RADIATA MANAGEMENT TECHNICAL NOTE

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Site Specific Radiata Pine Productivity Modelling Using Terrain Attributes

Summary

Existing national models for *Pinus radiata* productivity explain 67% and 58% of the variance in Site Index and 300 Index respectively. The unexplained variance may be due to a number of site-specific factors not available at the national level, such as variation due to microsite effects. For example, analysis of plot measurements in a study site at Puruki identified substantial differences in growth with aspect and slope (Beets pers. comm.). The current study was designed to assess microsite variation on tree productivity in Esk Forest, Hawke's Bay.

At the Esk forest we mapped terrain attributes at a 1-m resolution and used these variables to predict 300 Index. The slope explained 21% of the variance in *Pinus radiata* 300 Index (P<0.001). Ruggedness index, stream power index, and plan curvature were also highly correlated with radiata pine productivity, but these variables were also strongly correlated with slope, rendering them unable to be implemented in the final model. On areas with slopes <20^o, the 300 Index averaged 35.1 m^3 ha^{-1} yr^{-1} while 20^o to 30^o slopes averaged 32.8 m^3 ha^{-1} yr^{-1}. On plots with slope greater than 30 degrees, the 300 Index averaged 29.8 m^3 ha^{-1} yr^{-1}.

Overall little of the variance in 300 Index across the Esk forest could be attributed to anything other than slope. This study shows how difficult it can be to predict variability across localised sites.

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Introduction

Scion's research has developed a *Pinus radiata* national productivity model and map that explains 67% and 58% of the variance in Site Index and 300 Index respectively. Validation data for these models illustrated that by kriging the residuals, predictions were improved substantially. Kriging is a geostatistical technique that interpolates the value of a random field at an unobserved location from observations of its value at nearby locations, where the residual is the difference between the observed and predicted values.

Although we considered the final productivity surfaces (national 300 Index surface) that were developed to be a major advance in the prediction of *P. radiata* productivity across New Zealand, validation statistics found that 30% and 39% of the variance for Site Index and 300 Index respectively were not explained. Some of the possible candidate variables not used in the model were; soil nutrition, leaf area index, topographic exposure index and the effects of soil compaction, erosion, and disease. The development of these surfaces (excluding topographic exposure because we have already developed these) and their inclusion into future models should provide increasingly accurate productivity models and surfaces.

The national 300 Index productivity model was developed using coarse ancillary data (e.g. scales of ~1:50,000) that do not always capture the variation at finer scales (e.g. scale of ~1:5,000). Therefore investigation into the role that fine resolution data (e.g. 1-m cell size resolution) such as terrain attributes and soil information may have on the local variation of forest productivity is warranted.

This research will determine the relationships between *P. radiata* productivity and (1) soil nutrition collected at the plot level, and (2) primary and secondary terrain attributes derived from fine resolution LiDAR height information.

Methods

LiDAR Information

Esk forest (~268 ha) has the advantage of already having high quality LiDAR information acquired through a previous FFR project. This high quality LiDAR data allows characterisation of the landscape to at least a one-metre resolution. From a 1-m DEM we developed a representation of the terrain at the time the LiDAR was collected.

Terrain Attributes

Primary and secondary terrain attributes were developed to determine if there was a relationship with *P. radiata* productivity at a finer scale. Primary terrain attributes that were directly developed from the 1-m DEM included elevation, aspect, slope, hillshade, flow-path direction, and total, profile and plan curvatures. Secondary terrain attributes that were derived from two or more primary terrain attributes included topographic wetness index, upslope contributing area, stream power index, roughness index, solar radiation index, topographic exposure, relative elevation, and combinations of slope and aspect. See Figure 1 for examples. All primary and secondary terrain attributes were developed at a 1-m resolution for Esk forest. Because *P. radiata* productivity was the main focus of this study and the Esk plots were ~0.05 ha, the final terrain attributes were averaged to the plot level using the focal neighbourhood function within ArcGIS.

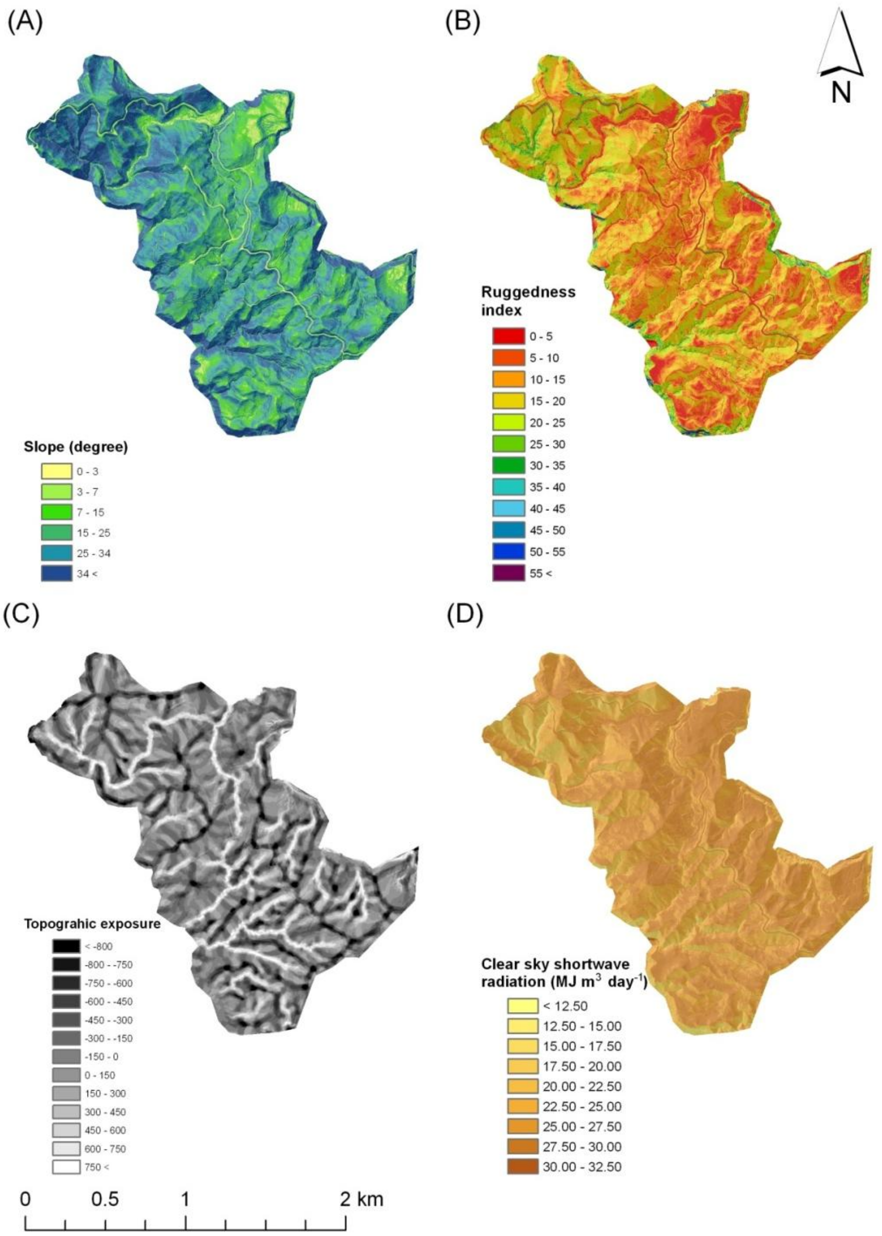

Figure 1: Graphics derived from LiDAR data showing the spatial variation in (A) Slope, (B) Ruggedness Index, (C) Topographic exposure, and (D) Clear sky shortwave radiation for the Esk forest (~268 ha).

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Ordinary and Regression Kriging

The geostatistical techniques ordinary and regression kriging were also used to assess whether a 300 Index map could be developed for Esk forest. Kriging is a geostatistical technique that interpolates the value of a random field at an unobserved location from observations of its value at nearby locations. Regression kriging develops a multiple linear regression model (MLR) and the residuals (difference between the observed and actual 300 Index values) are kriged using the ordinary kriging technique. The kriged residual surface is added to the original MLR model in an attempt to improve model and surface predictions. The mapping process was undertaken using ArcGIS geostatistical analyst program.

Pre-harvest Inventory Plots and Soil Nutrition

A total of 209 pre-harvest inventory plots were available for the calculation of stand volume across the Esk forest (Figure 2).

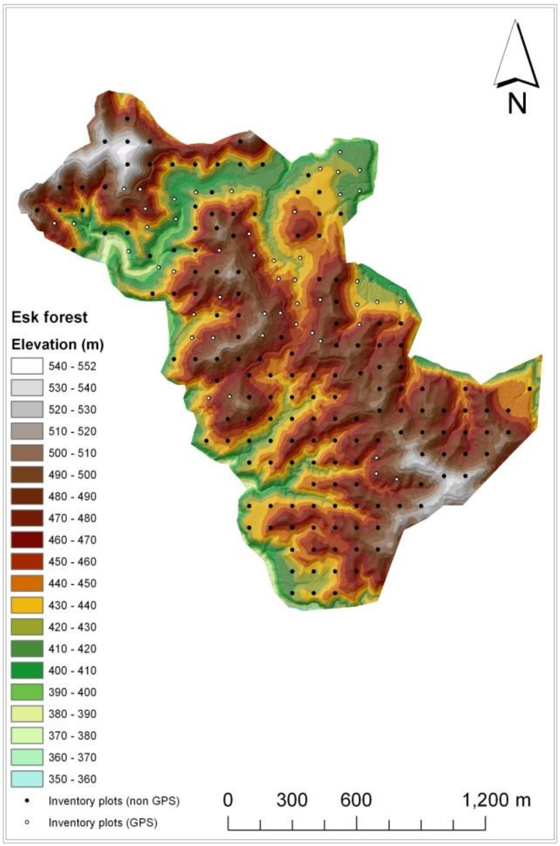

Figure 2: Distribution of preharvest inventory plots used to model *Pinus radiata* productivity (black filled circles). White circles indicate soil sample plots with corrected GPS locations.

The radiata pine calculator was used to estimate the 300 Index for each plot. Input data included management history, plot stocking, basal area, and mean top height. At 50 of the inventory plots (white enclosed circles, Fig. 2) soil samples were collected (0 to 5 cm) using standard Scion plot sampling protocol to provide samples for total carbon and nitrogen. At each of the 50 subplots a GPS was used to determine exact plot locations. Locations of the remaining 159 plots were known, but to a lower, unknown, level of precision.

Statistical Analysis

Correlation analysis was undertaken to determine the main factors associated with site-specific productivity. Multiple linear regression was undertaken on a randomly selected subset of 167 plots, with the remaining 42 plots set aside as a validation dataset. Multiple linear regression was also performed separately for the 50 plots with accurate GPS locations.

Results

The measured 300 Index shows a large range in productivity from 17.5 to 45.7 m^3 ha^{-1} yr^{-1}. The measured carbon-to-nitrogen ratio had a relatively narrow range with a mean of 16.8 (Table 1).

Table 1: Variation in productivity, soil nutrition, and terrain attributes.

Variable	Range	Mean
300 Index (m^3 ha^{-1} yr^{-1}) [a]	17.5 - 45.7	32.1
Total carbon (%) [b]	2.4 - 8.1	5.2
Total nitrogen (%) [b]	0.1 - 0.5	0.3
C: N ratio [a]	14.6 - 21.7	16.8
Slope (degrees) [a]	3 - 47	25
Ruggedness index [a]	1.8 - 27.7	12.6
Stream power index	-1.9 - 2.2	0.9
Profile curvature (radians per 100m) [a]	-6 - 13.6	0.1
Summer solar radiation index (clear sky shortwave radiation – MJ m^{-2} day^{-1}) [a]	16.8 - 29.9	26.2
Topographic exposure [a]	-739 - 706	-31

[a]: *N*=209 observations
[b]: *N*=50 observations

Correlation analysis showed that slope, ruggedness index, stream power index, followed by profile curvature all had highly significant correlations with 300 Index (Table 2). Note that correlations were higher for the 50 sites where exact GPS locations

were known, with summer solar-radiation index the only exception.

Table 2: Correlations (*r*) between 300 Index and independent environmental variables for *Pinus radiata*. *P* values describe the level of statistical significance.

	Model sites		50 sites	
Variable	*r*	*P* values	*r*	*P* values
Slope	-0.46	<0.0001	-0.59	<0.0001
Ruggedness index	-0.46	<0.0001	-0.59	<0.0001
Stream power index	-0.38	<0.0001	-0.47	0.0005
Profile curvature	-0.26	0.0007	-0.3	0.03
Curvature	0.26	0.0008	0.33	0.02
Summer solar radiation index	0.3	0.0001	0.29	0.04
Topographic exposure	-0.25	0.001	-0.31	0.03

We also investigated the impact of aspect and slope by combining the two variables into high and low slopes in a north, south, east, and west direction. For the Esk data, slope was found to be a main determinant, and aspect was not found to play a role in productivity across Esk.

Investigation using ordinary and regression kriging was also attempted. However, the dataset was found to have poor spatial dependence (little or no relationship with distance separating observations).

Discussion and Conclusion

Using multiple linear regression, the strongest relationship between 300 Index and soil or terrain attributes was slope. A final model using slope was able to explain ~ 21% of the variance in 300 Index for the Esk forest.

On areas with slopes <20^o, the 300 Index averaged 35.1 m^3 ha^{-1} yr^{-1} while 20^o to 30^o slopes averaged 32.8 m^3 ha^{-1} yr^{-1}. On plots with slope greater than 30 degrees, the 300 Index averaged 29.8 m^3 ha^{-1} yr^{-1}. Ruggedness index, stream power index, profile and total curvature, summer solar radiation index, and topographic exposure had a strong relationship with productivity indices. However, all of these variables were highly correlated with slope, rendering these variables unusable within a model that included slope.

Neither the soil C:N ratio, nor any other soil variable, was found to be significantly associated with productivity at this site. However, although soil C and N ranged considerably across the site, their ratio did not (Table 1). Therefore, the lack of any association with productivity was not surprising.

All pre-harvest inventory plots were located using the standard industry methods. The 50 plots randomly selected for soil data collection were GPS located, substantially improving correlations with terrain attributes. Interestingly, Table 2 shows the overall improvement found in correlation analysis by increasing the spatial location accuracy even without increasing numbers. This improvement in the relationships between independent variables and productivity highlights the importance of determining spatial locations accurately.

Overall little of the variance in 300 Index across the Esk forest could be attributed to anything other than slope. This study shows how difficult it can be to predict variability across localised sites.