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# The effect of thinning on structural attributes of a low rainfall forest in eastern Australia

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A B S T R A C T

Forest thinning is a widely used silvicultural practice that has potential to provide benefits for biodiversity, but there is little direct evidence for this, particularly for regrowth in low rainfall forests and woodlands. This study examined the long-term effects of thinning on structural attributes of white cypress pine (*Callitris glaucophylla*) in the Pilliga forests of eastern Australia. A chronosequence approach was used which included six replicates of five forest management treatments; Unthinned (> 80 years) with high density regrowth; Recent thinning (< 8 years); Intermediate thinning (8–20 years); Old thinning (21–40 years); Long undisturbed (> 80 years) with large *Callitris* and *Eucalyptus* trees present. Thinning reduced the dominance of species that form dense single-aged stands (*Allocasuarina luehmannii* and *Callitris* spp.). Following thinning there was a ~4-fold reduction in small stems (< 10 cm, diameter breast height (DBH)); 6030 stems ha$^{-1}$ (Unthinned) compared to 1583 stems ha$^{-1}$ (Recently thinned). The reduction in small stemmed vegetation was associated with lower cover in both the mid-storey (2–6 m) and sub-canopy (6–14 m) which persisted for 21–40 years while the long undisturbed treatment had mid-storey densities which were similar to the unthinned treatment. Density of medium-sized *Eucalyptus* spp. (10–30 cm DBH) was highest (> 90 trees ha$^{-1}$) where thinning had occurred (recent, intermediate and old thinning treatments) or where stem density of *Allocasuarina* and *Callitris* regrowth was low (long undisturbed), suggesting both these species competitively exclude recruitment of *Eucalyptus* spp.. The post-thinning reduction in woody vegetation was accompanied by an initial increase in the volume of downed coarse woody debris (DCWD), which was long lasting (21–40 years) and four to eight times greater than in long undisturbed sites, with greatest mean hollow diameter occurring in the old thinning treatment. Commercial thinning, in which some residue is removed from sites, still supported up to four times the DCWD volume as the long undisturbed treatment. There was a trend for a negative effect of thinning on the density of dead trees, but no effect on density of hollow-bearing trees and large trees (> 50 cm DBH). Overall, our results indicate thinning had a mixed effect on key structural attributes that contribute to habitat structural complexity, indicating a need to record the direct responses of biodiversity.

## 1. Introduction

Globally, forests support around 90% the world's terrestrial biodiversity (Brooks et al., 2006) but less than 8% is protected in reserves or conservation areas which have been inadequate in conserving biodiversity (Schmitt et al., 2009). Internationally competitive forest industries are increasingly required to produce wood products that can demonstrate environmental sustainability but emerging carbon farming and bioenergy activities are also being asked to assess their potential impacts on biodiversity (Grabowski and Chazdon, 2012; Rothe et al., 2015; Morán-Ordóñez et al., 2016; Stutz and Lang, 2017) and these activities may represent opportunities to enhance biodiversity outside protected areas.

Restoration thinning of regrowth forest has been proposed as a method to benefit both carbon and biodiversity, but there are uncertainties over optimal stem densities and the spatial configuration of regrowth in the landscape matrix to achieve these dual outcomes (Dwyer et al., 2009). The long and short term effects of thinning on biodiversity have also been shown to be variable and contingent on target species, management and disturbance histories. For example, in

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subtropical *Callitris glaucophylla* dominant forests of eastern Australia, the abundance of some reptiles (small terrestrial skinks) was higher in unthinned areas but large terrestrial skinks/dragons favoured thinned areas (Eyre et al., 2015). Other studies have shown some reptiles (Santos and Poquet, 2010; Craig et al., 2014) and birds (Gaines et al., 2007) also display varied responses to changes in canopy structure. Among insectivorous bats, the open forest structure produced by thinning is favoured by a range of species for foraging (Blakey et al., 2016), while other species avoid roosting in thinned areas due to a net loss of dead trees with hollows (Law et al., 2016).

In the short-term, thinning can reduce tree and shrub canopy density by up to 50% (Harrod et al., 2009) and increase vertical canopy gaps which has implications for both fauna and flora. In the longer-term, thinning has been shown to increase the rate of hollow formation in retained trees (Horner et al., 2010). In semi-arid environments, unthinned shrub regrowth has been associated with low plant species richness (Price and Morgan, 2008), but also varying levels of ground cover and canopy layers (Thompson and Eldridge, 2005a, 2005b; Eldridge et al., 2011; Good et al., 2011), including higher species richness (a decrease in trees and shrubs and an increase in herbs) where there is high above ground biomass of *C. glaucophylla* (Hunter, 2013). In a meta-analysis of North American forests, Verschuyl et al. (2011) reported an overall increased abundance of both birds and mammals in thinned areas, but stated that short term effects may be negative.

However, unmanaged regrowth forest can provide habitat that is used to varying extents by many species, with previous management history an important determinant of the structural and compositional characteristics of the forest (Bowen et al., 2007). As a result, the scientific evidence to identify the effects of thinning for biodiversity in many forest communities, particularly in the fragile ecosystems of semi-arid environments, is lacking. This hinders the provision of forest thinning guidelines for these areas, but also more broadly, makes the trade-offs between production, biodiversity and woody regrowth within agricultural landscapes difficult to quantify.

The removal of trees during thinning can substantially impact both the availability of food and habitat which support biodiversity. The amount and quality of downed coarse woody debris (DCWD) and number of hollows are two key structural and functional attributes that contribute to habitat and provide refugia for mammals, birds, and reptiles as well as microsites for the germination and growth of plants (Lindenmayer et al., 2002; Marx and Walters, 2008; Bailey et al., 2012). Both volume and type of DCWD have been shown to be drivers of biodiversity (Mac Nally et al., 2001), with larger volumes and size classes supporting the greatest richness and abundance of fauna (Craig et al., 2014). Over longer time-frames the availability of DCWD is contingent on levels of disturbance through thinning and the density and species of residual trees. The initial impact of thinning and other silvicultural harvesting is to provide a 'pulse' input of DCWD where non-commercial timber remains on site (Collins et al., 2012; Stares, 2015).

White cypress pine (*Callitris glaucophylla*) is a geographically widespread Australian native tree (Thompson and Eldridge, 2005a; Lunt et al., 2006; Whipp et al., 2012). The Pilliga forests support a large contiguous area of cypress pine in eastern Australia, originally thought to be open woodland with a similar plant species composition to today (Rolls, 1981; van Kempen, 1997), albeit with a different extent and density. Pre-European estimates for larger stems range from 14–20 stems $ha^{-1}$ in the 40–60 cm size class and 5–11 stems $ha^{-1}$ in the > 60 cm size class (Lunt et al., 2006; Gibbons et al., 2010). High stem density regrowth, particularly *Callitris*, can display limited growth for decades (Whipp et al., 2012; Thompson and Eldridge, 2005a) and this has led to a long history of silvicultural thinning in the Pilliga forests (Jurskis, 2009). These historical thinning activities provide an opportunity to examine the impact of thinning on habitat features over the long (up to 40 years) and short-terms (< 8 years) and elucidate the longevity of thinning effects.

The objectives of this study were to identify the short- and long-term effects of thinning on key forest structural attributes that contribute to habitat structural complexity (McElhinny et al., 2005) in a low rainfall native forest. A chronosequence of time since thinning was used and where possible, focused on non-commercial thinning treatments, which left residue on the forest floor at the end of the operation and only included sites that had not been logged after thinning. Specifically, we predicted that key forest structural attributes would respond positively in thinned relative to unthinned treatments. For example, thinning treatments would have greater shrub and ground cover due to increased light penetration and greater levels of DCWD than the unthinned treatment and potentially greater numbers of hollow trees in the old thinning treatment.

## 2. Methods

### 2.1. Study area and experimental design

The Pilliga forests (30°46ʹS, 149°18ʹE) cover an area of 535,000 ha in SE Australia. Across the study area, a rainfall and elevation gradient exists from 530 mm $year^{-1}$ and 190 m above sea level (ASL) in the west to 660 mm $year^{-1}$ and 420 m ASL in the east, respectively (Fig. 1). The area is dominated by dense stands of white cypress pine *Callitris glaucophylla*, black cypress pine *C. endlicheri*, bulloak *Allocasuarina luehmannii*, narrow-leaved ironbark *Eucalyptus crebra* and an understorey of shrubs, predominantly *Acacia* spp. In all, 30 sites were sampled within each of six clusters (defined by a 5 km radius, excepting one cluster that required a larger radius) to encompass the variability across the Pilliga forests (Fig. 1). We accounted for any influence of the environmental variation among clusters across the Pilliga by sampling each of five forest management treatments within each cluster; Unthinned (> 80 years) with high density regrowth; Recent thinning (< 8 years); Intermediate thinning (8–20 years); Old thinning (21–40 years); Long undisturbed (> 80 years) with large *Callitris* and *Eucalyptus* trees present. The unthinned treatment contained high stem density and was suitable for thinning. The recent thinning treatment had been non-commercially thinned (i.e., residue not removed from the forest) < 8 years ago using mechanical and manual (brushcutting) thinning techniques. Mechanical thinning involved using machinery to 'chop and roll' trees along narrow alleys, while adjacent areas were treated manually with mechanised hand-held brushcutters. Sites with non-commercial thinning could not be located for the intermediate thinning treatment. Instead, sites that had been thinned between 8–20 years ago for commercial purposes (i.e., thinning operations targeted dense stands with larger stems for sawlogs and timber products removed from the forest) were selected for the intermediate thinning treatment. The old thinning treatment had been non-commercially thinned 21–40 years ago. Typically, ~1 m high, small diameter) stumps (< 10 cm DBH) were evident in this treatment. The long undisturbed treatment was selected based on the presence of large *Callitris* and *Eucalyptus* trees, a lack of stumps and generally patchier, less dense regrowth than the unthinned treatment. We specifically selected sites that had not been logged following the thinning operation to avoid confounding with this disturbance, although some sites may have been thinned, logged and then thinned again. Evidence of fire was absent at all study sites except one site in the intermediate thinning treatment that was lightly burnt in 2006. Grazing by a range of herbivores (including goats, cattle and horses) was widespread across the Pilliga. Further details of each of the 30 sites are given in Table 1 and the study location in S1.

Differences among clusters were examined at a large-scale (landscape variables) and differences among forest management treatments were examined at a smaller, or local scale (habitat variables), including (i) vegetation structure and composition (density of vegetation, stumps, tree hollows and fissures, and vegetation cover) and (ii) DCWD (density of logs, logs with hollows, logs with fissures, log decay status, log source