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Natural tree regeneration in agricultural landscapes: The implications of intensification

Chloe F. Sato[a,*], Jeff T. Wood[a], John A. Stein[a], Mason Crane[a], Sachiko Okada[a], Damian R. Michael[a], Goeffrey M. Kay[a], Daniel Florance[a], Julian Seddon[b], Philip Gibbons[a], David B. Lindenmayer[a,c]

[a] Fenner School of Environment and Society, The Australian National University, Acton, ACT 2601, Australia
[b] Conservation Research Unit, Environment and Planning Directorate, ACT Government GPO Box 158, Canberra, ACT, 2601, Australia
[c] ARC Centre of Excellence for Environmental Decisions, The Australian National University, Acton, ACT 2601, Australia

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ABSTRACT

Concern about food security is prompting a push to intensify agriculture globally. However, agricultural intensification can inhibit regeneration of vegetation in natural ecosystems. This may jeopardise the persistence of trees in agricultural landscapes and the ecosystem services these treed landscapes offer. Here, we study one of the world's most altered ecosystems – temperate eucalypt woodlands – to explore patterns in natural regeneration of trees, and factors influencing regeneration occurrence, across 300 000 km^2 of south-eastern Australia between 2008 and 2014. During this period, we found the proportion of remnants supporting natural regeneration was stable, and that regeneration occurrence was negatively associated with variables coincident with agricultural intensification: continuous livestock grazing by sheep and cattle, increased exotic plant cover, increased natural soil fertility, and lower elevation. These results indicate that intensive agriculture is incompatible with natural regeneration in our study area. Left unaddressed, low levels of regeneration may result in the widespread loss of trees and the ecosystem services they provide in agricultural landscapes. Thus, strategic implementation of land-sparing and land-sharing strategies is required across broad spatial scales to satisfy production and conservation needs. Based on our results, we recommend that land sharing be prioritised where: (1) livestock grazing can be removed or employed intermittently, (2) exotic plants do not dominate the ground layer, and (3) natural soil fertility is low. For locations that are continuously grazed or dominated by exotic plants, a land-sparing strategy may be more appropriate. Here, farmland should be managed to maximise production, and the next generation of trees should be 'moved' to areas where natural regeneration can be supported.

1. Introduction

By 2050, the global human population is estimated to reach 9.6 billion (UN, 2013). To meet the food demands for a population of this size, worldwide agricultural production will need to increase by 70% (Alexandratos and Bruinsma, 2012). Agricultural expansion and intensification (i.e. means by which production gains are made using increased inputs per unit land area; Tilman et al., 2011) are strategies that can be used to meet this demand (Cunningham et al., 2013; Godfray et al., 2010) and have served to increase agricultural yields and total production in the past (Nellemann et al., 2009). However, agricultural expansion and intensification can degrade ecosystems by reducing water quality (e.g. through nitrogen and phosphorous-driven eutrophication; Tilman et al., 2001), exhausting soil nutrients (Matson et al., 1997) and reducing the ability for native vegetation to regenerate naturally (Dorrough and Moxham, 2005; Weinberg et al., 2011).

Natural regeneration (i.e. the establishment of young trees from seed; Dorrough and Moxham, 2005) is critical because it supplies landscapes with the next generation of trees as well as the ecosystem services they offer. The conservation value of scattered paddock trees compared to native remnant vegetation is disputed

* Corresponding author.
E-mail addresses: chloe.sato@anu.edu.au (C.F. Sato), jeff.wood@anu.edu.au (J.T. Wood), john.stein@anu.edu.au (J.A. Stein), mason.crane@anu.edu.au (M. Crane), sachiko.okada@anu.edu.au (S. Okada), damian.michael@anu.edu.au (D.R. Michael), geoffrey.kay@anu.edu.au (G.M. Kay), daniel.florance@anu.edu.au (D. Florance), Julian.Seddon@act.gov.au (J. Seddon), philip.gibbons@anu.edu.au (P. Gibbons), david.lindenmayer@anu.edu.au (D.B. Lindenmayer).

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by some agencies (e.g. there is a movement away from protecting scattered paddock trees under the *Native Vegetation Regulation 2013* in New South Wales, Australia). However, in agricultural landscapes where scattered paddock trees comprise a large proportion of total tree cover (e.g. south-eastern Australia; Gibbons and Boak, 2002), the value of scattered trees (in terms of the services they provide) is disproportionately high (Fischer et al., 2010; Manning et al., 2006). In agricultural landscapes, the services provided by native trees include: (1) provision of essential habitat for fauna (e.g. hollows for obligate hollow nesters; Manning et al., 2013), (2) supporting insect pollinators (Lentini et al., 2012), (3) maintaining or improving soil quality (e.g. increasing water retention capacity; Jonsson et al., 1999; controlling erosion; Plieninger et al., 2004; buffering salinity; Reid et al., 2000; buffering acidity; Wilson, 2002), (4) provision of wind protection for crops (Bird et al., 1992), and (5) provision of shade for stock and crops (Bentley et al., 2004; Reid et al., 2000). Given the benefits derived from the continued presence of trees in agricultural landscapes, understanding the regeneration niche (as described by Grubb, 1977) and factors that influence tree regeneration is essential for determining whether an ecosystem will persist or potentially collapse.

Factors influencing tree regeneration in agricultural landscapes are well researched – particularly the effects of land-use history and current grazing regimes (Carmona et al., 2013; Fischer et al., 2009; Weinberg et al., 2011). This research has informed, and continues to inform, attempts to restore and revegetate degraded agricultural ecosystems through regional-scale agri-environment schemes in Europe (Environmental Stewardship Program in UK; DEFRA, 2014; Ecological Compensation Areas in Switzerland; Kleijn et al., 2006), North America (Conservation Stewardship Program; USDA, 2014) and Australia (Environmental Stewardship Program; Lindenmayer et al., 2012; Biodiversity Baseline Monitoring Program; Michael et al., 2014). However, despite the growing body of literature regarding tree regeneration, the occurrence and extent of regeneration across broad spatiotemporal scales is poorly understood, making effective management for biodiversity conservation challenging.

In this paper, we address this issue using temperate eucalypt woodlands – a critically endangered ecosystem in Australia (TSSC, 2015) – in agricultural landscapes as a focal study system. Since European settlement, almost 90% of Australian temperate eucalypt woodlands have been cleared for agricultural purposes (Kabii and Horwitz, 2006), and remaining woodland remnants are often degraded (Yates and Hobbs, 1997). These remnants represent a significant proportion of the global extent of this biome (Hoekstra et al., 2005), but face the continued threat of degradation from agricultural activities (particularly agricultural intensification; McIntyre, 2012). To better understand and manage regeneration in temperate eucalypt woodlands, we use – for the first time – empirical data of eucalypt regeneration spanning a six year period, four study regions and a vast agricultural area (approximately 300 000 km^2) in south-eastern Australia to answer two questions, (1) Is the spatial extent of natural regeneration declining through time in agricultural landscapes in different bioclimatic regions? and (2) Across broad spatial scales, are there consistent site-level and landscape-scale factors associated with natural regeneration in agricultural landscapes?

First, we postulate that over time, there will be a decline in the number of sites supporting natural regeneration as predicted by Vesk and Dorrough (2006) and Fischer et al. (2009, 2010). Second, we postulate that a combination of site-level and broad-scale factors will be associated with natural regeneration. We expect that continuous livestock grazing (Carmona et al., 2013; Weinberg et al., 2011), cover of exotic plants (Gibbons et al., 2008b; Meiners, 2007) and soil fertility (Dorrough and Scroggie, 2008; Skinner et al., 2010) will have consistent negative associations with regeneration across broad spatiotemporal scales, given the marked effect these factors have in regional and snapshot regeneration studies. We also expect that factors such as elevation (Curtis, 1990), and cover and richness of native plant species (Spooner et al., 2002; Weinberg et al., 2011) will have positive associations with regeneration, consistent with previous research.

Our results provide important new information about contemporary patterns in natural regeneration in agricultural systems. Our results also provide new perspectives on where and when to prioritize landscapes for land-sharing (associated with extensive farming) or land-sparing strategies (associated with intensive farming; Fischer et al., 2014; Green et al., 2005; Norris, 2008) across broad spatial scales, using factors associated with natural regeneration as key criteria in the decision-making process.

2. Methods

2.1. Study region

We examined quantitative data on regeneration in four broad-scale, medium-term studies in south-eastern Australia: Biodiversity Baseline Monitoring Program ('BBMP'; Michael et al., 2014), South-west Slopes restoration study ('SWS'; Cunningham et al., 2007), Nanangroe study ('Nanangroe'; Lindenmayer et al., 2001), Environmental Stewardship Program ('Stewardship'; Lindenmayer et al., 2012) (Fig. 1). The area covered by the four study regions is approximately 300 000 km^2. All four studies were located in landscapes with a land-use history dominated by livestock (predominantly cattle and sheep) grazing and cropping (predominantly wheat). Grazing pastures may be modified (e.g. fertilized or fertilized and oversown with exotic forage plants to increase productivity) or unmodified (e.g. no intentional fertilizer and/or exotic forage plant addition) native grasslands (Dear and Ewing, 2008). Prior to European settlement, the study regions would have been largely covered by temperate woodlands (Lindenmayer et al., 2010; Yates and Hobbs, 1997). Remaining woodland remnants are largely embedded within an agricultural matrix and are dominated, or were previously dominated, by a variety of *Eucalyptus* and *Callitris* tree species (Yates and Hobbs, 1997). The understorey of more intact remnants contains a species-rich mix of tussock grasses, herbs and scattered shrubs (TSSC, 2015; Yates and Hobbs, 1997). In relatively unmodified examples of these remnants, the occurrence of natural regeneration is the norm (e.g. between 90 and 100% of remnants support natural regeneration; Gibbons et al., 2008a). For a detailed description of each study, see Appendix A in Supplementary material.

2.2. Data collection

Our investigation comprised 662 remnant woodland sites across four studies (BBMP: n = 105, SWS: n = 138, Nanangroe: n = 111, Stewardship: n = 308) in New South Wales, Australia. We established all sites in eucalypt woodland remnants that ranged in size from <1 ha to 150 ha. At all sites, we collected a consistent set of site-level vegetation attributes (see Table A.1 in Supplementary material) along a permanent 200 m transect. We measured percentage cover of ground layer native and exotic plants, bare ground, soil crust, leaf litter, overstorey and mid-storey along two 50 m sections of the transect between 0–50 m and 150–200 m, using the point-intercept method (Goodall, 1952). We measured native plant species richness within a 20 × 20 m plot centred on the 100 m point of the transect, and structural vegetation attributes – including total length of fallen logs and measures of natural eucalypt regeneration (i.e. eucalypt seedling abundance, proportion of overstorey eucalypt species present as seedlings/