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Empirically validating a dense woody regrowth 'problem' and thinning 'solution' for understory vegetation

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ABSTRACT

In landscapes with a short history of intensive land use, woody plant regrowth on cleared land is often favorably received as a shift back to a more natural state. However, it is common for these regrowth stands to be much denser than undisturbed forest. High stem density can adversely affect stand structure, understory composition, and habitat for dependent fauna. Thinning to reduce stem density is one common silvicultural method used to manage dense stands for ecological or restoration objectives. The effect of thinning on the stand structure is well understood but those on the understory vegetation are not. We address this knowledge gap in anticipation of an increasing call for public investment in 'ecological' thinning across public and private land. Our case study is from the eucalypt woodlands and forests of central Victoria, Australia, an ecosystem in which dense woody regrowth is common. From a broad survey of 98 sites, spanning a range of stem densities, we explored the effect of density on understory vegetation. High densities of small trees (<20 cm DBH) caused the greatest suppression of native and exotic cover and species richness. We compared our observations with benchmarks and found that sites with stem densities exceeding their benchmark had median values approximately one-seventh of the benchmark native understory cover, which was also less than a quarter of the cover of those sites with benchmark or lower stem density. We conducted an additional targeted survey of 11 thinned sites paired with non-thinned sites to evaluate the effects of thinning. We built models combining broad and targeted survey data relating understory response to stem density, thinning, land tenure and environmental covariates. These models predicted that thinning is likely to elicit positive responses from the understory plant community in the short term. This is the desired response from native species, but we caution that thinning can equally favor exotic plant species.

1. Introduction

Prolific recruitment of one or few woody plant species commonly occurs where agricultural production or intensive resource extraction has ceased on land formerly occupied by woodlands and forests (Doherty, 1998; Geddes et al., 2011; Gifford and Howden, 2001; Lunt, 1998; Lunt et al., 2006; Rumpff et al., 2011; Wallin et al., 2004). Hereafter we refer to this phenomenon as "dense woody regrowth". It is particularly common in landscapes that retain substantial remnant woodland and forest cover as a seed source.

The cultural and ecological context and origin of dense woody regrowth typically determine how it is perceived. In Europe, where dense woody regrowth following land abandonment is common (Flinn and Vellend, 2005; Gellrich et al., 2007), it is generally regarded negatively, having replaced anthropogenic grassland meadows maintained for centuries by clearing and grazing (Anthelme et al., 2001). Similarly, woody encroachment into natural savannas (Smit, 2004; Wiegand et al., 2006), and grasslands (Van Auken, 2000) following changes to grazing or fire regimes can reduce the capacity of grazing land. In the Neotropics, the structural and functional attributes of dense regrowth can be ecologically similar to pre-cleared forest and represent a desirable state (Aide et al., 2000; Aide et al., 2012). Elsewhere, there can be considerable nuance where dense stands are defined in comparison to benchmark or reference states that are thought to have existed prior to the post-industrial period of anthropogenic impact. Dense stands are generally considered ecologically undesirable compared to stands with benchmark density. In Australia and North America, these benchmarks typically represent vegetation

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states predating European arrival (Eyre et al., 2011; Gibbons et al., 2010; Gibbons and Freudenberger, 2006; Jackson et al., 2000; Parkes et al., 2003; Wallin et al., 2004). In Australia for example, spontaneous woody regrowth is positively received while the plants are young but there is concern about the biodiversity and habitat value of these simplified stands as they age (e.g., Geddes et al., 2011; Kyle and Duncan, 2012). Dense woody regrowth is considered problematic because it is presumed to retard or exclude desirable biodiversity and habitat values. However, few have attempted to (a) validate the existence of a dense woody regrowth problem (but see Geddes et al., 2011), or (b) demonstrate the efficacy of thinning as a proposed solution.

Effects of high stand density on tree growth are reasonably well understood and abound in the silvicultural literature (e.g., Goodwin, 1990; Kariuki, 2008). However, the impact that dense stands have on understory vegetation remains largely unresolved (Dwyer et al., 2010b). The negative impacts of high stand density may include suppression of understory floristic richness and cover (Aguiar et al., 1996; Briggs et al., 2005; Harrington and Edwards, 1999; Hobbs and Mooney, 1986; Lett and Knapp, 2003; McHenry et al., 2006; Price and Morgan, 2008; Wienk et al., 2004), reduction in stand growth rate (Dwyer et al., 2010a; Kenkel, 1988; McHenry et al., 2006; Sala et al., 2005; Vesk et al., 2008), delayed provision of desirable habitat features such as large boughs and hollows (Vesk et al., 2008), reduced stand fecundity (Vesk et al., 2010), and increased risks of fire, pathogens and insect attack (Sala et al., 2005; Wallin et al., 2004) and soil degradation (McHenry et al., 2006). There is also concern that regrowth stands may stabilise as degraded novel ecosystems (Cramer et al., 2008; Fensham, 2008; Geddes et al., 2011).

Eventually, dense stands will self-thin (Kenkel, 1988; Olson et al., 2014; Westoby, 1984). However, intervention with mechanical or chemical thinning has been demonstrated to benefit tree growth, hasten the development of structural diversity, reduce pest attack risk and tree mortality, and increase carbon storage (Comfort et al., 2010; Dwyer et al., 2010b; Harrington and Edwards, 1999; Horner et al., 2010; McHenry et al., 2006; Pollock and Beechie, 2014; Wallin et al., 2004). It is often assumed that reducing stem densities will maintain or increase understory condition, and in combination with increasing the growth rate of remaining trees, maintain or increase ecosystem diversity, function and structural complexity (Czembor and Vesk, 2009; Fensham, 2008; Good et al., 2011; Good et al., 2012; Horner et al., 2010; Stanturf et al., 2014). Yet it is unclear to what extent thinning achieves these aims and if it varies according to context. The ecological and silvicultural literatures contain examples of positive, negative and neutral responses of understory cover, composition and species richness to thinning treatments (Dwyer et al., 2010b; Eldridge et al., 2011; Good et al., 2011, 2012; Harrington and Edwards, 1999; McHenry et al., 2006; Olson et al., 2014; Thomas et al., 1999; Tolsma, 2012; Walker et al., 1972, 1986). Some studies have reported greater effects of thinning on understory vegetation than the effect of stem density alone (Good et al., 2011, 2012; Scanlan and Burrows, 1990).

In Australia, dense woody regrowth commonly manifests as dense stands of one or few tree or shrub species (Doherty, 1998; Dwyer et al., 2010a; Geddes et al., 2011; Good et al., 2012; Lunt, 1998; Lunt et al., 2006; Rumpff et al., 2011). Thinning is increasingly being considered as a management tool for ecological restoration objectives, as large regions of Australia are shifting from agriculture to amenity land uses (Fensham, 2008; Geddes et al., 2011). However, deciding whether to apply thinning is a policy challenge (Cramer et al., 2008; Czembor and Vesk, 2009; Fensham, 2008; Gibbons et al., 2008; Lindenmayer et al., 2012). Native vegetation clearing is controlled in Australia, but some government agencies have sought flexibility for land-holders to manage their dense stands, recognizing that dense woody regrowth can impede native vegetation management (Fensham, 2008). However, thinning is viewed as a risky management action because many of the claimed ecological benefits are yet to be demonstrated equivocally (Czembor and Vesk, 2009).

The Box-Ironbark eucalypt woodlands and forests of central Victoria were extensively cleared in the early 19th century (Sinclair et al., 2012) and are an ideal system to research the management of dense woody regrowth. In the last 50 years dense woody regrowth has increased over an expanding area (Geddes et al., 2011; Kyle and Duncan, 2012). Thinning has been infrequently implemented in Victoria for ecological purposes but has recently come into favor with land-managers and is likely to be employed at greater rates in the future (Archibald et al., 2010; Cunningham et al., 2009; DSE, 2009; Horner et al., 2010; Pigott et al., 2010).

Here we address the knowledge gaps impeding informed management of the commonly perceived problem of dense woody regrowth and 'ecological' thinning, its commonly cited solution. We focused our research on understory effects because they are the least well understood, yet are ecologically important, and can experience rapid and detectable rates of change. We conducted a broad survey to corroborate the link between dense stands and low understory richness and cover relative to benchmarks (Gibbons et al., 2010). We also exploited the few Victorian examples of thinning for ecological outcomes by conducting a paired-site survey to estimate understory response to thinning in Box-Ironbark eucalypt woodlands and forests, where we evaluated stem density influences and short term responses to thinning on a range of understory attributes. We then tested the applicability and generality of regression models of understory vegetation that incorporate stem density, thinning, land tenure, and environmental covariates.

2. Materials and methods

2.1. Study area

The study area was central Victoria, Australia, approximately 150–180 km from Melbourne (see Supplementary Material). The region has a temperate climate with average annual temperatures of 8–9 °C (min) and 21 °C (max) and an average annual rainfall of 515–650 mm (BOM, 2012). We sampled 120 sites from Box-Ironbark woodlands and forests. Of these, 98 sites were from a broad survey of sites (hereafter "background"), and a targeted survey of 11 pairs of thinning treatment and control sites (hereafter "experimental"). Sites with high stem densities formed the majority of the background sample, but sites with lower stem densities were also surveyed for comparison. Land tenures were categorized into two types: Crown and Freehold, based on current and historical land ownership and use (see Table 1, and see Sinclair et al., 2012). Land use history has influenced site condition, with all sites in our study experiencing some form of tree clearing and anthropogenic disturbance, but detailed histories are very difficult to acquire for individual sites (Foster et al., 2003; Lunt and Spooner, 2005). The exception in this study being a group of 16 (8 control and 8 treatment) sites on Crown land that were part of the Box-Ironbark Thinning Trial (Pigott et al., 2010). Prior to the thinning trial, these sites had been used primarily for timber and firewood provision (ECC, 2001).

Thinning was conducted between 2004 and 2012 using a cut-and-paint herbicide technique to prevent resprouting. Since exact thinning dates could not be determined, and uncertainty about them was considerable relative to the full range, we analyzed thinning as a binary proposition. Variable rates of stem removal were employed at the Box-Ironbark Thinning Trial sites (8 out of 11 treatment sites) to assess the efficacy of different final densities (Pigott et al., 2010).