th>
<th>Final classes</th>
<th># observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>deep dry till</td>
<td>45</td>
<td>deep dry till</td>
<td>45</td>
</tr>
<tr>
<td>deep wet till</td>
<td>24</td>
<td>deep wet till</td>
<td>24</td>
</tr>
<tr>
<td>outwash</td>
<td>8</td>
<td>outwash</td>
<td>8</td>
</tr>
<tr>
<td>moderately deep dry till</td>
<td>25</td>
<td>moderately deep dry till</td>
<td>25</td>
</tr>
<tr>
<td>shallow dry till</td>
<td>21</td>
<td>shallow dry till</td>
<td>21</td>
</tr>
<tr>
<td>very shallow dry till</td>
<td>27</td>
<td>very shallow dry till</td>
<td>27</td>
</tr>
<tr>
<td>wet lacustrine</td>
<td>16</td>
<td>wet lacustrine</td>
<td>16</td>
</tr>
<tr>
<td>wet lacustrine, mantled</td>
<td>11</td>
<td>wet lacustrine, mantled</td>
<td>11</td>
</tr>
<tr>
<td>dry lacustrine</td>
<td>4</td>
<td>dry lacustrine</td>
<td>8</td>
</tr>
<tr>
<td>dry lacustrine, mantled</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dysic organics</td>
<td>6</td>
<td>organics</td>
<td>11</td>
</tr>
<tr>
<td>euic organics</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lithic organics</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mod dep wet till</td>
<td>3</td>
<td>mod deep wet till/shallow wet till</td>
<td>11</td>
</tr>
<tr>
<td>shallow wet till</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>15 classes</strong></td>
<td><strong>207</strong></td>
<td><strong>11 classes</strong></td>
<td><strong>207</strong></td>
</tr>
</tbody>
</table>
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RESULTS AND DISCUSSION

– Random forests

• Due to limited training data and poor model performance when all 11 classes were modeled simultaneously, each class was modeled separately (binary approach)
  – Decreased out-of-bag error (OOB) from 58-75% to 4-22%
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RESULTS AND DISCUSSION

- Random forests

Very shallow dry till probability surface

Moderately deep/shallow wet till probability surface
RESULTS AND DISCUSSION

– Random forests

• Deep dry till, deep wet till, moderately deep/shallow wet till, and moderately deep dry till class results favored by local experts

![Image of soil survey map]
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RESULTS AND DISCUSSION

- Hybrid assemblage
  - Local experts qualitatively reviewed and selected the best representation of each class resulting in a hybrid raster map product

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very shallow dry till</td>
<td>Rule base (RB)</td>
</tr>
<tr>
<td>Shallow dry till</td>
<td>RB</td>
</tr>
<tr>
<td>Deep dry till</td>
<td>Random Forest (RF)</td>
</tr>
<tr>
<td>Moderately deep dry till</td>
<td>RF</td>
</tr>
<tr>
<td>Deep wet till</td>
<td>RF</td>
</tr>
<tr>
<td>Moderately deep and shallow wet till</td>
<td>RF</td>
</tr>
<tr>
<td>Dysic organic</td>
<td>Unsupervised &amp; NWI</td>
</tr>
<tr>
<td>Euic organic</td>
<td>Unsupervised &amp; NWI</td>
</tr>
<tr>
<td>Lacustrine</td>
<td>Logistic</td>
</tr>
<tr>
<td>Eskers</td>
<td>Heads-up</td>
</tr>
<tr>
<td>Water</td>
<td>LiDAR break lines</td>
</tr>
</tbody>
</table>
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RESULTS AND DISCUSSION

- Hybrid assemblage
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RESULTS AND DISCUSSION

- Initial accuracy assessment – Fall 2014
  - Based on hybrid raster map
  - Used areas of opportunity to identify potential sampling areas based on accessibility
  - Primary sampling units randomly selected in each area of opportunity
    - Greater than 100m from any training point
    - Based on foot/canoe accessibility and proximity to campsites
  - Sampling points randomly stratified by class in each primary sampling unit
  - 109 observations collected
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RESULTS AND DISCUSSION

1. Areas of opportunity
2. Random primary sampling units
3. Randomly stratified points by class

- Initial accuracy assessment
RESULTS AND DISCUSSION

– Initial accuracy assessment

• Overall accuracy 64%
• KHAT 0.6
• User accuracy

<table>
<thead>
<tr>
<th>User Accuracy</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.67</td>
<td>Deep wet till</td>
</tr>
<tr>
<td>0</td>
<td>Mod Deep-shallow wet till</td>
</tr>
<tr>
<td>0.83</td>
<td>Very shallow dry till</td>
</tr>
<tr>
<td>1</td>
<td>Lacustrine</td>
</tr>
<tr>
<td>0.46</td>
<td>Mod Deep Dry till</td>
</tr>
<tr>
<td>0.93</td>
<td>Dysic Organic</td>
</tr>
<tr>
<td>0.47</td>
<td>Deep dry till</td>
</tr>
<tr>
<td>0</td>
<td>Shallow dry till</td>
</tr>
<tr>
<td>0.14</td>
<td>Euic Organic</td>
</tr>
<tr>
<td>1</td>
<td>Eskers</td>
</tr>
<tr>
<td>0.91</td>
<td>Water</td>
</tr>
</tbody>
</table>
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RESULTS AND DISCUSSION

– Evaluation and amendment

Accuracy Assessment

Combination

Strata Summaries

Tacit Knowledge

Local Conventions

Rule-Based

1. Class Combination
Shallow & Very Shallow Soils

Before Process

After Process

Other Classes

 moderately deep dry till
moderately wet till

Deep dry till

Shallow dry till and very shallow till

Ve ry shallow till

So il

W ater

3. Esker

Above:

Deep dry till

Lacustrine

Deep moderately wet till

Deep wet till

Moderately deep dry till

Organic (clayey subsoil)

Organic (non-acid)

Shallow dry till and very shallow till

8. Remaining Organic Soils
Deep vs. Terric

Before Process

After Process

Dysic organic

Eluic organic

Terric Organic (local relief)

Terric Organic (< 5 cm)
RESULTS AND DISCUSSION

- Raster correlation
  - Site Data
    - 500 Descriptions Reviewed
    - 378 Descriptions Correlated
RESULTS AND DISCUSSION

- Raster correlation
  - Aggregated Data
  - Map Unit Development
    » Ancillary Data
    » MLRA Components
  - Project & Legend Mgt.
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RESULTS AND DISCUSSION

- Final accuracy assessment (Fall 2016)
  - 253 validation points collected
  - Overall accuracy - 66%
  - KHAT = 0.61
  - User Accuracy

<table>
<thead>
<tr>
<th>User Accuracy</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.89</td>
<td>Deep wet till - Aquepts, rubbly</td>
</tr>
<tr>
<td>0.57</td>
<td>Organic (alluvial) - Bowstring</td>
</tr>
<tr>
<td>0.33</td>
<td>Organic (loamy subsoil) - Tacoosh</td>
</tr>
<tr>
<td>0.45</td>
<td>Organic (clayey subsoil) - Dora</td>
</tr>
<tr>
<td>0.57</td>
<td>Alluvial - Fluvaquents</td>
</tr>
<tr>
<td>0.96</td>
<td>Organic (acid) - Greenwood, Merwin</td>
</tr>
<tr>
<td>0.29</td>
<td>Organic (non-acid) - Rifle</td>
</tr>
<tr>
<td>0.84</td>
<td>Lacustrine - PD and SWP lacustrine</td>
</tr>
<tr>
<td>1</td>
<td>Esker - Rollins</td>
</tr>
<tr>
<td>0.5</td>
<td>Deep dry till - Eveleth</td>
</tr>
<tr>
<td>0.63</td>
<td>Moderately deep dry till - Conic</td>
</tr>
<tr>
<td>0.29</td>
<td>Moderately deep and shallow wet till - Babbit BR, Aquepts lithic</td>
</tr>
<tr>
<td>1</td>
<td>Water</td>
</tr>
<tr>
<td>0.58</td>
<td>Moderately deep and deep moderately wet till - Eaglesnest, Soudan</td>
</tr>
<tr>
<td>0.68</td>
<td>Shallow dry till and very shallow till - Insula, Quetico, BR</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

- Accuracy assessment by broad classes
  - Drainage class - Overall 86%
  - Depth to BR - Overall 75%
  - Organic/Mineral - Overall 92%
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RESULTS AND DISCUSSION

- Vectorization
RESULTS AND DISCUSSION

- Progressive correlation (SSURGO)
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RESULTS AND DISCUSSION

- Data availability
  - Raster Data is on the Geospatial Data Gateway

<table>
<thead>
<tr>
<th>Soils</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gridded Soil Survey Geographic (gSSURGO) by State or Conterminous U.S., 1 map 2045.409 MB</td>
<td>i+</td>
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<td>U.S. General Soil Map (STATSGO2) by State, 1 map 12.049 MB</td>
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<td>Major Land Resource Areas by State, 1 map 2.251 MB</td>
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<tr>
<td>Common Resource Areas by State, 1 map 2.503 MB</td>
<td>i+</td>
</tr>
<tr>
<td>Raster Soil Survey, 1 map 14.192 MB mn075 Lake</td>
<td>i-</td>
</tr>
</tbody>
</table>
CONCLUSIONS

- Lessons learned
  - Consider clustered or multi-stage sampling with high cost/sample in future projects
  - Some sampling at SS discretion was accommodated for this project – continue option
  - All applied modeling methods are common in DSM community and found applicable
  - Rule-based methods are intuitive for soil scientists and offer the advantage of refinement as knowledge of soil-landscape relationships develops
  - Utilization of random forests in ‘binary’ mode is viable procedure for future projects with limited training data
  - Strive for developing expertise within project offices across SSD
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