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Ecological outcomes for multiple taxa from silvicultural thinning of regrowth forest

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ABSTRACT

Management of forest regrowth is a key issue globally, particularly where it occurs as high densities of small-sized stems and where there is little to no self-thinning. Thinning can reduce stem density to accelerate tree growth and potentially restore forest-structural complexity. Yet, in some forest types, it remains unclear how biodiversity responds to thinning, especially over longer periods. White cypress pine *Callitris glaucophylla* is geographically widespread in Australia and has history of silvicultural thinning in parts of its distribution. We used a chronosequence approach to assess the short- and longer-term responses of multiple taxa (bats, birds, invertebrates, reptiles, non-volant mammals, and plants) to thinning of *C. glaucophylla* in the dry Pilliga forests of New South Wales. We recorded data from a total of 227 taxa. The short (< 8 years)- and longer-term (> 20 years) responses to thinning of *C. glaucophylla* regrowth were mostly positive or neutral for the taxa considered. Bat activity and diversity were comparable to levels in long-undisturbed reference forest, though this was influenced by time since thinning. Reptile diversity and abundance was positively associated with thinning at an intermediate time since thinning (8–20 years), with both metrics greater than unthinned regrowth and long-undisturbed reference forest. Bird diversity was greater in recent and old thinning treatments when compared to unthinned forest regrowth, although species composition was not affected by thinning. Though thinning did not affect volant invertebrate biomass, it was associated with a relatively more even distribution among size classes > 8 years post-thinning, and a greater representation of beetles to overall insect biomass. The activity, diversity and composition of non-volant mammals did not differ among treatments, nor did understorey plant diversity or composition. Combining these multiple taxa into a composite 'biodiversity' index demonstrated a 16–22% increase with thinning relative to index values in long-undisturbed reference forests. Overall these results indicate that thinning has neutral to positive effects on biodiversity, but responses are species-specific and likely to be dependent on forest-type and the broader landscape of a site. Given unthinned forest represented habitat of similar value to thinned forest for some taxa, we recommend that that regrowth patches of varying size are retained across the landscape to provide a mosaic forest structure suitable for a diverse suite of flora and fauna.

1. Introduction

Globally, forest regrowth (naturally regenerating stands that show visible indications of human activity) represents > 50% the world's forest cover (FAO, 2010) and management of such forests is a key issue for biodiversity. This is particularly the case for vegetation communities where regrowth occurs as high densities of small-sized stems, with high intra-stand competition and little to no self-thinning. Thinning is a common silvicultural practice used to reduce stand density to accelerate tree growth (Tappeiner et al., 1997; Finkral and Evans, 2008; Kariuki, 2008; Horner et al., 2010), with thinnings either retained on site (non-commercial) or recovered as a product (commercial), such as sawlogs or firewood. Thinning can also be applied for specific ecological outcomes, such as restoring stand complexity to benchmark levels (see Gorrod et al., 2017). Nevertheless, thinning changes the physical structure and habitat value of forest regrowth. For example, thinned stands of regrowth in *Eucalyptus camaldensis* forests produce, over time, larger stems and a greater number of hollow-bearing trees than unthinned stands with higher stem densities (Horner et al., 2010).

Meta-analyses from North America have found forest thinning has

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generally positive or neutral effects on diversity and abundance across taxa, although thinning intensity, time since thinning and the type of thinning applied partially drives the magnitude of response (Kalies et al., 2010; Verschuyl et al., 2011). In Australia, Eyre et al (2015) identified mixed responses to thinning from functional groups of reptiles when controlling for logging effects. Larger skinks and dragons were 7-times more abundant in thinned compared to unthinned white cypress pine *Callitris glaucophylla*, while arboreal geckos and snakes and fossorial skinks and snakes were twice as abundant (Eyre et al., 2015). Small skinks, however, were twice as abundant in unthinned than thinned stands (Eyre et al., 2015). For functional groups of birds, responses to thinning when controlling for logging effects were neutral (Eyre et al., 2015). Blakey et al. (2016) found that bat activity was 60% lower in unthinned river red gum *Eucalyptus camaldulensis* regrowth compared to thinned and reference stands, with responses of individual bat taxa to thinning mostly neutral. Responses of insect taxa to thinning were also variable and tended to mostly be neutral (Blakey et al., 2016). Clearly, responses of fauna to thinning are complex and taxa-specific (e.g., Kalies et al., 2010; Eyre et al., 2015; Blakey et al., 2016).

Callitris glaucophylla is a native conifer that is geographically widespread in Australia (Thompson and Eldridge, 2005a; Lunt et al., 2006; Whipp et al., 2012). The species often occurs in mixed woodland communities, including various eucalypts and other tree species such as *Allocasuarina luehmannii* (buloke) (Boland et al., 1984). Fire exclusion and selective removal of associated eucalypts and other co-occurring tree species (Lindsay, 1967) has resulted in *C. glaucophylla* dominating stands in many parts of its distribution, with > 80% of basal area represented by the species (Thompson and Eldridge, 2005a). The species is slow growing and long-lived, tolerating intense intra-specific competition at high densities (Lacey, 1972; 1973; FCNSW, 1988), with little evidence of self-thinning (Thompson and Eldridge, 2005b) for up to 200 years in low rainfall environments (Read, 1995). Recruitment of the species occurs episodically under suitable conditions (Horne, 1990a; Horne, 1990b) and is influenced by climate, existing stand densities, and land use (Lacey, 1973). In many State forests, estimated densities of regenerating cypress vary from 163,000 trees ha^{-1} to 620,000 trees ha^{-1} (Horne, 1990b).

Callitris glaucophylla regrowth has been thinned in the Pilliga forests in northwest New South Wales (NSW) since the 1930s, with non-commercial and commercial treatments applied to dense regrowth (Knott, 1995). This extensive history of thinning provided an opportunity to assess the short- and longer-term effects of thinning on biodiversity. Thinning produced a 4-fold reduction in density of small stems (< 10 cm diameter at breast height over bark - dbhob) and an increase in coarse woody debris volumes (Waters et al., 2018). It also had a marginally, negative effect on density of dead trees, but no effect on the number of hollows or density of large trees, while density of medium-sized (10–30 cm dbhob) eucalypts was greatest where thinning had occurred.

Given responses to thinning can be taxa-specific, our aim was to assess responses of multiple taxa (bats, birds, invertebrates, non-volant mammals, reptiles, and plants) to thinning. We compared the diversity of different taxa among unthinned, thinned and long-undisturbed forest treatments using the geometric mean of species abundances (Buckland et al., 2011), developed a composite biodiversity index (di Stefano et al., 2013), and also considered species composition. For mobile taxa, we predicted that bat diversity would increase rapidly with thinning (Blakey et al., 2016; Gonsalves et al., in press), while volant insect biomass or composition would not be affected (Blakey et al., 2016; Gonsalves et al., in press). Bird diversity was expected to be positively associated with an increase in the density of understorey shrubs (*Acacia* spp.) associated with thinning (Brown et al., 1991), though initial effects of thinning can be neutral (Kalies et al., 2010). For less mobile taxa, we predicted that diversity and abundance of reptiles would respond positively over time to thinning (Craig et al., 2009) as reduced stem density and sub-canopy cover in thinned sites may increase the penetration of sunlight (Wetzel and Burgess, 2001) for basking (Vitt et al., 1997, 1998). For non-volant mammals, we predicted no consistent response to thinning (Craig et al., 2009), but rather responses would be species-specific (Converse et al., 2006). We also explored associations between individual species and habitat characteristics using ordination techniques.

2. Methods

2.1. Study area

The study was undertaken in the Pilliga forests in north-west NSW. Approximately half of these forests are managed by Forestry Corporation of NSW for timber production, while the remaining areas are managed for conservation by the National Parks and Wildlife Service, with much of this area previously managed for timber production. In all, the managed forests of the Pilliga cover 535 000 ha and constitute the single largest block of inland plains forest and woodland in Australia. Dominated by white cypress pine *Callitris glaucophylla* and narrow-leaved ironbark *Eucalyptus crebra*, the area has been important for timber production since the 1800s. Much of the Pilliga area was thought to be originally open woodland with a similar plant species composition to today (Rolls, 1981; van Kempen, 1997). However, increasing tree density, particularly *Callitris*, appears to have resulted from a combination of altered burning regimes, introduction of rabbits and interactions with drought and flood years. The vegetation of the Pilliga is today dominated by dense stands of *C. glaucophylla*, black cypress pine *C. endlicheri*, buloke *Allocasuarina luehmannii*, with *Acacia* spp. and *E. crebra* scattered throughout the forest (Thompson and Eldridge, 2005a; Law et al., 2016; Waters et al., 2018). Silvicultural treatment to maximise tree growth for timber production (Forestry Commission of NSW, 1986) has developed a forest with a range of management histories, including logging and thinning of various ages.

We selected 30 sampling sites within the Pilliga to encompass the variability that exists in forest productivity across the entire area and have been previously described in Waters et al. (2018). Sampling took place in six site clusters across the Pilliga in eight State Forests (Baradine, Cumbil, Euligal, Jacks Creek, Pilliga East, Pilliga West, Wittenbra and Yearinan), one Flora Reserve (Wittenbra), and two State Conservation Areas (Pilliga West and Yearinan) (Fig. 1).

To control for variability across the large study area, each site cluster contained five different forest treatments (unthinned, recent thinning, intermediate thinning, old thinning and long-undisturbed reference). Unthinned sites supported a high density (~6500 stems ha^{-1}) of small (< 10 cm diameter at breast height over bark - dbhob) stems that were suitable for thinning. Post-thinning, stem density was reduced to ~1600 stems ha^{-1}. Recent thinning sites had been thinned < 8 years ago using mechanical (chopper-roller) and manual (brushcutting) thinning techniques, with thinnings left on site. Intermediate thinning sites were thinned 8–20 years ago. However, thinning operations at these sites also targeted larger stems for sawlogs which were removed from the site, resulting in a relatively more patchy thinning treatment than our recent thinning treatment. Old thinning sites had been thinned > 20 years ago, with thinnings left on site. Approximately 1 m high small diameter stumps were evident in this treatment, which had persisted over time due to termite resistance of white cypress. All thinning treatments were typically 20–30 ha in size. Long-undisturbed reference sites were those that represented the greatest period without disturbance within a 5 km radius of the recent thinning site for a particular cluster. They were characterised by few stumps and large diameter trees (cypress and ironbark), and often contained patches of dense *C. glaucophylla*.

At each site, we established a 200 m transect for sampling biodiversity. The start of each transect was at least 50 m from a road, and transects were directed through areas representative of each forest treatment (as mapped in GIS but also based on the presence of