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Restoration potential of native forests after removal of conifer plantation: A perspective from Australia

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ABSTRACT

This study investigates whether undertaking a rotation of pine plantation on abandoned farmland facilitates the return of native species. Plant functional traits were used as a means of assessing the effects of land-use change on vegetation. We explored the relationships among plant traits, time since harvesting and environmental variables for the vegetation found in *Pinus radiata* plantations after clear-felling. Vegetation was monitored 1–3 years following harvesting and repeated eight years later. We compared species richness, composition and traits to those in reference native forest and abandoned farmland. There was a significant temporal shift in attribute associations of harvested plantations towards those in native forest and a move away from plant attributes common to the pre-plantation use of abandoned farmland. Cluster analysis produced ten emergent groups of plant functional traits for 144 plant species. After harvesting, attribute associations were typical of therophytes and included high specific leaf area (SLA), small stature, arbuscular or non-mycorrhizal associations and small, wind-dispersed seed. These were predominantly introduced species that were dominant in abandoned farmland. The repeat survey identified an obvious decrease in therophytes and an increase in species with low SLA, ant dispersal, large seed and ectomycorrhizal associations. This was largely due to an increase in native *Myrmecochorous shrubs*. Similar attributes were also shared by *Ericoid heaths* but these species failed to recolonise harvested sites. Relationships among plant traits of species and environmental variables changed over time with a greater proportion of the variance in attribute associations explained by prevailing site conditions (e.g. type of ground cover, edaphic properties) with increasing time since harvesting. There were no relationships among plant attribute associations and stem density or basal area of planted overstorey species suggesting that planting of tubestock seedlings of native overstorey species does not effectively promote the development of native vegetation. The persistence of introduced grasses in areas of former plantation, recruitment failure of native species and a ready supply of introduced species from surrounding land uses suggest that additional rehabilitation measures will be required to promote the return of a fuller complement of native species.

1. Introduction

Forestry plantations are typically characterised by densely planted monocultures of introduced trees, often with very different trait sets than those represented in indigenous forests (Stephens and Wagner, 2007; FAO, 2010). Worldwide, up to 39% of plantations are composed of coniferous species that are often non-native (FAO, 2010; Gavran, 2013). With the continuing expansion of plantation estates and the global trend for a decline in area of natural forests, there is an increasing focus on the role of plantations in conserving biodiversity, and of approaches to returning native vegetation to sites after plantation crops have been harvested (Stephens and Wagner, 2007; Brockerhoff et al., 2008). For coniferous plantations, forest management practices aimed at improving biodiversity have focussed on the incorporation of broadleaved species to form mixed-species plantations (Heinrichs and Schmidt, 2009; Felton et al., 2010), and less frequently, the total replacement of non-native coniferous species with native broadleaved species (Ferracin et al., 2013; Spracklen et al., 2013). Despite

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the increased emphasis on returning native species to sites with coniferous plantations, relatively little is known about the restoration potential of clear-felled conifer plantations (Zerbe, 2002).

Clear-felling directly affects the diversity and composition of vegetation through removal and disturbance of extant vegetation and reproductive material, and indirectly through soil disturbance and changes to microclimate, light conditions, soil chemistry and hydrology (Vitousek et al., 1982; Marshall, 2000; Hope et al., 2003; Heinrichs and Schmidt, 2009). If left untouched after clear-felling, natural regeneration proceeds via extant vegetation, regeneration via suppressed rootstocks or clonal spread, germination of the soil seed bank or via seed rain and animal dispersal depending on the proximity and composition of surrounding vegetation (Halpern, 1989; Wunderle, 1997; Hérault et al., 2005). Associated changes in the composition of vegetation over time include an increase in species richness due to invasion of ruderal species (Prach and Pyšek, 1999; Heinrichs and Schmidt, 2009; Saure et al., 2013) followed by a reduction in shade intolerant and moisture-demanding species (Hannerz and Hånell, 1997; Heinrichs and Schmidt, 2009). In addition, the succession of plants after clear-felling is influenced by the severity and spatial and temporal variation of the disturbance caused during harvesting (Halpern, 1989).

The Australian softwood plantation estate, dominated by *Pinus radiata*, has remained relatively static at 1,000,000 ha since 2002 (Gavran, 2013). Plantations of *P. radiata* were most commonly established on cleared agricultural land. Between 2011 and 2012 there was a net decline of 1000 ha which is expected to increase over the next 5–10 years as plantations are harvested and not replanted. This is due to a number of reasons including reducing plantation area as a means to increase ground-water recharge, because they are considered commercially unviable, or due to incompatibility with biodiversity conservation values (Kasel and Bennett, 2007; Gavran, 2013). Decommissioned plantations have been converted to other land uses including native broadleaf vegetation (Kasel and Bennett, 2007). The conversion process typically involves the planting of overstorey species (Kasel, 2008) as a means of facilitating the return of understorey species by providing a 'nurse-tree' function (Lugo, 1988; Wilkins et al., 2003; Munro et al., 2009).

This study aims to identify general patterns in plant functional traits (*sensu* Violle et al., 2007) of species following harvesting of *P. radiata* plantation. Previous work in pine plantations also conducted in the same study location revealed that myrmecochorous trees, shrubs and herbs were largely excluded from the understorey while perennial herbs with intermediate specific leaf area (SLA) and clonal spread were tolerant of shaded conditions in pine plantations (Meers et al., 2010b). The soil seed bank of pine plantations was dominated by species with trait associations including therophyte and hemicryptophyte life forms with high SLA, wind-dispersed or small round seed and arbuscular or non-mycorrhizal associations (Meers et al., 2012). These patterns in plant functional traits suggest that the extant understorey vegetation and the soil seed bank have limited restoration potential in a post-harvesting landscape. Further, the reduction or destruction of vegetative propagules through harvesting disturbance may further increase the dependence on seed rain from surrounding vegetation (Martins and Engel, 2007).

Using repeated sampling of permanent monitoring plots, we examined the response of both individual traits and emergent groups (*sensu* Lavorel et al., 1997) as plant succession occurred following harvesting of *P. radiata* plantations. We addressed the following broad questions:

1. Is there a shift in vegetation with time since harvesting and if so, does this shift trend toward the pre-plantation state (abandoned farmland), follow a trajectory towards the desired state (native forest), or towards some alternate state?
2. What are the relationships among plant traits and environmental variables? In the scenario we used, environmental variables included location (e.g. distance to native forest, topography), land-use history (e.g. time since harvesting, time since revegetation), site factors (e.g. planted overstorey trees, litter cover) and edaphic conditions.

2. Methods

2.1. Study area

The Delatite Peninsula is located on the western slopes of the Great Dividing Range in Victoria, Australia (145°58′E, 37°8′S). The Peninsula was formed in 1956 by the construction of the Eildon Reservoir. The area has a steeply dissected topography with altitude ranging from 300 to 500 m above sea level. Annual rainfall is approximately 850 mm and falls mainly in winter and spring (Bureau of Meteorology, 1887–2011). Mean monthly maximum temperature ranges from 12.0 °C in July to 29.0 °C in February, with corresponding mean monthly minimum temperatures ranging from 3.5 to 12.5 °C. Native vegetation consists of open eucalypt forest with a sparse understorey of sclerophyllous shrubs, grasses and herbs (Specht, 1981).

Land was cleared in the 1850s and then heavily grazed by cattle (D'Arcy, 1998) until 1952 when farmland was sold purchased for inclusion in the Eildon Reservoir. *P. radiata* plantations were established on much of the farmland to the south of the Delatite Valley from 1959 to 1965 as a measure to protect water quality of the Eildon Reservoir and for production of wood products. Some farmland areas remained, primarily on steep slopes unsuitable for cultivation. These areas were lightly grazed by sheep until the late 1970s (J. Walker, pers. comm. 2005, Plantation Manager). Historical aerial photographs show that these farmlands had a scattered cover of eucalypts at the time of abandonment.

Harvesting of the pine plantation has proved uneconomic, providing impetus to return native vegetation to the area (Kasel, 2008). Tree planting was identified as a key element to returning native vegetation to the Delatite Peninsula and in 2000 a large-scale revegetation program began (Kasel, 2008). Planting density of eucalypt seedlings ranged from 800 to 1000 stems ha^{-1} and included a variable mix of *Eucalyptus dives*, *E. globulus* subsp. *bicostata*, *E. goniocalyx*, *E. radiata*, *E. polyanthemos*, *E. macrorhyncha* and *E. melliodora* according to the original Ecological Vegetation Class (Muir et al., 1995) that included Grassy Dry Forest, Valley Grassy Forest and Herb-rich Foothills Forest. Eucalypt seedlings were supplied under contract using seed collected from surrounding areas and planted according to standard silvicultural guidelines (DCNR, 1993). At the time of planting, seedlings had at least 6 leaves, with a root collar of 3–6 mm and height of 15 cm (Kasel, 2008). Pine wildling control was an integral component of the revegetation works and 1–3 years following harvesting all pine wildlings were removed from former plantations using manual techniques.

2.2. Site selection and survey

Sites located in harvested pine plantations were restricted to areas that had supported un-thinned plantations established on abandoned farmlands within a 25 km^2 area on the Delatite Peninsula. Sites were established on middle to upper slopes with a north-east or north-west aspect in areas that had been harvested by cable-harvesting methods and were not subsequently mechanically ripped. Plantations are typically harvested between November and April and selected sites were harvested during 1999/2000 (referred to as 2000 sites, $n = 8$), 2001/2002 (2002 sites, $n = 2$), and 2002/2003 (2003 sites, $n = 10$). No areas within the Delatite Peninsula were harvested in 2000/2001. Pine plantations were mature