Enhancing the productivity of radiata pine forestry within environmental limits

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Abstract

Ensuring that forestry remains a profitable land use is critical to providing a stable long-term timber supply. Productivity improvements are a key means for achieving increased profitability, all other factors remaining equal. In developing strategies aimed at increasing productivity, it is important to consider that productivity is a measure of business efficiency or how well input resources are converted into outputs. If increases in outputs are simply achieved through a proportional scaling up of inputs then there is no gain in productivity. Such an approach may actually carry with it an increased exposure to biophysical and market risks.

Forest managers therefore need to increase the biological productivity of their forests in a cost-effective and sustainable way, and this is a key focus of the Growing Confidence in Forestry's Future research programme. In this paper we present an overview of forest productivity concepts, which can be used to develop strategies aimed at increasing the biological productivity of forests. Such strategies include the choice of genetic material, manipulation of soil resources and improved site utilisation through stand stocking. We also discuss the importance of ensuring that gains in productivity are achieved through practices that can be demonstrated as being environmentally acceptable and are sustainable over multiple rotations.

The drive for enhanced productivity

Raising the profitability of commercial forestry investments is an imperative for the entire New Zealand forestry sector. Further investment in forest growing relies on current operations being profitable and competitive with other land uses. To achieve the Woodco and Business Growth Agenda targets (Wood Council of New Zealand, 2012; New Zealand Government, 2012) of more than doubling the value of this country's forest industry export earnings, major investment is required in new and upgraded processing facilities. The assurance of a consistent future wood supply, both in terms of quantity and quality, will increase the confidence of those considering investment into the processing sector.

One key factor that will influence the long-term wood supply is the competitiveness of forestry investments. Land is the single biggest capital cost for forest investors and its value is a major driver of investment return. To secure new land for forestry, or to retain existing forest land, investors must compete with other rural land uses. Productivity improvements over time are therefore essential to sustain or increase profitability and thus enable forestry to compete successfully with alternative land uses.

What is productivity and how is it measured?

Productivity is a measure of business efficiency or how well a forest grower converts input resources into production. It is one of the components that impacts profit; the other is price. If log prices and the price of all inputs remain constant, the only way to increase profit is to improve productivity. As log prices are set by market forces outside the forest, productivity is the one factor that can be controlled or influenced by the grower. If productivity cannot be improved, the only way to increase profit is via a change in the terms of trade, either through an increase in output prices and/or a decrease in input prices (Figure 1).

For a forest grower to become more efficient they must increase the amount and inherent value of wood they produce and/or reduce the cost of inputs such as site preparation, silvicultural operations and harvesting. Productivity enhancement and improving operational efficiencies are therefore key research priorities in the Forest Owners Association Science and Innovation Plan (Forest Owners Association, 2012). Increasing forest productivity in a sustainable manner is also the major focus area of the Growing Confidence in Forestry's Future programme, which is funded by the Ministry for Business, Innovation and Employment and the Forest Growers Levy Trust.

Productivity can be measured in a number of different ways giving rise to a number of different productivity metrics. These can be grouped into single factor (relating a measure of output to a single measure of input such as land or labour) and multi-factor (relating a measure of output to a bundle of inputs). DairyNZ use a multi-factor approach to assess the productivity of the dairy sector in this country. During the decade ending June 2012, milk production per hectare on the average New Zealand owner-operator dairy farm increased by 18% (DairyNZ, 2013). However this extra production has come from increases in inputs such as capital (cows and infrastructure) and farm working inputs (feed, fertiliser, overheads, etc). Overall, the value of outputs has increased 6.3% over the last decade, while input costs increased 6.5% (DairyNZ, 2013, p.14). Total factor productivity has therefore actually declined by 0.2% over this period. This decrease does not take into account the recent drop in milk prices, which will have had a further substantial negative impact on total factor productivity.

There are several aspects to forestry productivity. One relates to the productivity of crews undertaking different silvicultural operations, such as planting, pruning, thinning and harvesting, while another relates to tree growth. Forest managers are familiar with the biological definition of productivity, which is the rate of biomass accumulation in a stand. A key productivity metric in this case is volume mean annual increment (MAI) and a fundamental challenge for the forest-growing sector is how to raise MAI. Earlier studies in the 1980s showed that the average value of maximum MAI for radiata pine stands was approximately 20 $m^3ha^{-1}yr^{-1}$ (based on total recoverable volume) (Shirley, 1984; Shula, 1989). A recent analysis of data from almost 2,500 permanent sample plots established in stands planted after 1975 showed that the average MAI of current forests was 24 $m^3ha^{-1}yr^{-1}$ (based on total standing volume).

Younger stands established during this period have yet to reach their maximum MAI, and this figure is therefore expected to increase in the future due to changes in silviculture and tree improvements. For example, the Central North Island stands to be harvested in 2032 are predicted to have a 30% higher MAI than those harvested in 2007 (Goulding, 2005). If the forest industry wants to double biological productivity then the average MAI will need to increase to more than 40 $m^3ha^{-1}yr^{-1}$. Provided these MAI increases do not adversely affect the inherent value of the wood grown (through a reduction in wood quality), they will translate directly into gross revenue growth. The challenge is that the increase in output must exceed the increase in inputs necessary to achieve it, otherwise there will be no increase in total factor productivity and hence profitability. Given the long-term nature of forest growing there is an added challenge in that the cost of inputs, particularly those incurred at the start of the rotation, is carried for many years and the revenue is only recognised at the end of the rotation. Substantially increasing the cost of inputs in order to achieve greater outputs therefore carries with it a degree of market and biophysical risk.

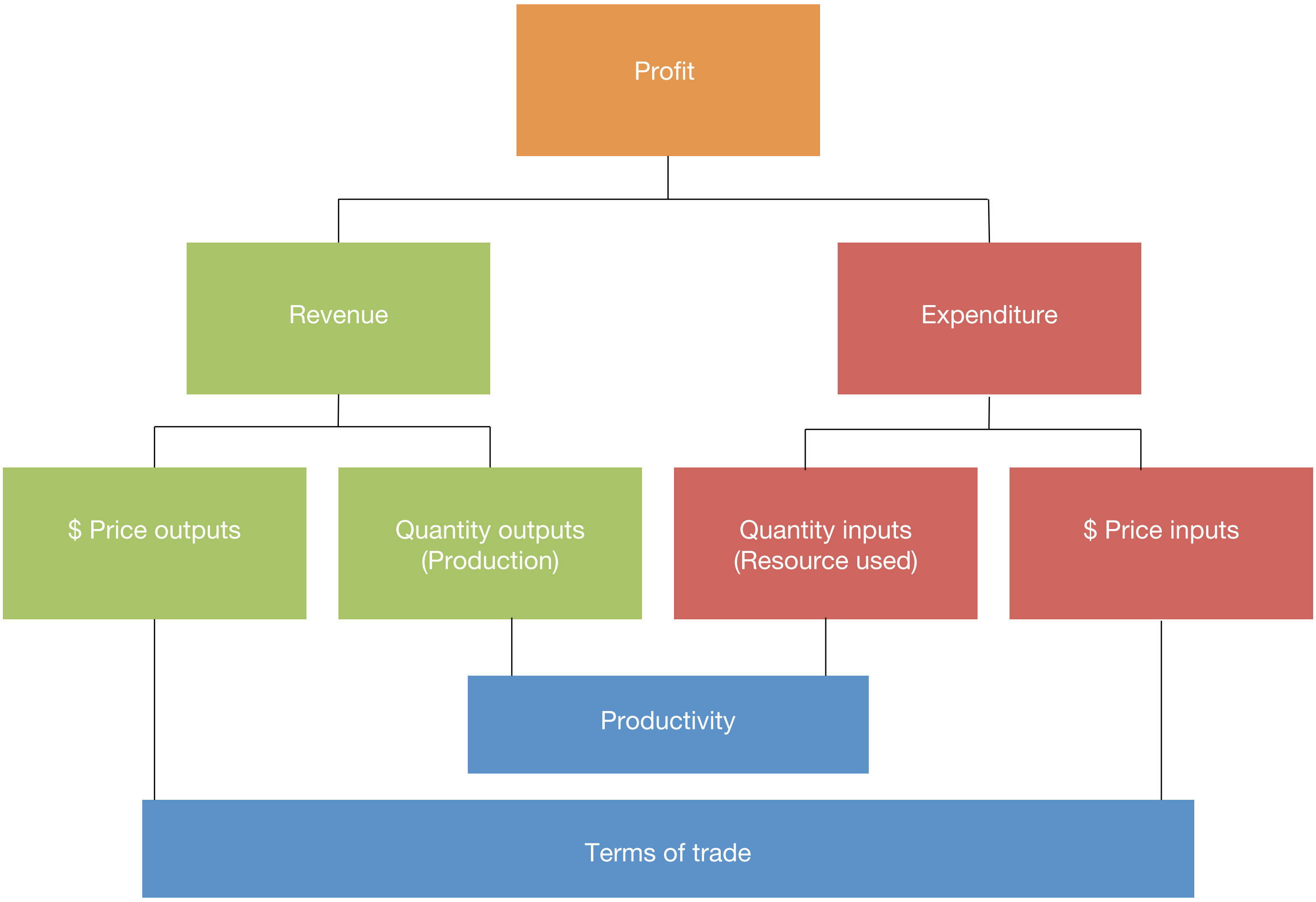

Figure 1: Components of profit (after DairyNZ, 2013)

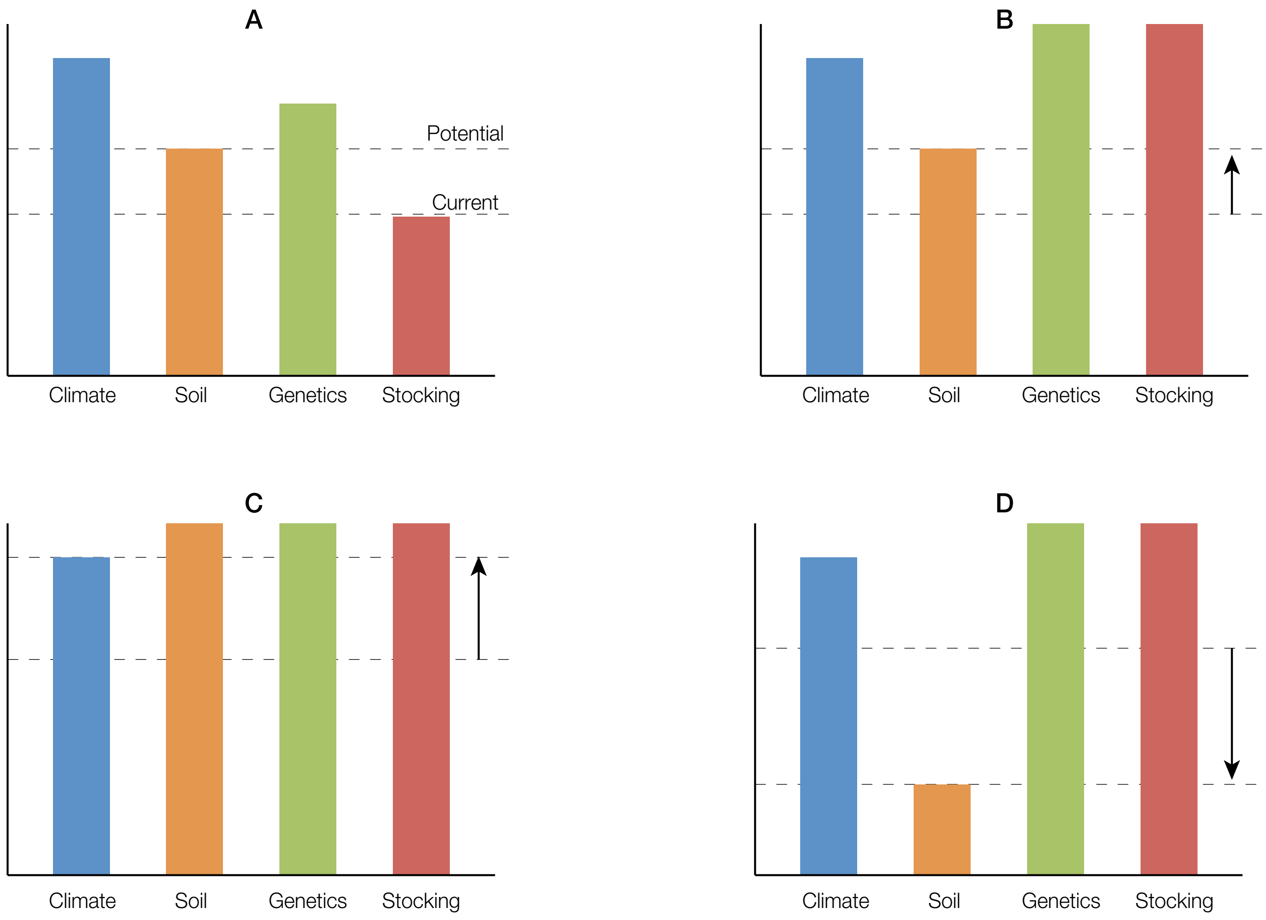

Figure 2: Relationship between current and potential productivity of a plantation as constrained by climate, soils, genetics and stocking. (A) An understocked stand is performing at less than potential as limited by the natural properties of the soil. (B) Improvements in genetics and stocking increase productivity to the level constrained by the soil. (C) Soil amelioration (fertilisation, drainage) raises productivity to a new potential set by local climate. (D) Both current and potential productivity are reduced through soil degradation. After Powers (1999) with kind permission from Springer Science and Business Media

How can we improve productivity?

Forest productivity is a function of site resources and the ability of trees to acquire and use these. It is therefore a function of the interaction between the inherent site productivity potential and forest management (Powers, 1999). Broadly speaking, productivity is affected by climate, soils, genetics and stocking (Figure 2). Climate and soils affect site productivity, while the choice of tree stocks (genetics) and silviculture (stocking) determine the degree to which the inherent site productivity is converted into stand productivity. For example, the potential productivity that can be achieved at a site might be limited by the properties of the soil, but the actual level of productivity might be limited by stocking (Figure 2a). While it is generally beyond the scope of the forest manager to influence climate at the macro level, they are clearly able to manipulate soils, stocking and genetics in order to control productivity. In the following section we present some key forest productivity concepts and outline strategies for increasing productivity.

Site productivity is usually quantified using a site index, which for radiata pine in New Zealand is defined as the mean top height of a stand at age 20 years. The concept of using a site index to define site productivity is based on a strong relationship between height and stand volume. However for radiata pine in New Zealand it has been shown that a site index is only weakly related to basal area growth, particularly in older higher-stocked stands (Kimberley et al., 2005). This is due to the wide range of silvicultural regimes employed and hence levels of growing stock on similar sites. To overcome this problem, a volume-based measure of site productivity called the 300 index was developed. The 300 index is defined as the volume MAI of a 30-year-old stand growing at 300 stems ha^{-1} managed under a direct sawlog regime (Kimberley et al., 2005). Both the site index and 300 index vary considerably across New Zealand (Watt et al., 2010), with higher values found at warmer coastal sites and lower values found at upland and more southerly sites (Figure 3). In addition to temperature, rainfall (soil moisture) and soil fertility are key drivers of site productivity.

Forest management has a major bearing on productivity. Tree improvement, species and provenance choice, establishment methods, stock quality, site modification, overcoming severe nutrient limitations, and control methods for disease and insects have all contributed to achieving current levels of forest productivity. The impacts of some site manipulation treatments, e.g. fertilisation and weed control, have been quantified in terms of a change in the 300 index. Genetic improvement can also be quantified through its impact on site productivity metrics such as the 300 index. For example, recent research has shown that there is a 1.6% increase in the 300 index for every unit increase in GF Plus rating for growth (Kimberley et al., 2015). This represents a volume gain at the end of the rotation of approximately 12% for highly improved radiata pine tree stocks relative to moderately improved tree stocks.

Considerable future productivity gains can be expected from genetically improved trees stocks (Carson et al., 2015), particularly through better matching of specific genotypes to certain sites. The manipulation of forest soils offers many possible options for increasing the productivity and value of future forests as well as mid-rotation stands in existing forests. One way to do this is to increase the sophistication of fertiliser use in forestry (Smethurst, 2010) and to bring it into line with state-of-the-art practices in other primary sectors. A key question here is the extent to which soil microbial activity can be manipulated, particularly in order to increase the availability and effectiveness of soil resources and the certainty with which this can be achieved (Smaill et al., 2010).

Profitability also depends on making best use of a site or the available growing space. In contrast to silvicultural regimes in many other parts of the world that focused on volume maximisation, New Zealand silviculture since the 1960s was characterised by heavy early thinning down to low stand densities (200 stems ha^{-1}) in order to concentrate diameter increment on the pruned butt logs and thus increase the volume of clearwood (Fenton, 1972; Fenton & Sutton, 1968). Based on the relative prices for pruned logs and a positive price-size gradient, Fenton and Sutton showed that more value could be created by growing large pruned logs quickly, which necessitated a deliberate under-stocking of the site.

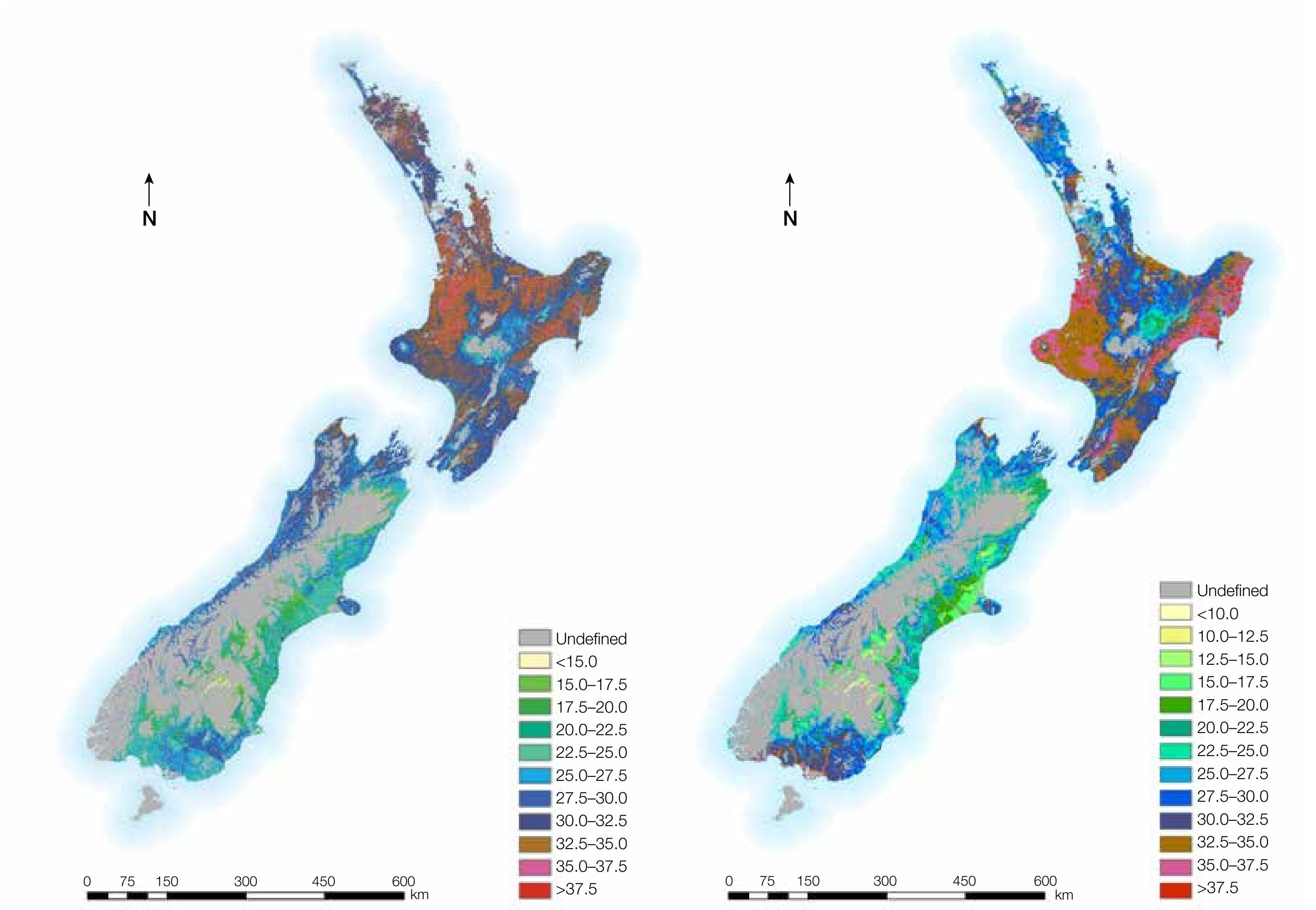

Figure 3: Spatial variation in site productivity across New Zealand based on (a) site index and (b) 300 index

However the current price premiums for pruned logs are generally not sufficient to offset the loss of volume that occurs in low-stocked pruned stands and many forest managers have increased stocking in order to more fully utilise sites. As an aside, this also highlights one of the challenges for forestry – we have to make silvicultural decisions based on unknown or uncertain future market conditions. Forest managers therefore also need to consider market risk and the consequences of making incorrect assumptions about future market conditions. A strategy that keeps future market options open may be most effective for managing such risk.

So how do we know if we are making effective use of our sites? A number of researchers have shown that for a given stand condition there is a well-defined relationship between the number of trees (stand density) and their maximum size (Reineke, 1933; Long & Vacchiano, 2013; Yoda, et al. 1963). This is often known as the maximum size-density relationship. By plotting data from almost 27,000 radiata pine permanent growth sample plots it can be seen that there is a relatively clear upper limit on tree size (quadratic mean diameter or QMD) for a given stand density (Figure 4). In order to quantify the degree to which a particular stand is occupying a site, we need a measure that includes both the number of trees and their size. One such metric is Reineke's stand density index (SDI), which is a composite of tree size (QMD) and number of trees per hectare (stems ha^{-1}) (Reineke, 1933).

SDI can be interpreted as the equivalent number of 25 cm diameter (approximate conversion from 10 inches) stems ha^{-1} in a stand. Applying this equation to the plot data in Figure 4, we find that the maximum SDI for radiata pine in New Zealand is approximately 1,200. This means that the maximum number of 25 cm diameter trees that can be grown per hectare is 1,200, which defines the effective carrying capacity (solid red line in Figure 4). In order for tree size to increase beyond 25 cm some mortality needs to occur. In reality, mortality starts to occur when SDI reaches 55% of the maximum value. Between 35% and 55% of maximum SDI (the dotted and dashed lines, respectively, in Figure 4), a stand is said to be fully stocked. Above 55% of maximum SDI a stand is said to be overstocked and there will be a loss of tree vigour and significant mortality (Smith, et al. 1997). The region between the 35% and 55% lines is known as the management zone. This is the zone in which a site is fully occupied, yet the individual trees still have room to grow.

In seeking to increase productivity, we need to understand the size of the gap between actual productivity and potential productivity on a particular site. A recent global analysis of the yield (productivity) gap in crop plants showed that potential attainable yields are 45% to 70% higher than current observed yields (Mueller et al., 2012). A similar analysis is currently underway for radiata pine in New Zealand using hybrid models to estimate the biophysical potential productivity that could be achieved for a given climate assuming that key soil limitations could be overcome. Data from permanent sample plots have already been used to provide an estimate of the attainable productivity for a particular level of site productivity. This analysis showed that there is a gap of approximately 6 m^3 ha^{-1} yr^{-1} (20%–25%) between the mean level of productivity for a given 300 index and the 90th percentile value. This may not sound that much, but it represents an increase in total standing volume of 180 m^3 ha^{-1} at the end of a 30-year rotation. Most of this gap appears to be due to stocking. Once the hybrid model runs have been completed they will enable us to quantify what further productivity gains are possible, and what factors need to be addressed to close the gap between this and current productivity.

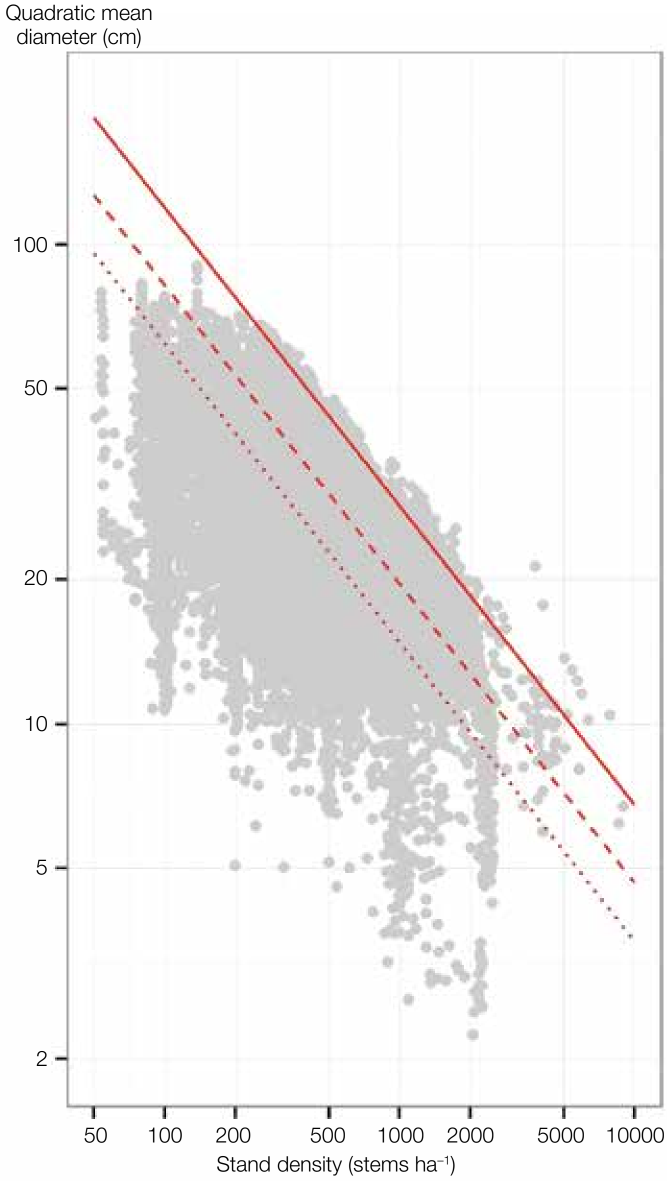

Figure 4: Relationship between the size and number of trees for radiata pine. The points represent data from almost 27,000 growth plots. The solid red line indicates the maximum SDI for this species of 1,200, while the dashed and dotted lines correspond to 55% and 35%, respectively, of this maximum value

International experience shows that large productivity gains are possible, particularly in Brazilian eucalypt plantations where two-fold to four-fold increases have been reported since the 1960s (Campinhos Jr, 1999; Goncalves et al., 2008). Six-fold increases in the productivity of loblolly pine plantations in the south-eastern United States have been reported, while gains (albeit more modest) have been reported in the Pacific Northwest and Midwest (Vance et al., 2010). While doubling productivity does at first seem like a tall order, there are a number of precedents, but it is important to note that many of these gains came off of a low base. A key challenge in closing the yield gap for radiata pine will be ensuring that the inputs needed to achieve this do not simply increase in proportion to the outputs gained.

Intensification within limits

Increases in agricultural productivity are often linked with questions about sustainability, and similar concerns exist for intensification of forest management. Intensification of management is likely to lead to greater and more frequent removals of biomass from sites, with associated increased nutrient and organic matter removals raising concerns over long-term site productivity (Dyck & Beets, 1987; Payn & Clinton, 2005). While research has shown that there does not appear to be a decline in productivity in the second rotation (Woollons, 2000), many forests in New Zealand are now in their third rotation, with some even entering their fourth. A question to consider is what additional nutrient inputs will be required to maintain productivity on these sites over subsequent rotations?

There is also concern over the impact that the increased inputs, such as fertiliser and herbicides, needed to increase productivity may have on the environment. These potential impacts include degradation of water quality through nitrogen leaching and loss of biodiversity (Pawson et al., 2013; Davis, 2014). It is therefore important that management interventions used to increase productivity need to be within environmental limits so that the forest industry's licence to operate is not compromised, i.e. 'sustainable intensification'. A recent review by Davis (2014) showed that nitrogen leaching from planted forests is normally less than other major land uses, however fertilisation can cause large leaching losses in coastal sand forests. A more targeted approach to fertiliser application would reduce nutrient overuse, which also has direct financial benefits too. On this latter aspect, local regulators are imposing limits on catchment nutrient loadings that will restrict current and future fertiliser use, particularly N and P. Research is required to avoid unnecessary restriction on forest productivity, but also to ensure environmental quality is not compromised.

Finally, it is important that intensification does not come at the expense of wood quality. One of the potential impacts of intensification is a reduction in rotation length as the target tree size can be produced more quickly. This would increase the proportion of corewood within a tree, which has low stiffness and a higher propensity to distort following drying (Burdon et al., 2004). While fertiliser application on N and P deficient sites can reduce wood density by as much as 50 kg m^{-3}, this effect only persists for one or two years and is not considered to have a major impact on end product quality (Cown & McConchie, 1981). However repeated applications of fertiliser throughout the rotation may cause a reduction in wood density that is of a much greater level of practical significance.

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