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Predictability of boreal forest soil bearing capacity by machine learning

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Abstract

In forest harvesting, terrain trafficability is the key parameter needed for route planning. Advance knowledge of the soil bearing capacity is crucial for heavy machinery operations. Especially peatland areas can cause severe problems for harvesting operations and can result in increased costs. In addition to avoiding potential damage to the soil, route planning must also take into consideration the root damage to the remaining trees. In this paper we study the predictability of boreal soil load bearing capacity by using remote sensing data and field measurement data. We conduct our research by using both linear and nonlinear methods of machine learning. With the best prediction method, ridge regression, the results are promising with a C-index value higher than 0.68 up to 200 m prediction range from the closest point with known bearing capacity, the baseline value being 0.5. The load bearing classification of the soil resulted in 76% accuracy up to 60 m by using a multilayer perceptron method. The results indicate that there is a potential for production applications and that there is a great need for automatic real-time sensoring in order to produce applicable predictions.

Keywords: Terrain trafficability; Soil bearing capacity prediction; Forest harvesting; Machine learning; Open data

1. Introduction

Terrain trafficability in forests is currently one of the most important issues in boreal timber harvesting. Conducting harvesting operations during good soil bearing conditions is crucial since improperly timed operations can cause serious economical and ecological damage. Vehicular loading exceeding soil strength causes not only soil damage, but also damage to trees, mostly to the tree roots, but sometimes to tree stem as well due to increasing uncontrolled motion of the forwarder.

Damage to roots and stems can lead to fungal infection which eventually causes wood discoloration and in the worst case decay. In addition, the water and nutrition conditions of the forest soil can change as a result of soil settling (Ring et al., 2006). The operation of forest machines is therefore avoided during the period of high soil failure risk and the harvesting is postponed to the winter when soil is normally frozen. It is estimated that the seasonal variation in timber procurement causes approximately 100 M €costs in Finland alone (Pennanen and Mäkelä, 2003). In addition, operations in poorly bearing conditions increase time and fuel consumption and decrease the efficiency of harvesting operations (Sirén et al., 2013).

Furthermore, deep ruts caused by forwarding affect the general acceptability of the forest operations. The costs caused by challenging trafficability conditions could be decreased by additional information on soil conditions, especially soil bearing capacity. The load bearing capacity

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of soil is often described by its penetration resistance. Accordingly, forest operations could be planned to be performed during adequate bearing capacity or routed to avoid sections of poor bearing capacity, thus minimizing the damage and maximizing the efficiency of harvesting.

In this study we conduct a research on the prediction of soil bearing capacity by using remote sensing and field measurement data. We have analyzed two cases, firstly visual soil damage classification and secondly soil penetration resistance prediction. The data sets are provided by Natural Resources Institute Finland (LUKE), Metsäteho Ltd., the Geological Survey of Finland (GTK), National Land Survey of Finland (NLS) and Finnish Meteorological Institute (FMI). Similar studies have been conducted in Pohjankukka et al. (2014a,b) where soil properties such as type and water permeability was estimated in order to have predictions on the soil bearing capacity using public data. Related studies have been conducted in Azzalini and Diggle (1994) where soil respiration rates are predicted from temperature, moisture content and soil type and (Schulte et al., 2005), where the soil type in desert landscapes was predicted using classification tree analysis.

2. Background

Timber harvesting systems vary across the world. In Finland, the mechanized cut-to-length harvesting system is utilized almost exclusively (Uusitalo, 2010). Harvesting operations in Finland are typically commercial thinnings or clear cuttings. In a traditional thinning operation only a part of the trees, on average 30%, are cut, leaving most of the trees standing (Äijälä et al., 2014). Depending on stand properties thinnings are typically done one to three times during the rotation of a stand (Äijälä et al., 2014).

The rotation period of a stand usually ends to a final felling, where all trees of commercial value are cut. Some individual tree clusters are left standing for example to retain biodiversity (Gustafsson and Perhans, 2010). The structure of private forest ownership in Finland has changed, which is causing pressure to change the forestry practices, as many forest owners are no more dependent of forest income and emphasize multiple values in management decisions. The commercial aspect of harvesting has become less pronounced, while environmental standpoint has gained more attention. More than a half of the forest owners are satisfied with the current forest management practices, where every sixth forest owner feels unsatisfied especially with clear cuttings, lack of management alternatives, soil preparation and damage caused by heavy machinery (Hänninen and Karppinen, 2010). So far the use of alternative forest management methods including selection cuttings has been marginal concentrating on urban forests, landscape protection areas, valuable habitats, riparian and other buffer zones. If uneven-aged forest management becomes more popular in future, it increases the amount of thinnings. Uneven-aged thinnings place even more challenges to harvesting machinery in respect to avoiding damages and risk of root rot.

3. Research area and data sets

3.1. Research area

The data sets were collected from various locations around the area of Pieksämäki, a municipality located in the province of Eastern Finland 62°18′N 27°08′E. The research areas were divided into two cases based on the response variable. The predictor data sets varied between the two cases as illustrated in Tables 1 and 2.

3.2. Multi-source national forest inventory data

The Multi-Source National Forest Inventory (MS-NFI) holds the state of Finnish forests in high spatial resolution (20 m). The data is updated every second year. The parameters are derived by generalizing the field measured sample plot data applying mainly Landsat imagery and KNN method as well as digital map information. 43 numerical features include information regarding, for example, biomass and volume of growing stock and site type. These multi-source features exhibit built-in dependencies, thus the final number of useful features is lower. An excellent, detailed description regarding the MS-NFI is given by Tomppo et al. (2008).

3.3. Digital elevation model data

We downloaded digital elevation model (DEM) data from the file service for open data by the National Land Survey of Finland. The DEM was made from airborne laser scanning data with the resolution of at least 0.5 samples/m^2, which is equivalent to approximately 1.4 m distance between samples. The grid size of the DEM data set was 2 m. Several geomorphometric variables were derived from the NLS DEM in SAGA GIS environment. In our analysis we used the geomorphometric features: plan curvature, profile curvature, slope, topographic wetness index, flow area, aspect, diffuse insolation and direct insolation (Zevenbergen and Thorne, 1987; Wood, 2009, 1996; Beven and Kirkby, 1979; Seibert and McGlynn, 2007). These derived features are more efficient for prediction than raw height data alone.

Table 1
Predictor data sets used in prediction of soil damage response variable. RS stands for remote sensing data and FM stands for field measurement data.

Data set	Type	Grid size
Digital Elevation Model data	RS	2 m
Multi-source National Forest Inventory data	RS	20 m
Soil type data	RS	20 m
Peatland data	RS	20 m
Gamma-ray spectroscopy data	RS	50 m
Weather data	RS	10 km