Forest Ecology and Management 357 (2015) 1–9

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Comparing parametric and non-parametric methods of predicting Site Index for radiata pine using combinations of data derived from environmental surfaces, satellite imagery and airborne laser scanning

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ARTICLE INFO

Article history:
Received 12 June 2015
Received in revised form 30 July 2015
Accepted 1 August 2015

Keywords:
airborne laser scanning, ALS
Enhanced Vegetation Index, EVI
LiDAR
Normalised Difference Vegetation Index, NDVI
Plantation forestry
Productivity surfaces
RapidEye

ABSTRACT

Site Index (*SI*) is one of the main measures of forest productivity used throughout the world. For even-age plantations Site Index is defined as the height of dominant trees at a given reference age. Site Index is normally determined from field measurements and expressed from these measurements at the resolution of the stand. Development of fine resolution spatial surfaces describing variation in productivity across broad landscapes would be of considerable use in improving stand management. Using data obtained from a large *Pinus radiata* D. Don forest located in the central North Island, New Zealand, the objective of this study was to compare the precision of parametric and non-parametric models of Site Index that included explanatory variables extracted from aerially acquired Light Detection and Ranging (LiDAR), satellite imagery or environmental surfaces and combinations of these three data sources. Models were constructed both with and without age as an explanatory variable as managers may not always have access to stand age. A total of 32 models (16 data sources × two model methods) were constructed using data from 484 plots. Validation methods used to examine precision and bias of these models included leave one out cross validation and *k*-fold analysis.

For all but one of the 16 data sources parametric models were found to be more precise than non-parametric models. Inclusion of stand age as an explanatory variable improved the precision of all but one model. For parametric models that included stand age, the R^2 and RMSE (in brackets) for models with (i) all metrics derived from satellite imagery, (ii) environmental surface variables, (iii) variables derived from satellite imagery and environmental surfaces, (iv) LiDAR metrics and (v) all available variables were, respectively, 0.237 (2.850 m), 0.613 (2.267 m), 0.716 (2.025 m), 0.883 (1.378 m) and 0.801 (1.672 m). These results show that LiDAR was the most useful data source for precise and unbiased prediction of Site Index. The parametric model created using variables derived from environmental surfaces and satellite imagery was also very precise showing that, in combination, these datasets may provide a useful alternative for predictions of Site Index when LiDAR data are not available.

1. Introduction

Site Index is the most common measure of forest site productivity used worldwide, serving as an important baseline for forest-level planning and helping to formulate silviculture strategies. This variable, which expresses the height of dominant and/or co-dominant trees at a given age (Skovsgaard and Vanclay, 2008), is a useful measurement as it is relatively unaffected by stand density. Site Index integrates the combined effects of the most important determinants of tree growth such as topography, soil characteristics and climate (Perron et al., 1996).

Determination of Site Index is generally undertaken from field measurements. Typically estimates of Site Index are made from measurements of tree heights within the plot and stand level estimates of Site Index are made by averaging plot values within a stand. However, the resulting estimate aggregations may not be adequate to detect local growing variations within stands resulting from interactions between climate, soil, and genetic factors (Véga and St-Onge, 2009). Consequently, many methods have been used to develop spatial maps that provide greater definition of Site Index.

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http://dx.doi.org/10.1016/j.foreco.2015.08.001

Spatial models of Site Index with reasonable accuracy have been developed from information held in geographic information systems (GIS). This approach has considerable merit as forest managers generally have access to GIS and a number of potentially useful predictive variables. The last two decades have seen rapid increases in the number of spatial surfaces covering a diverse range of climatic and edaphic variables (Watt and Palmer, 2012). These environmental surfaces have been successfully used to develop spatial surfaces describing Site Index for a range of plantation species (Palmer et al., 2009a, 2012; Watt et al., 2009).

Airborne Light Detection and Ranging (LiDAR) provides a very useful means of characterising the forest canopy in three dimensions. Since the first application of LiDAR in forestry over a decade ago (Nilsson, 1996), the technology has been widely used to spatially quantify variation in tree height and crown dimensions at resolutions ranging from the stand level (Naesset and Bjerknes, 2001; Hall et al., 2005), plot level (Hyyppä et al., 2001; Holmgren et al., 2003; Lim and Treitz, 2004; Popescu et al., 2004) to individual tree level (Persson et al., 2002; Coops et al., 2004; Holmgren and Persson, 2004; Yu et al., 2004; Roberts et al., 2005; Chen et al., 2006; Popescu and Zhao, 2008).

Studies have shown that LiDAR can also be used to predict Site Index. Empirical models have been constructed using the relationship between LiDAR metrics and plot level measurements of predominant tree height, that is then corrected for age and converted to a Site Index (Rombouts et al., 2010). Stand age and LiDAR metrics describing height have also been directly combined in a non-linear mixed effects modelling formulation to predict Site Index from measurements of dominant height (Packalén et al., 2011). An alternative approach has used LiDAR estimates of height for individual trees that are then combined with stand age to estimate stand level Site Index (Chen and Zhu, 2012).

Although less detailed than LiDAR the use of metrics derived from satellite imagery provides a far more cost effective means of predicting stand attributes. Numerous studies have shown that multispectral satellite data that includes various combinations of spectral information, spectral ratios and texture can be utilised in models to map important forest attributes, such as tree height and volume over the land surface (Donoghue and Watt, 2006; Kayitakire et al., 2006; McRoberts and Tomppo, 2007; Ozdemir, 2008; Shamsoddini et al., 2013). Given the utility of this data source for predicting stand dimensions satellite imagery should also provide a means of predicting Site Index particularly when stand age can be included in the model to normalise spectral, ratio and textural information. Despite the potential of this data source less research has investigated the utility of satellite imagery in predicting productivity indices such as Site Index.

Managers of forests are likely to have access to a wide variety of spatial information. Although stand age is an important determinant of Site Index this variable is often not available for some species or settings such as national forest inventories or in tropical zones (Tomé et al., 2006). Consequently, there is considerable interest in determining the utility of a variety of different sources of information, in the development of productivity surfaces such as Site Index. Despite this, we are unaware of any research that has compared the precision of models of Site Index created from environmental surfaces, satellite imagery or LiDAR or various combinations of these three data sources.

This study used data obtained from a *Pinus radiata* D. Don plantation located in the central North Island of New Zealand. The objective of the research was to compare the accuracy of parametric and non-parametric models of Site Index that included explanatory variables extracted from LiDAR, satellite imagery or environmental surfaces and combinations of these three data sources. Models were constructed either with or without age as an explanatory variable.

2. Methods

2.1. Study site

Data was acquired from Kaingaroa forest which is located in the Central North Island of New Zealand (Fig. 1). Kaingaroa is New Zealand's largest contiguous plantation covering around 180,000 ha. The majority of the forest occupies the pumice plateau within the Central North Island and has generally flat topography. The northern part of the forest is characterised by rolling hills and areas of steeper terrain. The terrain gradually slopes upwards towards the forest's southern extent leading to a notable gradient in productivity. The forest soils are classified as Orthic Pumice belonging to the Kaingaroa series (Hewitt, 1993) with those in the north of the forest derived from Tarawera ash. The dataset was restricted to stands of *P. radiata* which cover 92% of the total forested area.

2.2. Field measurement

Systematic sampling was employed to locate field plots throughout the study forest. In total 500 plots were located at the intersections of a grid that had a randomised start point and orientation and were measured between the 1st March and 8th August 2014. The sampling unit was a slope adjusted 0.06 ha bounded, circular field plot. A survey grade global positioning system (GPS) was used to fix the centre of each plot. Within each field plot diameter at breast height (*dbh*) was measured for all trees. Tree height was measured for a subset of plot trees, selected from across the *dbh* range, that were free from excessive lean or malformation.

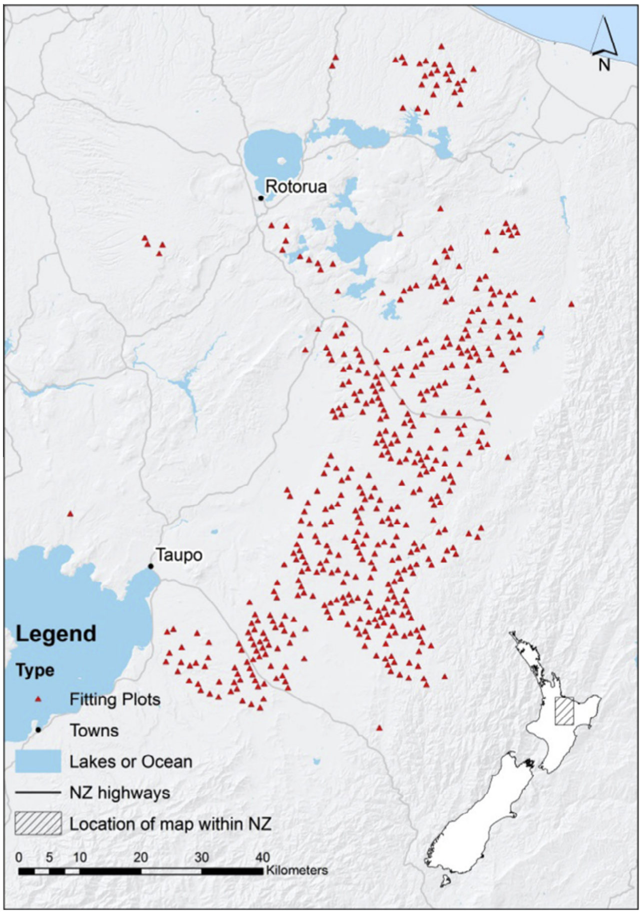

Fig. 1. Map showing the location of the field plots used in this study.