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Modelling the impacts of various thinning intensities on tree growth and survival in a mixed species eucalypt forest in central Gippsland, Victoria, Australia

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ABSTRACT

The response of tree survival and diameter growth to thinning treatments was examined over 29 years, in various thinning treatments established in a 21-year-old even-aged mixed species regenerating forest in Victoria, Australia. The treatments were control, crown release, strip thinning and three different intensities of thinning from below (light, moderate, and heavy). Each treatment was replicated three times in a complete randomised design. Logistic and multilevel regression analyses showed that tree survival, growth and thinning response (change of tree growth due to a thinning treatment) were functions of tree species, size, age, removed and remaining competition, as well as time since the treatment. Mean annual tree diameter growth in unthinned stands was highest for *Eucalyptus sieberi* L. Johnson (1.9 mm) followed by *Eucalyptus baxteri* (Benth.) Maiden & Blakely ex J. Black (1.6 mm), and lowest for both *Eucalyptus consideniana* (Maiden) and *Eucalyptus radiata* (Sieber ex DC) combined (0.7 mm). Diameter growth increased with tree size for both *E. sieberi* and *E. baxteri*, but not for *E. consideniana* and *E. radiata*. Smaller trees were more likely to die due to shading and suppression than their larger counterparts. A mortality model suggested, however, that both shading and suppression had very little effect on trees in both *E. consideniana* and *E. radiata* species, which were less likely to die compared to trees in the other species. This result indicates that both *E. consideniana* and *E. radiata* species may be relatively shade tolerant compared with the other species. Total thinning response was a sum of positive (increased growing space) and negative (thinning stress) effects. Following thinning, smaller trees showed signs of thinning stress for the first one or two years, after which the highest percentage thinning response was observed. While larger trees were initially less responsive to thinning, the rate of decrease in the response for subsequent years was greater in smaller trees than larger ones. The average amount of thinning response showed similar trends to diameter growth increasing from *E. sieberi* (1.7 mm) through *E. baxteri* (0.6 mm) to both *E. consideniana* and *E. radiata* (0.5 mm). This translates into low average percentage thinning response in *E. baxteri* (34%), twice as much in both *E. consideniana* and *E. radiata* (69%) and highest overall percentage response in *E. sieberi* (87%). Thinning response and the duration of this response appeared to increase with thinning intensity and was still evident 29 years after thinning. Heavy thinning did, however, reduce the number of trees to a severely under-stocked condition, which prohibited optimum site occupancy, requiring 29 years of post-thinning development for the heavily thinned stands to regain their pre-thinning stand basal area.

1. Introduction

The amount of natural forest available for timber management in the State of Victoria, Australia, has rapidly decreased throughout the last three decades (Fagg and Thomson, 2001). This reduction can be partly attributed to land-use decisions that have led to the reservation of large areas of mature forest for conservation purposes (Connell and Kellas, 2001; McCaw et al., 2001). With an increasing demand for wood products along with decreasing forest area, the regenerating forests, especially from previous large-scale clear-felling and wildfires that have produced a large amount young even-aged forests are seen as a key element in sustainable forest management (Connell and Kellas, 2001; McCaw et al., 2001; Kanowski and Buchy, 2001). The young stands, however, will not produce significant quantities of sawlogs until 2030 (Raison et al., 2001). In the intervening period, silvicultural

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treatments such as thinning and other stand improvement strategies should be designed as a part of intensive forest management to increase potential commercial wood yields.

Thinning treatments, which are an integral part of intensive forest management, improve the quality of the residual stand by removing slow-growing, damaged or unhealthy trees. This shifts the future growth of the stand to the larger, better quality retained trees (Beveridge, 2001; Connell and Kellas, 2001). The amount and duration of thinning response in Australian natural eucalypt forests is uncertain, perhaps due to the paucity of documented studies, which generally represent shorter periods than rotation length and fail to incorporate the results into generalized thinning models (Goodwin, 1990). Although there exists a reasonable range of general models for estimating Australian eucalypt forest growth and yield (Opie, 1972; Incoll, 1974; Campbell et al., 1979), the capacity of these models to predict growth and yield at the intensive end of the forest management spectrum is not well understood (Parkes, 2001). In fact, the lack of stand-based decision support systems that incorporate predictions of long-term forest growth and hardwood quality has been identified as one of the major impediments to intensive native forest management (Raison et al., 2001). The implementation of thinning regimes under intensive forest management therefore requires growth and yield models that can accurately forecast future yields for both thinned and unthinned stand conditions. The development of these models will require a thorough understanding of thinning responses at both the individual tree and stand levels across a range of conditions.

The main objective of this study is to use an empirical thinning experiment to estimate tree growth and mortality, and to quantify thinning responses at both the individual tree and stand levels. The resultant models can be used for a variety of purposes, including prediction of both tree and stand growth under various stand conditions and evaluation of thinning effects on stand dynamics. This study also examines the rate of both tree growth and mortality, to identify to what extent this can be attributable to species. The following specific questions are considered:

- How does tree diameter growth differ along a thinning intensity gradient?
- Are there differences in tree diameter growth across tree species?
- How does tree mortality rate differ along a thinning intensity gradient?
- Are there differences in tree mortality rate across tree species?

Answers to these questions are discussed in terms of tree growth, thinning response and mortality rate in both thinned and unthinned stands in a regenerating forest.

2. Material and methods

2.1. The study area

The study area is in central Gippsland, Victoria, Australia and lies between latitudes 38°04′37″ and 38°05′20″ South, and longitudes 146°25′30″ and 146°26′1″ East. Although there are high mountains in the locality, the altitude where the plots are located ranges from about 290 to 320 m.a.s.l. The climate is generally temperate. Between December 1967 and August 1968 a thinning experiment was established in mixed eucalypt forests that were clear felled and regenerated naturally in 1947 (Loyn et al., 1980) at Boola Boola camp in the Erica Forest Management District, approximately 130 km east of Melbourne city. Although *Eucalyptus seiberi* L. Johnson, locally known as silvertop ash, is the dominant species, this coexists with other eucalypt species including *Eucalyptus baxteri* (Benth.) Maiden & Blakely ex J. Black, *Eucalyptus consideniana* (Maiden) and *Eucalyptus radiata* (Sieber ex DC). This combination of species is widely distributed in the region on soils classified as Spodosols, Psamments and Ultisals, which are infertile and deficient in nitrogen, phosphorus, potassium and calcium (Isbell, 1998).

Rainfall patterns show a pronounced maximum of over 100 mm per month in spring (September to December) and a minimum of less than 70 mm per month in late summer (February to April). According to the Australian Bureau of Meteorology (2007), the mean annual rainfall for the last 75 years (average for the region at Erica weather station 14 km from the study site) is around 1105 mm and the mean monthly temperature ranges from 4.2 to 10.8 °C in winter to 11.6 to 23.0 °C in summer. The annual mean minimum and maximum are 7.9 and 21.1 °C, respectively (Australian Bureau of Meteorology, 2007).

2.1.1. Description of the thinning trial

The thinning experiment was established to measure and define thinning responses in *Eucalyptus sieberi* dominated stands in a wide range of thinning intensities. The experiment involved six treatments including control (unthinned; UT), crown release (CR), strip thinning (ST) and thinning from below with increasing thinning intensity: light (LTB), moderate (MTB) and heavy thinning (HTB). Increasing thinning intensities were based on stand basal area removed (BAR) for a given mean dominant height (see Section 2.1.2 below). The treatments were replicated three times in a complete randomised design. The plots were, as far as possible, established in fully and evenly stocked stands, although the presence of old skidding tracks and patch regeneration could not be avoided. Plots were rectangular, each measuring approximately 36 m × 49 m (0.17–0.18 ha), with a total area of about 3.2 ha (all plots combined). Before thinning, plot boundaries were marked and the plot divided into approximately 20 m × 20 m subplots. These smaller plots were used systematically for logistical reasons such as ease of tagging, treatment and measurement of trees in the larger plots. All trees in the plot were tagged at 1.6 m and diameter at 1.3 m over bark (*dbh*) measured. After thinning, retained trees were retagged in numerical order and *dbh* was measured again. The height of the 10 largest diameter trees of good potential sawlog quality in each plot was taken with a Suunto clinometer and averaged to obtain mean dominant height (MDH) for the plots. The mean dominant height at 20 years was used as a measure of site quality (site index).

2.1.2. Thinning treatments

The thinning treatments were as follows:

1. Control (UT) no thinning (0% BAR).
2. Crown release (CR): thinned from below around selected 170 trees ha^{-1} with the largest diameter per plot excluding malformed trees to give a free crown space around each tree for a projected time span of 10 years. Free crown space (m) = 0.5145 × *dbh* (cm) − 0.0152.
3. Strip thinning (ST): clear fell a strip of approximately 1.8 m wide on either side of the plot, plus three strips of 3.7 m wide each, leaving four strips of unthinned stand each measuring about 7.3 m wide. This removed approximately one-third of the total plot basal area (BA).

   Three different intensities of thinning from below based on the expected growth for the text 10 years specified in terms of MDH and retained BA range.