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The extent and pattern of *Eucalyptus* regeneration in an agricultural landscape

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ABSTRACT

The process of natural regeneration is critical for sustaining remnant native vegetation and the ecosystem services it supports. We quantified the extent and pattern of *Eucalyptus* regeneration within remnant vegetation in a fragmented agricultural landscape in south-eastern Australia. *Eucalyptus* regeneration was absent at 42% of sites. Using an information-theoretic approach, we explored 13 possible models of *Eucalyptus* regeneration across multiple scales. The explanatory variables in the four models with empirical support (and their summed Akaike weights) were: grazing intensity (1.0), native ground cover (0.99), remnant area (0.83), tenure (0.67), canopy cover (0.21) and vegetation type (0.11). Averaging across these four models we predicted that the probability of *Eucalyptus* regeneration was highest (0.95) in relatively unmodified remnant native vegetation, that is, remnant vegetation on public land where grazing was light and the understorey was dominated by native plants. In contrast, the predicted probability of *Eucalyptus* regeneration was lowest (0.12) in small remnants on private land where grazing was heavy. Our results suggest that a large proportion of all remnant native vegetation in this landscape will disappear under existing land management and farming practices. Reducing grazing pressure within intensively grazed remnants appears to be the single most effective management intervention that will mitigate this threat. This will require a shift in conservation priorities away from large, intact remnants where regeneration does not appear to be affected, to poorer quality remnants—often small remnants or scattered trees—where regeneration is typically absent.

1. Introduction

Low levels of natural tree regeneration have been reported in agricultural and intensively grazed landscapes globally. These include *Quercus* stands in Europe (Mountford et al., 1999; Pulido et al., 2001; Plieninger et al., 2003), Asia (Saxena et al., 1984) and North America (Griffin, 1971; Palmer et al., 2004); savanna in Africa (Ben-Shahar, 1998); *Eucalyptus*, *Callitris* and *Allocasuarina* stands in southern Australia (Dorrough and Moxham, 2005; Maron, 2005); rainforest remnants in central America (Harvey and Haber, 1999); and *Aspidosperma* stands in South America (Barchuk and Diaz, 1999). Low levels of regeneration is a significant factor in the decline of tree cover in agricultural landscapes (Gibbons et al., 2008b).

The decline of native tree cover in agricultural landscapes is of concern because mature trees in partially cleared landscapes provide ecosystem services in quantities proportionally greater than their abundance (Manning et al., 2006). These include habitat for native species (Manning et al., 2006), salinity control (Cramer and Hobbs, 2002), a range of beneficial soil properties (Jonsson et al., 1999; Wilson, 2002) and financial benefits to farmers in terms of shelter for livestock and crops, forage for livestock, honey production, timber production and fuel wood (Harvey and Haber, 1999; Reid and Landsberg, 1999; Bentley et al., 2004; Western and Maitumo, 2004).

There is growing evidence that natural regeneration of Australia's dominant tree genus (*Eucalyptus*) is inhibited in intensively managed agricultural landscapes (Dorrough and Moxham, 2005; Briggs et al., 2008; Fischer et al., 2009), which is also the case for many widespread tree genera (Griffin, 1971; Pulido et al., 2001; Plieninger et al., 2004). Natural regeneration of *Eucalyptus* depends on the coincidence of a proximal seed source (Dorrough and Moxham, 2005), appropriate soil moisture and temperature (Yates et al., 1996), the degree of harvesting by seed predators (Odowd and Gill, 1984) and an appropriate seedbed (Faunt et al., 2006), leading to speculation that *Eucalyptus* regeneration is naturally episodic (Curtis, 1990). However, *Eucalyptus* regeneration has been recored as present in virtually all relatively unmodified remnants (Gibbons et al., 2008a), suggesting that factors associated with land

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management are the principal causes for the lack of *Eucalyptus* regeneration in agricultural landscapes. These factors are known to include cultivation, grazing by livestock and other herbivores and competition with exotic plants (Yates and Hobbs, 1997; Dorrough and Moxham, 2005; Spooner and Allcock, 2006).

An understanding of the extent and pattern of natural regeneration is critical to help land-managers, conservation agencies and governments understand the magnitude of this issue and use their limited resources to target areas where remnant native vegetation is under greatest threat. We observed natural tree regeneration in a fragmented agricultural landscape in south-eastern Australia to: (1) determine whether the proportion of remnants with natural regeneration differed to what is expected in relatively unmodified landscapes, (2) identify what parts of the landscape are at greatest threat from the lack of regeneration and (3) identify what land uses represent the greatest threat to regeneration.

2. Materials and methods

2.1. Study area

We surveyed *Eucalyptus* regeneration within, and immediately adjacent to, remnants of native vegetation over a landscape of 2577 km^2 in the Boorowa Shire within the Murray-Darling Basin in south-eastern Australia (34.0–34.6°S, and 148.6°–149.1°E). The climate is temperate with warm summers and cool winters (average maximum temperature is 20.7 °C and average minimum is 6.2 °C at Boorowa [weather station 070220]) and moderate rainfall (mean annual precipitation varies from 642 mm in the north [weather station 73051] to 713 mm in the southeast of the study area [weather station 70028]) (Australian Government Bureau of Meteorology, unpublished data).

Most (85%) of the woody native vegetation in the study area has been cleared for grazing by livestock (predominantly sheep and beef cattle) and cultivation since European settlement in the early 1800s (NPWS, 2002). Ridge-lines and upper slopes support dry sclerophyll forest in which red stringybark (*Eucalyptus macrorhyncha*) is usually present. Open forest and woodland dominated by red stringybark, long leaved box (*Eucalyptus goniocalyx*), and candlebark (*Eucalyptus rubida*) generally occur on sedimentary rocks of poor fertility on intermediate slopes of the study area. Box Gum Grassy Woodland dominated by white box (*Eucalyptus albens*), yellow box (*Eucalyptus melliodora*) and Blakely's red gum (*Eucalyptus blakelyi*) is widespread across the study area but occupies <10% of its pre-European extent and is listed as threatened nationally (DEH, 2006).

2.2. Sampling methodology

The study area was divided into 13 strata based on tenure (two levels), remnant size (four levels) and vegetation type (two levels) because these are broad indicators of grazing regime, native vegetation condition and environmental variation, each of which is potentially associated with *Eucalyptus* regeneration (note that three of all possible strata did not exist in the field). Stratification was undertaken using the following spatial layers: (1) a land tenure layer, derived from the NSW digital cadastral database and reclassified into two levels (public and private); (2) a vegetation community layer (NPWS, 2002) reclassified based on structural attributes into two vegetation categories (forest and woodland); and (3) a woody vegetation layer derived from a Landsat 5 multi-spectral image pan-sharpened with a finer-resolution (10 × 10 m) *Satellite Pour l'Observation de la Terre 4* (SPOT 4) panchromatic image (Seddon et al., 2007) classified into four remnant size classes based on a logarithmic scale (small [0.1–1 ha], medium [1–10 ha], large [10–100 ha] and very large [>100 ha]).

Four to 16 remnants (mean = 9) were sampled within each of the 13 strata with a total of 115 remnants sampled. The boundary of each remnant was defined as the edge of the tree crown plus an additional 10 m buffer. Remnants were each sampled with 1–10 plots with larger remnants sampled with more plots because these are more heterogeneous than small remnants (i.e., larger remnants are more likely to contain >1 vegetation type, tenure, etc.). A single plot was measured in all small ($n = 32$) and some medium ($n = 28$) remnants, two plots were measured in most medium and all large ($n = 39$) remnants, while between six and 10 plots were measured in all very large ($n = 16$) remnants. Plots were typically 30 × 30 m (0.09 ha). A modified plot layout was used to accommodate remnants that were ⩽30 m wide, whilst ensuring the total area surveyed (0.09 ha) remained constant. Field data were collected between January and March 2005.

2.3. Dependant variable

We analysed natural *Eucalyptus* regeneration as a binary variable (present/absent) rather than a continuous variable (density) for the following reason. *Eucalyptus* regeneration occurs more-or-less continuously in the vegetation types examined in this study via a process of gap-phase replacement (Florence, 1996) and is therefore virtually ubiquitous in relatively unmodified remnants (Gibbons et al., 2008a). However, relatively unmodified remnants can variously support sparse or dense regeneration depending on the history of stochastic events such as fires and floods (because *Eucalyptus* can regenerate profusely in these conditions) and competition from mature over-storey (because *Eucalyptus* are relatively intolerant to over-storey competition) (Florence, 1996). Thus, more regenerating stems does not equate with better function or better condition (i.e., the capacity of the remnant to support regeneration). We therefore considered the presence/absence of *Eucalyptus* regeneration was more indicative of condition than the density of regeneration, which is consistent with the approach adopted in other studies on *Eucalyptus* regeneration (Dorrough and Moxham, 2005; Fischer et al., 2009).

Natural *Eucalyptus* regeneration was recorded as present in a plot if at least one stem was observed. Natural *Eucalyptus* regeneration was defined as stems that were not the result of planting or artificial seeding, had a basal diameter <5 cm and were ⩽300 cm tall. Minor stems in close proximity to a larger stem were only considered regeneration if greater than 20 cm distant because they were often joined below ground.

2.4. Independent variables

A number of potential explanatory variables were recorded in each 0.09 ha plot (Table 1). Some potential explanatory variables (exotic cover, native cover, bare ground, rock cover, log cover and litter cover) were not recorded across the entire plot area, but were averaged across eight, 2 × 2 m sub-plots established at 15 m intervals around the perimeter of each 0.09 ha plot (Table 1). Patch metrics (area, perimeter, and perimeter/area ratio) were calculated using Patch Analyst for ArcGIS (Elkie et al., 1999).

2.5. Data analyses

We explored associations between the dependent variable (presence of *Eucalyptus* regeneration) and the independent variables (Table 1) using an information-theoretic approach. First, we undertook an initial exploratory analysis to check for colinearity between potential explanatory variables (Table 1). From the remaining potential explanatory variables we identified a set of

Table 1
Potential explanatory variables recorded for each site.

Variable	Description
Area	Remnant area (m^2) measured using a woody vegetation layer and GIS
Perimeter	Remnant perimeter (m) measured using a woody vegetation layer and GIS
Perimeter-area ratio	Patch perimeter to area ratio
Tenure	Public tenure (crown land) or private tenure (farm land)
Vegetation type	Dominant vegetation formation derived from pooling vegetation communities: forest (dominated by red stringybark or candlebark); woodland (dominated by white box, yellow box or Blakely's red gum)
Topographic position	Predominant location in the landscape: 1. Flat; 2. Drainage line; 3. Lower slope; 4. Upper slope; 5. Ridge/crest
Grazing intensity	Visually estimated as: (1) zero (no evidence of grazing by herbivores), (2) light (no or little evidence of grazing – little herbivore dung present, few signs of disturbance by hooves, some evidence of vegetation removal), (3) moderate (signs of patch grazing, tussock structure still evident, some dung and soil disturbance present, vegetation biomass moderate), or (4) heavy (no evidence of patch grazing, no native tussocks, considerable dung and soil disturbance, vegetation biomass low and even).
Canopy cover (%)	Derived from crown separation ratio following Specht et al. (1974)
Exotic cover (%)	Visual estimate of exotic annual and perennial grass and forb cover
Native cover (%)	Visual estimate of native grasses and forbs
Bare ground (%)	Visual estimate of bare ground cover
Rock cover (%)	Visual estimate of rock cover
Log cover (%)	Visual estimate of woody debris (>5 cm diameter)
Litter cover (%)	Visual estimate of litter cover

candidate models to examine whether (a) *Eucalyptus* regeneration responds to variables reflecting fine-scale processes only, (b) variables indicative of landscape-scale processes only, or (c) variables reflecting processes at both scales.

Because our data were hierarchical or nested (149 plots were measured in 115 remnants) there was potential for dependence between plots where they were located within the same remnant. We tested for dependence by examining relationships between the probability of *Eucalyptus* regeneration and the explanatory variables in the candidate models using Generalised Linear Mixed Modelling (GLMM) (McCulloch et al., 2008) with a logit link implemented with the "lmer" package in R (R Development Core Team, 2010) in which a factor representing all unique remnants was fitted as a random effect to each model. In all models the variance component for the random effect representing remnants was zero suggesting no evidence for dependence. We therefore undertook all analysis of the relationships between the probability of *Eucalyptus* regeneration and the explanatory variables using more parsimonious Generalised Linear Models (GLM) (McCulloch et al., 2008) with a logit link using the "stats" package in R (R Development Core Team, 2010).

Each candidate model was ranked from best to worst fitting on the basis of ascending Akaike's Information Criterion (AIC) values. AIC values were transformed into AIC weights (ω) and AIC differences (Δ) (Burnham and Anderson, 2004). Akaike weights (ω_i) can be interpreted as the probability that model *i* is the best model, of the set, for the data (Burnham and Anderson, 2004). Models with AIC differences less than two ($\Delta_i < 2$) have substantial empirical support and should all be considered (Burnham and Anderson, 2002). Models with substantial empirical support ($\Delta_i < 2$) were therefore averaged using the procedure outlined in Burnham and Anderson (2002) and predictions made from this average-weighted model.

3. Results

We sampled 149 plots across 115 remnants. The frequency distribution of sampled remnant sizes was positively skewed, with sampled remnants ranging in area from 0.1 ha to 9876.4 ha with a median area of 8.6 ha. *Eucalyptus* regeneration was present in 86 of the 149 (0.09 ha) plots sampled (or 58% of plots). The percentage of plots in which regeneration was present was significantly different ($\chi^2 = 1533$, df = 1, $p \leqslant 0.001$) to the percentage of plots (97%) expected to contain *Eucalyptus* regeneration in these vegetation types (Gibbons et al., 2008a).

3.1. Variables associated with natural regeneration

The log of remnant area was highly correlated with perimeter ($r = 0.73$) and perimeter to area ratio ($r = -0.82$). The latter two variables were removed from further analysis as the area of a remnant is the easiest of the three variables to interpret. From the remaining explanatory variables we identified ten potential GLMs predicting the probability of natural regeneration (Table 2) based on what we considered to be the key site and landscape variables that are likely to affect regeneration and are informative to land-managers. In each of the models containing grazing intensity there were no significant differences between several levels of this factor. This variable was therefore collapsed from the original four levels that were recorded in the field (see Table 1) to two levels as follows: zero, light and moderate grazing = 'light' grazing; and heavy grazing = 'heavy' grazing.

Akaike weights and evidence ratios suggested that four of the 13 candidate models had strong support (Akaike difference < 2) (Table 2). The summed Akaike weights from the 13 candidate models indicated that the most influential variables affecting *Eucalyptus* regeneration in descending order were: grazing intensity (1.00), native cover (0.99), remnant area (0.83), tenure (0.67),

Table 2
Candidate models for natural regeneration that were examined and their associated AIC, AIC differences (Δ_i) and Akaike weights (ω_i). Models with empirical support ($\Delta_i < 2$) are in bold (G = grazing intensity, N = native understorey cover, C = canopy cover, B = bare ground, T = land tenure, A = $\log_{10}$(remnant area), V = vegetation type).

Model	AIC	Δ_i	ω_i
G	179.99	7.69	0.01
G + N	175.70	3.40	0.05
G + N + C	177.50	5.20	0.02
G + N + C + B	179.49	7.19	0.01
T	197.07	24.77	0.00
T + A	188.73	16.43	0.00
T + A + V	190.73	18.43	0.00
G + N + T	174.85	2.55	0.08
G + N + A	**172.73**	**0.43**	**0.24**
G + N + T + A	**172.30**	**0**	**0.30**
G + N + T + A + V	**174.22**	**1.92**	**0.11**
G + N + C + T + A	**173.97**	**1.67**	**0.13**
G + N + C + B + T + A	175.87	3.57	0.05

canopy cover (0.21) and vegetation type (0.11). Each of grazing intensity, native cover and remnant area occurred in the four models with strong support (Table 2).

3.2. Predictions from an average-weighted model

An average-weighted model (across the four models with strong support) contained the explanatory variables grazing intensity, native understorey cover, tenure, remnant area ($\log_{10}$) vegetation type and canopy (Table 3). Predictions for each of the significant explanatory variables in the average-weighted model (with other significant explanatory variables held at reference levels) are illustrated in Fig. 1. In an averaged-sized remnant, the mean proportion of sites with regeneration decreased from 0.95 on public land where grazing was 'light' and the understorey was totally native to 0.14 on private land where grazing was 'heavy' and the understorey was totally exotic. In remnants with average native understorey cover, the mean proportion of sites with regeneration decreased from 0.84 in large remnants (10,000 ha) on public land where grazing was 'light' to 0.12 in small remnants (0.1 ha) on private land where grazing was 'heavy'. Other things equal, predictions from the average-weighted model suggested that regeneration, on average, was less likely to be present in woodland relative to forest and was negatively associated with canopy cover. However, these two relationships are extremely weak as indicated by the low parameter estimate and/or high standard error around this estimate for these variables (Table 3).

4. Discussion

4.1. Is there a tree regeneration problem in agricultural landscapes?

Our study adds to a body of evidence that over-storey regeneration is restricted in agricultural landscapes. In this study *Eucalyptus* regeneration was present at 58% of sampled sites. Other studies in agricultural landscapes have reported similar results. For example, in an agricultural landscape dominated by *Eucalyptus* species south of our study area Dorrough and Moxham (2005) found that 27% of sites they surveyed (including sites without remnant vegetation) contained regeneration. In a review of landscapes dominated by *Quercus lobata* in North America 45% of sites contained regeneration (Zavaleta et al., 2007). *Quercus* regeneration in Spanish dehesas was 2% of the density of regeneration in comparable forest (Pulido et al., 2001). Tree regeneration can be naturally episodic because of the range of conditions that must be coincident for it to occur (Barnes, 1983; Barchuk and Diaz, 1999), so do our observations that regeneration occurred at 58% of sites represent a deviation from the expected pattern of natural tree regeneration for *Eucalyptus* in this landscape?

Our results suggest the answer to this question is "yes". The per cent of sites that we observed regeneration (58%) was significantly different to the per cent of sites expected to contain regeneration (97%), in a study of comparable, but relatively unmodified, sites by Gibbons et al. (2008a). Further, the predicted proportion of relatively unmodified remnants (i.e., remnants on public land with a predominantly native understorey) that contained regeneration (0.95) was considerably higher than the predicted proportion of sites that contained regeneration on private land where grazing was heavy and either the understorey was exotic (0.14) or the remnant small (0.12). These results support the suggestion that these ecosystems naturally regenerate via a process of continual gap-phase replacement (Florence, 1996) and *Eucalyptus* regeneration is inhibited where agricultural activities are intensive.

Table 3
Parameter estimates and standard errors (SEs) for the average-weighted model of natural regeneration of eucalypts.

Term	Estimate	SE
Intercept	−1.66	0.89
Grazing intensity 'light'	0	–
Grazing intensity 'heavy'	−2.22	0.80
% Native understorey cover	0.03	0.02
Land tenure 'private'	0	–
Land tenure 'public'	0.69	0.44
Remnant area ($\log_{10}$)	0.30	0.14
Vegetation 'forest'	0	–
Vegetation 'woodland'	−0.13	0.47
Canopy	−0.01	0.02

4.2. Land use and landscape factors associated with the pattern of tree regeneration

Of the measured variables, grazing intensity was the primary factor affecting *Eucalyptus* regeneration, with no empirical support for models that did not include this variable (models not containing this variable had AIC differences $[\Delta_i] > 16$). This finding is replicated across agricultural landscapes globally (reviewed by Manning et al. (2006)). High grazing intensity is likely to inhibit regeneration directly via at least two mechanisms: (1) germination is inhibited from modifications to the seedbed and (2) the survival of seedlings is compromised from browsing pressure. Several environmental conditions that can be affected by grazing must be met for a *Eucalyptus* seed to germinate. *Eucalyptus* seed lacks an endosperm and does not persist in the soil, but is released from the canopy when conditions are likely to be suitable for germination (Florence, 1996). While it is believed that eucalypts require exposed mineral soil to germinate (Jacobs, 1955), an exposed seedbed that is also compacted by livestock (a major herbivore in this landscape) can be hostile to germination (Yates et al., 1996; Pettit and Froend, 2001). If *Eucalyptus* seed germinates then it can be affected by browsing. In our study area potential browsers of young *Eucalyptus* foliage include invertebrates (Landsberg et al., 1990), livestock (Dorrough et al., 2004), some native vertebrates such as the swamp wallaby (*Wallabia bicolor*) (Di Stefano et al., 2007) and introduced rabbits and hares (Saunders et al., 2003).

We recorded no significant differences in the proportion of sites with regeneration between sites that we classified as 'zero', 'light' and 'moderate' grazing intensity (see definitions in Table 1). This is consistent with several studies in which natural *Eucalyptus* regeneration was observed in the presence of intermittent periods of heavy grazing by livestock between periods of no grazing or light grazing (Curtis and Wright, 1993; Spooner et al., 2002; Briggs et al., 2008; Fischer et al., 2009)—an observation that has also been made for other tree genera (Hester et al., 1996; Pulido et al., 2001). These observations are further supported by the patterns of regeneration that we observed in different land tenures. Remnant native vegetation on private land in the study area is more likely to have a history of continuous grazing by livestock, while grazing by livestock in public land within the study area (roadsides and travelling stock reserves) is typically intermittent or has been absent for a long period (Prober and Thiele, 1995; Dorrough and Moxham, 2005). Land tenure was a significant explanatory variable in three of the four best regression models with public land, on average, having a greater probability of supporting natural *Eucalyptus* regeneration than private land (Fig. 1).

Eucalyptus regeneration was positively associated with the per cent of native understorey cover in each of the four models with empirical support (Table 2) and the average-weighted model (Table 3). This result is consistent with other studies (Cluff and Semple, 1994; Li et al., 2003; Dorrough and Moxham, 2005). This result may be indirectly linked to grazing pressure. Although native understorey cover and grazing intensity were not highly

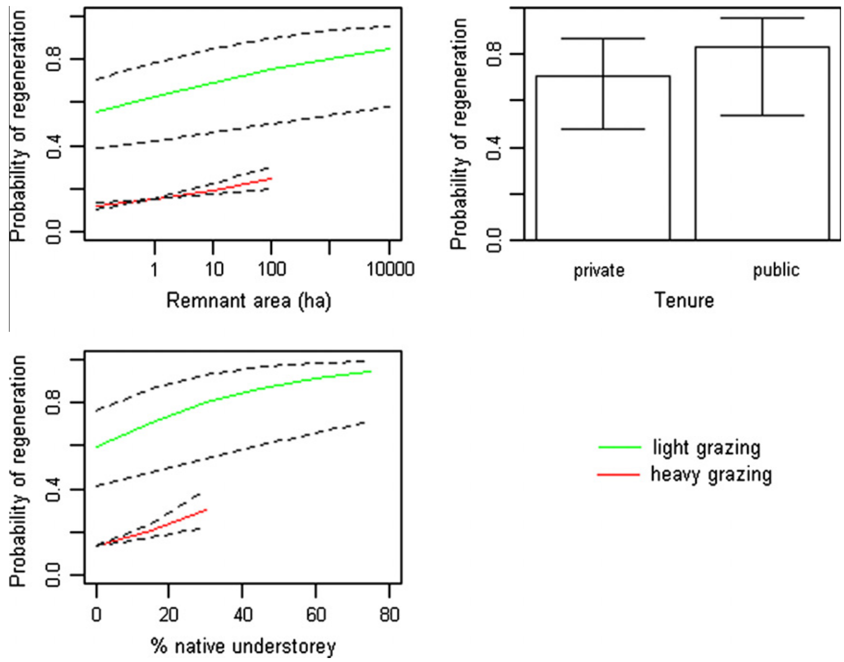

Fig. 1. Predicted probabilities (mean ± SE) of regeneration for the explanatory variables with the highest importance values (⩾0.67) in the average-weighted model. Predictions for the variables remnant area ($\log_{10}$) and per cent understorey cover were made with the other continuous variable fixed at their mean, tenure fixed at 'private' and vegetation fixed at 'woodland'. The prediction for the variable tenure was made with the other continuous variables held at their mean, grazing fixed at 'light' and vegetation fixed at 'woodland'.

correlated, sites that were intensively grazed did not support high native understorey cover (Fig. 1). Intensive grazing by livestock is associated with pasture improvement, which involves soil disturbance, the introduction of exotic pasture species and the use of superphosphate. These actions all affect natural regeneration (Fischer et al., 2009).

Remnant area was a significant explanatory variable in the four best models (Table 2), with the probability of regeneration lowest in smaller remnants (Fig. 1). Remnant area was correlated with remnant perimeter and perimeter to area ratio. The effects of small remnants, remnants with a long perimeter or remnants with a high perimeter to area ratio include: loss of genetic vigour from reduced out-crossing (Burrows, 2000), increased susceptibility to the effects of grazing and invasion by exotic plants (McIntyre and Lavorel, 1994) and influxes of nutrients from surrounding land uses (Yates and Hobbs, 1997).

Seedlings of many tree species, including each *Eucalyptus* species observed in this study, form lignotubers. Lignotubers enable seedlings to resprout after perturbations such as drought, grazing or fire. Lignotuberous seedlings of the genus *Eucalyptus* can potentially persist for decades when conditions are not suitable for growth (e.g., because of over-storey competition) (Noble, 1984). Survival of *Eucalyptus* seedlings from fire was positively associated with the size of the lignotuber (Noble, 1984). We did not measure the size of lignotubers in this study. However, it is feasible that the size of the lignotuber (or the age of the seedling) is an important factor affecting seedling persistence which was not examined in this study. Further, if the ability of a seedling to survive perturbations such as grazing is affected by the size of the lignotuber, then sites in which seedlings with lignotubers no longer persist (e.g., due to a history of grazing or soil disturbance), may be more difficult to regenerate naturally because they can only regenerate from seed. Pulido et al. (2001) noted that Holm oak (*Quercus ilex*) regeneration in agricultural landscapes in Spain only occurred vegetatively, suggesting that regeneration from seed was not possible under conditions of intensive grazing by livestock.

4.3. The importance of small, modified remnants for conservation in agricultural landscapes

Our results illustrate that modified and/or small remnants can be important conservation priorities in fragmented agricultural landscapes. Governments invest considerably in conservation actions within agricultural landscapes via agri-environmental schemes (Ribaudo et al., 2001; Kleijn et al., 2006). In these schemes conservation priorities in remnant native vegetation are often set according to condition or quality (e.g., proximity of a site to reference conditions, the number of species on a site) and/or irreplaceability (the importance of a site for meeting a conservation target) (Pressey and Bottrill, 2008), with the total area protected often used as the metric to summarise conservation achievement. Our study demonstrates that this can be a dangerous strategy for prioritising conservation investment in these landscapes. In our study area this strategy would place a priority on the conservation of large patches of woodland vegetation on public land as these are the remnants that are in best condition and with highest irreplaceability (*sensu* Pressey and Bottrill, 2008). However, our results suggest that this conservation strategy would result in considerable loss of remnant native vegetation. This is because large remnants on public land are at relatively low threat of decline from lack of regeneration (Fig. 1). Similarly, these remnants cannot generally be cleared under native vegetation laws in Australia, tend to have relatively low cover of exotic plants and are generally not available for intensive grazing. Conversely, small and/or modified remnants on private land are at considerable risk of further decline without a change in management. This is because these remnants have relatively low probabilities of containing regeneration (Fig. 1), tend to have higher exotic plant cover, are more likely to be intensively grazed and can be cleared under some circumstances (Gibbons et al., 2009). Further, Gibbons et al. (2008b) found that tree cover is on a steep trajectory of decline in highly modified stands in agricultural landscapes, but this can be ameliorated with management intervention. Thus, conservation efforts on large, intact remnants are unlikely to result in much improvement in conservation values within these landscapes relative to small and/or highly modified remnants that have the highest likelihood of loss under the status quo.

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