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Diameter–basal area ratio as a practical stand density measure for pruned plantations

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Abstract

The ratio of mean tree diameter to stand basal area (D:BA) is a simple and practical index to guide stocking rates in plantations. When plotted on a Reineke style stand density diagram the D:BA ratio implies a size:stocking trend steeper than that measured in naturally self thinning forests of both *Eucalyptus delegatensis* and *Eucalyptus regnans*. Eucalypt plantations held at a constant D:BA ratio will therefore become more competitive with age rather than less competitive as is the case with constant stand basal area. Data from eucalypt and pine plantations in Australia and New Zealand are used to demonstrate the utility of this index as a management tool for small-scale non-industrial forest owners.

Keywords: Stand density; *Eucalyptus nitens*; Thinning; pruning; Farm forestry; *Pinus radiata*

1. Introduction

Multipurpose forests strategically integrated into the agricultural landscape can be managed to produce commercial sawlogs (Reid and Stephen, 2001). However, the mix of objectives and small scale mean that harvest viability often requires high individual log values to offset poor economies of scale. The most important factors that determine the standing value of eucalypt sawlogs are tree diameter and knots (Blakemore et al., 2004). Pruning and thinning are effective means of improving wood quality and promoting diameter growth (Reid and Washusen, 2001). Because pruning is essentially a fixed cost per tree the return on the investment is directly related to diameter increment (Reid, 2002). Being able to effectively manage the competition between trees is therefore critical to the viability of pruned sawlog management regimes.

In conventional plantation forestry, stand indices, such as stocking rate, dominant height and basal area, are used to develop complex site-productivity and age dependent growth models which can then be used to design silvicultural regimes (Wong et al., 2000). Unfortunately, such models offer little potential for adaptive management once the trees are planted and, due to the edge effect, are of no value to those growing trees in belts or corridors through open farmland. In any case, there is rarely sufficient data available to develop models for the full range of sites and species that farmers are interested in, particularly in the medium to low rainfall areas.

Farmers and other non-industrial forest growers require practical and effective measures of competition that cannot only help them plan silvicultural regimes but also provide guidance for the management of stocking rates over time. The measures need to be robust across a range of forest types, including mixed species forests of irregular shape, and management. Although numerous authors have proposed possible competition measures, some with a particular interest in eucalypts (Opie, 1968; West, 1982), most are either too complex or cumbersome to apply in practice or become widely adopted. This is confirmed by the fact that while stressing the importance of thinning for eucalypt sawlog production many authors fail to suggest how growers might judge the timing and intensity of these critical operations (Neilsen and Pinkhard, 2000; Medhurst and Beadle, 2000; Montagu et al., 2003).

In 1987 the author commenced a series of demonstrations to promote better silvicultural management of multipurpose farm plantations. By 2005 a network of more than 10 ha of integrated forest incorporating more than 40 commercial timber species had been established on his 40 ha farm in southern Victoria. Selected trees are pruned and competing trees thinned with the aim of producing large diameter clearwood logs. Small scale harvesting of pruned eucalypt sawlogs, some over 50 cm in diameter (DBH), has begun from a riparian buffer. The need for a practical stand density measure and the proposal for using the

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diameter–basal area ratio arose from this experience. Its validity and practical application has been tested using consecutive measurements of trees on the property and data drawn from the published literature.

1.1. Stand density diagrams

Reineke (1933) proposed that the natural self-thinning curves comparing quadratic mean diameter (Dg) and stocking rate (N) in even aged forests approximated a linear line when plotted on a log–log scale and that the gradient for different species was very similar (−0.625):

$$\mathrm{Dg} = a_0 N^{-0.625} \tag{1}$$

Each species' self thinning line was thought to be independent of site quality and management and that only the position of the line (as determined by the constant) varied with species thus indicating their relative tolerance of competition. Although the relationship may not be as robust as originally proposed by Reineke many authors do argue that Reineke-style stand density diagrams provide a useful basis for understanding competition in even aged forests (Zeide, 2005; Lonsdale, 1990).

Curtis (1982) demonstrates how Eq. (1) can be translated into a relationship between the basal area (BA) and quadratic mean diameter (Dg):

$$\mathrm{BA} = a_1(\mathrm{Dg}^b) \tag{2}$$

Whereas the Reineke's model (self thinning line gradient of −0.625) infers that $b = 0.4$, Curtis points out that for natural stands of Douglas-fir (*Pseudotsuga menziesii*) b is in the range of 0.45–0.5. Rounding out to an exponent of 0.5, Curtis then suggests that the constant, a_1, might be a useful measure of both relative and absolute density:

$$\mathrm{RD} = \mathrm{BA}/(\mathrm{Dg}^{0.5}) \tag{3}$$

The self thinning lines for naturally regenerated even-aged forests of *Eucalyptus delegatensis* and *Eucalyptus regnans* based on field measurements taken every 5 years (Borough et al., 1984) suggest a self thinning line gradient for tall wet forest eucalypts higher than that proposed by Reineke (1933) but very similar to that proposed by Curtis (1982) for coastal Douglas-fir (Fig. 1).

Fig. 2 presents data from more than 260 measurements of eucalypt plantations growing in Australia and New Zealand drawn from a number of sources (Appendix A). The data includes a range of commercial species between 5 and 70 years growing on a wide variety of sites. Mean diameters were taken as quoted (true mean) or calculated from basal area measurements (quadratic mean). The potential limit of eucalypt plantation growth appears to be well represented by both the self thinning line for eucalypts proposed by Reineke in 1933 and a line representing a relative density (RD) of 12 using Eq. (3), particularly at stocking above 400 stems per hectare. At lower stockings both lines may be optimistic. This could be due to the fact that it is more difficult to fully-occupy a site when there are fewer stems (Zeide, 2005). To do so would require an

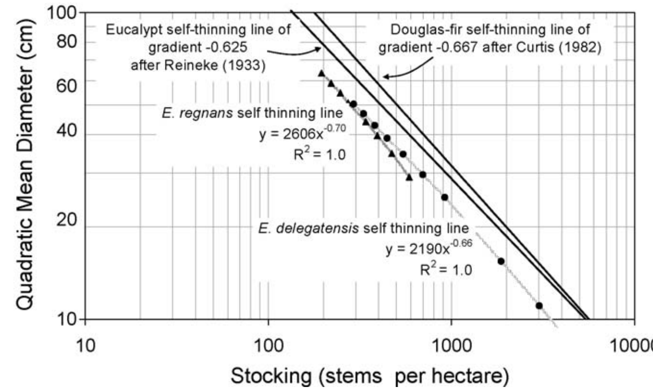

Fig. 1. Fitted self thinning lines for even aged native forests of *E. delegatensis* and *E. regnans* based on measurements taken every 5 years (Borough et al., 1984). The gradients (−0.66 and −0.70) are very similar to that proposed by Curtis (1982) for Douglas-fir but steeper than that suggested by Reineke (1933) as constant for all species (−0.625).

evenly stocked stand of very large mature trees. Such forests are rare due to the pattern of thinning and the fact that commercial plantations are commonly harvested before they have an opportunity to develop a mean diameter of more than 70 cm. The choice of RD = 12 is based on a visual assessment of a family of parallel relative density lines (Fig. 3).

A number of authors, including Renieke (1933), suggest that it is possible to use the stand density diagrams to define the degree of competition in an even age forest using a series of lines drawn parallel to the self thinning line (Dean and Baldwin, 1996). Theoretically there are five competition zones for plantations ranging from a *zone of excessive exposure*, within which tree height growth is retarded due to a lack of mutual shelter, through to a *zone of imminent mortality*, which is presumed to be unobtainable. Within the *zone of free growth* individual tree diameter increment is maximized whereas in the *zone of full stocking* stand productivity is maximized. Once the forest passes into the fully stocked zone, the volume increment is simply distributed over a greater number of stems. Between the free growth and fully stocked zones there is presumably a *zone of increasing competition* in which individual tree growth is increasingly restricted.

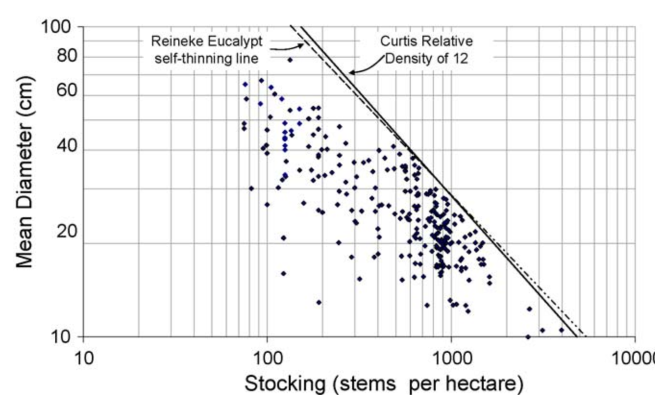

Fig. 2. Data from more than 260 measurements of eucalypt plantations in Australia and New Zealand matched against Reineke (1933) self thinning line for eucalypts (a) and a relative density line (RD = 12) derived from Curtis (1982) (RD = BA/Dg$^{0.5}$). Species and sources listed in Appendix A.