Modeling Norway spruce (*Picea abies*) forest line in Finnish Lapland

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Norway spruce range in Europe

*Picea abies* Karst.
Spruce forest line in Finland runs approximately 60-140 km south of Scots Pine. The position of spruce forest line is suspected to depend on both climatic/topographic and soil/lithologic factors.

Vertical forest line elevation of the conifers in Finnish Lapland
Spruce does not exist on soils developed from nutrient-poor granitoids – the conifer is pine

• Vertical forest line elevation of the conifers in Lapland

Sutinen et al. 2005 Arctic, Antarctic, and Alpine Research
Soil Mg-content at pine and spruce sites (mature >150 yrs stands) along gradient from mafic greenstone belt to felsic granulite belt
Spruce forms the alpine treeline only on mafic, nutrient rich fells (Sutinen et al. 2011 Scan.J.For.Res.; Boreas 2012). The vertical soil zonality (soil nutrients decrease along with elevation) was introduced by V.V. Dokuchaev in 1899.
Materials and methods

- Soil/lithologic factors from Geological Survey of Finland
  - 3782 sample points (grid size 1 x 1 km) located north and south from the current spruce forest line.
- Site data: polygons from the National Board of Forestry
- Digital elevation model provided by National Land Survey of Finland
The spruce forest line information was sampled from the Finnish National Board of Forestry site polygon data.

Soil sampling points were categorized as 0/1 (role variable) according to the distance to the nearest spruce site polygon: those within the distance of 500 m from the nearest spruce growth site were given value ”1” and the rest got value ”0”.

Four models with different covariates were constructed.
• The aim of the comparison of models with different covariates:
  – To test which covariates predict most accurately the position of the BORDER LINE between the southern spruce and northern pine and birch forests compartments (forest line).
  – How does the adding of soil, snow thickness and bedrock data improve "climatic" (based on position) spruce forest line model
Procedures:

The most likely values (0/1) of the sample plots, calculated by regression model, were imported to a GIS-program (ArcGis). A raster layer of probabilities was created using ArcGis Natural Neighbour-algorithm for each model.

Contours of probability value of 0.5 were constructed from the gridded models with different predictive parameters.

An euclidian distance grid using the actual spruce forest line was built: here each pixel value shows the distance to the real spruce line in meters.

Probability contour lines were transformed to points using the line vertex midpoints.

The underlying distance grid values were then imported to the different contour point features and the mean value of distance of each model point group from the real spruce forest line was calculated to express how accurately the modeled line tracks it.
Maps of predictive variables

DEM

AI

V

Fe

Mg

Aeroradiometric K

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Snow thickness
Model spruce forest line

Model 1
Coordinates and DEM

Model 2
+ soil chemistry

Model 3
+ lithology

Model 4
+ snow thickness
Comparison of the models

ROC (Receiver Operating Characteristics) values
$R^2(U)$
Unaccuracy of the 0.5 probability value contour (mean spatial distortion) compared to the real spruce forest line

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<table>
<thead>
<tr>
<th>Model</th>
<th>Covariates</th>
<th>ROC-value</th>
<th>$R^2(U)$</th>
<th>Model 0.5 contour line mean spatial error m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>X,Y,DEM</td>
<td><strong>0.81</strong></td>
<td><strong>0.22</strong></td>
<td><strong>4773</strong></td>
</tr>
<tr>
<td>Model 2</td>
<td>+ Al,Fe,V,AR_K,Mg</td>
<td><strong>0.87</strong></td>
<td><strong>0.34</strong></td>
<td><strong>3747</strong></td>
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<tr>
<td>Model 3</td>
<td>+ lithology</td>
<td><strong>0.90</strong></td>
<td><strong>0.41</strong></td>
<td><strong>3540</strong></td>
</tr>
<tr>
<td>Model 4</td>
<td>+ Snow thickness</td>
<td><strong>0.91</strong></td>
<td><strong>0.45</strong></td>
<td><strong>2458</strong></td>
</tr>
</tbody>
</table>

The predictive variables used in the models were chosen using Effect Likelihood Ratio tests (Prob > ChiSq < 0.0001). The Likelihood-ratio Chi-square tests are calculated as twice the difference of the log-likelihoods between the full model and the model constrained by the hypothesis to be tested (the model without the effect).
Lithology impact

Dotted areas depict significant rock types in the analysis

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The role of snow?

• Even the plain model with mere coordinates and approximated snow thickness produced quite a decent fit: $R^2(U) = 0.36$, ROC = 0.87
Conclusions

Spruce forest line in northern Finland follows climatic drivers (temperature and late winter snow pack) but the small- and midscale spatial variation is contributed by the edaphic factors.

Snow-pack thickness has an important predictive value. The early season soil water content is higher with sites of thick late winter snow - a critical factor for spruce growth and survival of seedlings.

Soil physical-chemical properties bring more small-scale accuracy to the model.

Models and experimental studies are needed to simulate the future forest line of spruce.