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Defining sustainability of plantation forests through identification of site quality indicators influencing productivity—A national view for New Zealand

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Abstract

New Zealand is committed to developing sustainable forest management practices as evidenced through Government involvement in international forestry agreements such as the Montreal Process, and the forestry sector's adoption of forest certification mechanisms. In support of this commitment, it has been identified that there is little quantitative evidence of the interactions of plantation forestry on site quality and long-term site productivity. To address this issue, a nationwide study of site quality was initiated at 35 key sites covering the range of edaphic and environmental conditions representing the productivity envelope for New Zealand plantation forests. At each location, within the productivity envelope, eight short-term site quality plots were planted at a very high stand density (40,000 stems ha^{-1}) to rapidly identify key soil indicators of growth which may be useful for determining site sustainability. In addition, a permanent sample plot was established by planting seedlings at conventional stem densities (500–1100 stems ha^{-1}). At each site, a factorial design was applied with the following three factors: species (*Pinus radiata* and *Cupressus lusitanica*), fertiliser (no fertiliser and nutrients supplied in excess of crop demands) and disturbance (low and high disturbances). After two years of increment, initial analyses are presented which partition treatment and site effects on increment and identify key soil properties that influence increment of the two species.

Volume increment over the two-year period was most strongly influenced by site, ranging 50-fold and 15-fold across sites for *C. lusitanica* and *P. radiata*, respectively. For the treatments, species accounted for most of the variance in increment, with mean volume increment across all sites of *P. radiata* significantly exceeding that of *C. lusitanica* by 56%. Fertilisation also significantly influenced volume increment inducing mean gains of 30%. Disturbance had a significant, but comparatively weak effect, reducing mean volume increment by 9%. After correction had been made for environment (temperature and rainfall), soil properties that were most strongly related to volume increment for both species included CN ratio, total soil nitrogen, total soil

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phosphorus, organic phosphorus and depth of the A horizon. When soil properties were included in combination, the best predictive models of volume increment formulated for both species included rainfall, temperature, the product of total soil nitrogen and total soil phosphorus and depth of the A horizon.

Keywords: Sustainability; Forest productivity; Soil quality; Indicators; *Pinus radiata*; *Cupressus lusitanica*; New Zealand

1. Introduction

New Zealand is a member of the 12 country Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests. "The Montreal Process" (Anon., 1995) and the New Zealand Government have agreed to report on progress towards sustainable forest management as measured by indicators grouped within seven criteria. Criterion 2, 'Maintenance of Productive Capacity of Forest Ecosystems', and criterion 4, 'Conservation and Maintenance of Soil and Water Resources', address the important issue of whether plantations can be grown for an indefinite number of rotations without adversely affecting soil quality or the site's capacity for net primary production. Although the Montreal Process and certification schemes identify potential indicators that can be used to describe site quality, foresters need tools, guidelines or management systems to enable them to turn these high-level, subjective sustainability goals into indicators that can be measured quantitatively (Richardson et al., 1999).

Despite the importance of sustainability for the long-term viability of the forestry sector, there is little direct evidence to indicate how successive rotations, characteristic of plantation forestry, influence site productivity. As well-designed long-term field trials for investigating sustainability are rare, evidence demonstrating changes in productivity are uncommon, even at a regional level (Dyck and Cole, 1990). Within New Zealand, there are considerable data that may be used to examine temporal changes in productivity of the most commonly planted plantation species *Pinus radiata*, as annual growth has been measured in permanent sample plots in some plantations for over 60 years (Woollons, 2000). However, these data are of questionable value in assessing temporal changes in soil quality because they are invariably confounded by changes over time in management practices, tree genotype and climate (Morris and Miller, 1994; Richardson et al., 1999; Woollons, 2000). Mechanistic models are also of limited use in assessing changes in site productivity as our knowledge of many of the key ecosystem processes is incomplete (Yarie, 1990).

The importance of well-designed long-term field experiments for detecting changes in site productivity over time has been emphasised by many researchers (Adlard et al., 1984; Dyck and Cole, 1990; Richardson et al., 1999). Ideally, these trials should be installed across a wide environmental range and run over a number of successive rotations. Within the trials, it is vital to control management and genotype factors and monitor climatic parameters, so that any changes in productivity can be correctly attributed to alterations in site quality (Morris and Miller, 1994).

Although long-term field trials are important for determining if site productivity changes over time, these trials do little to elucidate the mechanisms causing alterations to site quality (Adlard et al., 1984; Richardson et al., 1999). Understanding these mechanisms is essential as it provides the information necessary for managers to predict and prevent or ameliorate declining site quality. Measurements of soil properties are useful in this regard as indicators of changes in site quality and provide considerable information on factors which result in changes in site quality and productivity over time. As forest productivity is an important indicator of sustainability, these soil properties must be related to measures of performance such as net primary production (Richardson et al., 1999). Use of this information and the development of relationships between various management practices and soil properties would enable site-specific recommendations to be made on management practices necessary to maintain the productive capacity of the site (Richardson et al., 1999).

One approach that could be used to rapidly determine the key soil properties influencing site