

RESEARCH ARTICLE

Biodiversity benefits of vegetation restoration are undermined by livestock grazing

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Extensive areas of the Earth's terrestrial surface have been subject to restoration, but how best to manage such restored areas has received relatively limited attention. Here, we quantify the effects of livestock grazing on bird and reptile biota within 61 restoration plantings in south-eastern Australia. Using path analysis, we identified some of the mechanisms giving rise to differences in patterns of species richness and individual species occurrence between grazed and ungrazed plantings. Specifically, we found evidence of both: (1) indirect effects of grazing on various elements of biodiversity mediated through changes in vegetation condition (primarily the leaf litter layer), and (2) direct effects of grazing on biodiversity (irrespective of modification in vegetation cover attributes), possibly as a result of trampling by livestock. We also uncovered evidence of direct effects on bird and reptile biota of other planting attributes such as planting width and planting age. The results of our study suggest that the biodiversity benefits of restoration programs can be undermined by grazing, especially by uncontrolled grazing. We suggest that where the objective of vegetation restoration is to enhance biodiversity conservation, grazing within plantings should be limited or excluded.

Key words: livestock grazing, restoration planting, south-eastern Australia, woodland birds, woodland reptiles, woodland restoration

Implications for Practice

- Livestock grazing in restored (replanted) areas should be limited or excluded to minimize negative impacts on birds and reptiles.
- In particular, uncontrolled grazing should be avoided wherever possible as it can have direct impacts on biodiversity (e.g. via trampling) and/or indirect effects mediated through altered ground layer conditions.
- A key implication for management is that fences should be maintained so that access to replanted vegetation by livestock can be either excluded or the amount of grazing pressure can be controlled.
- In addition to grazing control, other key attributes of plantings that can have significant impacts on the effectiveness for biodiversity and on which managers can have a direct influence include planting width and the age of plantings.

Introduction

Billions of dollars are being spent annually by governments and organizations to restore the millions of hectares of degraded land worldwide (Hajkowicz 2009; Aronson & Alexander 2013; Menz et al. 2013; Kimball et al. 2015; Crouzeilles et al. 2016). A wide range studies as well as extensive meta-analyses have highlighted the biodiversity benefits of restoration efforts (e.g. Gibb & Cunningham 2010; Crouzeilles et al. 2016; Lindenmayer et al. 2016). However, how restored areas are managed may influence their biodiversity values. For example, livestock grazing may influence the habitat value of restored vegetation,

especially as it is the largest user of agricultural land globally (FAO 2009). Livestock grazing can alter the amount and structure of vegetation cover (Lunt et al. 2007; Sato et al. 2016) and influence the suitability of habitats for biodiversity (Williams & Price 2011; Lindenmayer et al. 2012). Grazing also can affect the composition of the vegetation, although this was not a focus of the article reported here. Whilst the effects of grazing on the biota inhabiting remnant vegetation are relatively well understood (e.g. Kay et al. 2017), its effects on biota in restored areas have only rarely been examined.

Here, we report the findings of an empirical study of grazing in restored areas in the South West Slopes of New South Wales, south-eastern Australia. This region is one of the most heavily modified by agricultural activities in Australia (Benson 2008) and it has been targeted for extensive revegetation efforts over the past 20 years (Crane et al. 2014; Lindenmayer et al. 2016). Indeed, the past studies in the South West Slopes have

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highlighted the value of planted areas for biodiversity (Barrett et al. 2008; Lindenmayer et al. 2010b, 2016). However, many revegetated areas are being grazed, in part because of the state of disrepair of fences around plantings, which means that they are increasingly accessible to livestock (M. Crane (author), 2017, personal observation). This presents an important opportunity to determine if the value of restored (planted) woodlands for bird and reptile biota is altered by grazing by domestic livestock. The key question which motivated our study was therefore: *Is there a difference in bird and reptile biodiversity between grazed and ungrazed plantings and, if so, what mechanisms might underpin such grazing impacts?* As different groups of biota have different habitat requirements, our investigation explored relationships between both birds and reptiles and vegetation structure.

We underpinned our work with a conceptual model of the potential direct and indirect inter-relationships between planting attributes (e.g. width and age), grazing, vegetation condition, and the species richness, and occurrence of birds and reptiles (Fig. 1). Previous studies have highlighted the impacts of grazing on the understory and other layers of vegetation (Spooner et al. 2002; Lunt et al. 2007; Martin & McIntyre 2007; Lindenmayer et al. 2012; Sato et al. 2016), albeit in remnant woodland patches and not in restored areas. Other work has produced evidence of the effects of livestock grazing on groups such as birds (Martin & McIntyre 2007; Lindenmayer et al. 2012) and reptiles (e.g. Kay et al. 2017; Pulsford et al. 2017), again in eucalypt remnants rather than plantings. We sought to quantify both indirect and direct effects of grazing on the biota inhabiting plantings. For example, indirect effects of livestock grazing on biodiversity may be mediated by grazing-related modification of vegetation cover (Fleishman & Murphy 2009; Williams & Price 2011) that, in turn, alters habitat suitability for birds and reptiles (Martin & McIntyre 2007). Direct effects of grazing may occur without intermediary impacts on vegetation change such as through livestock trampling of bird nests located on the ground (Higgins 1991–2006; Williams & Price 2011). Direct effects of planting attributes may arise because animals respond to measures like width and/or age irrespective of modification of vegetation condition that may result from livestock grazing (Fig. 1). These indirect and direct effects of planting attributes and grazing represent different mechanisms or pathways (sensu Shipley 2009) giving rise to patterns of species richness and individual species occurrence.

Millions of hectares of the Earth's terrestrial surface are planned to be targeted in large-scale restoration programs (Menz et al. 2013; Crouzeilles et al. 2016; McAlpine et al. 2016), in part to tackle problems associated with land degradation but also to address other environmental problems such as biodiversity loss (Aronson & Alexander 2013; Crouzeilles et al. 2016). How restored areas are managed, including grazing management, may have a significant influence on their effectiveness for both conserving biodiversity. The work reported in this article is therefore relevant to the management of the increasing amount of restored native vegetation globally.

Methods

Study Area

Our study region was a 150 × 120 km agricultural area within the South West Slopes bioregion of New South Wales, south-eastern Australia. The South West Slopes was formerly dominated by temperate eucalypt woodland (Lindenmayer et al. 2010a), but has been cleared of an estimated 85% of its original cover (Benson 2008) to facilitate livestock grazing and cereal cropping. As a result, the South West Slopes region has been the target of major planting programs (Cunningham et al. 2014).

Plantings Attributes

We focused on 61 areas of replanted native vegetation on 25 farms in our study region. A total of 41 plantings have never been grazed by domestic livestock. For the remaining 20 plantings, grazing was “controlled” in that it occurred infrequently (e.g. occasional “crash” grazing) on 10 sites or “uncontrolled” in that cattle (*Bos taurus*) and sheep (*Ovis aries*) had continuous access to plantings on a further 10 sites. The width of plantings ranged from 10 to 300 m. Age of planting ranged from 6 to 61 years old (25th percentile = 13 years, median = 18 years, and 75th percentile = 23 years) (Table S1, Supporting Information).

Our plantings were characterized by a mix of local endemic and exotic Australian ground cover, understory, and overstory plant species. Most plants were typically spaced 2 m apart, but there was not a standard set of spacing and plant species composition protocols applied in revegetation efforts. In spring 2013, we completed a survey of vegetation structure and composition in the plantings with the primary focus of this study being on six attributes. These were the percentage cover in the understory, midstory, and overstory, the percentage cover of leaf litter, the percentage of tussocks of exotic grass, and the percentage of tussocks of native grass. We measured the six vegetation cover variables in three 20 × 20 m plots at 0, 100, and 200 m points along a permanent transect at each site. We defined understory, midstory, and overstory based on height; the overstory was vegetation exceeding 10 m in height, midstory was 2–10 m in height, and understory was woody vegetation less than 2 m in height. To obtain a site-level description of the vegetation cover variables, we aggregated plot-level data to the site-level.

Bird Surveys

We gathered bird data in the spring of 2013 using repeated 5-minute point interval counts at 0, 100, and 200 m along the fixed transect at each of the 61 plantings. For each point-interval count, an observer recorded all bird species seen or heard within 50 m of the centre of a field plot point. Each site was surveyed twice by two observers on different days. We did not undertake surveys during poor weather (rain, high wind, fog, or heavy cloud cover). We observed these protocols to maximize the detection of bird species and reduce the effects of observer heterogeneity and day effects (Lindenmayer et al. 2009). All bird surveys were completed by the same group of experienced observers from The Australian National University.

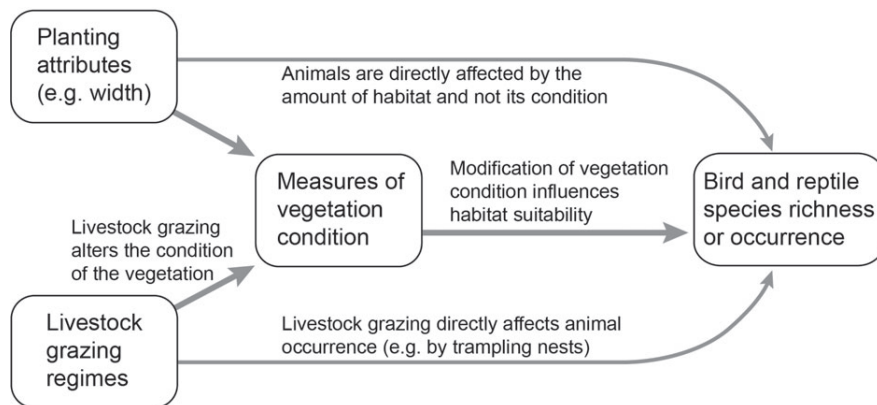


Figure 1. Conceptual model (path diagram) of potential inter-relationships between management, vegetation characteristics, and biodiversity response in Australian temperate woodlands.

Reptile Surveys

We surveyed reptiles in two ways. First, we completed time-constrained (20 minutes) active searches (see Michael et al. 2012). Second, we deployed three kinds of artificial refuge arrays to survey the occurrence of reptile species in each of the 61 plantings. The artificial refuges were: (1) one double-layered stack of corrugated galvanized steel; (2) four 1.2 m long railway sleepers; and (3) four concrete roof tiles (32 × 42 cm) (Michael et al. 2012). At each site, we established two reptile monitoring stations located at the 0 and 100 m point along the same 200 m transect on which bird surveys were completed (see above). Surveys were conducted during the spring of 2013 and confined to clear sunny days between 09:00 and 14:00 hours by experienced herpetologists from The Australian National University. Previous analysis has indicated that the use of an array of search and survey methods ensures that almost all species of reptiles are detected in plantings (see Michael et al. 2012).

Statistical Analysis

Shipley (2009) and the references therein lay out an approach to path analysis based on directed acyclic graphs and the concept of *d*-separation. We employed Bayesian regression models with paths chosen via leave-one-out cross-validation information criteria (LOOIC) (Gelman et al. 2014). The specific details are described below. Following Shipley (2009), we combined the results of the implied independence claims using Fisher's *C* statistic, with the frequentist *p*-values in the definition replaced by their Bayesian counterparts. If the data are generated according to the specified causal model, then Fisher's *C* statistic follows a chi-squared distribution with $2c$ degrees of freedom (*df*) (where *c* is the number of implied independence claims; Shipley 2009). Therefore, large values of Fisher's *C* statistic relative to a chi-squared distribution with $2c$ *df* give evidence against the specified causal model (i.e. small significance levels).

We converted vegetation cover variables (percentage cover of: understory, midstory, overstory, native tussock, exotic

tussock, and leaf litter) to proportions and modeled them with zero-inflated beta regression to account for zeros [the beta distribution is restricted to the open interval [0, 1]]. Beta regression was used for midstory cover as no zeros were observed for this variable. Our study design has plantings nested within farms. Therefore, farm was included as a random effect (i.e. we have a multilevel model). The predictor variables for this stage of analysis were: age of planting, width of planting (log transformed), and type of grazing (none, controlled, and uncontrolled). Note that we examined two additional variants of grazing, grazed versus nongrazed (i.e. we combined controlled and uncontrolled grazing) and uncontrolled versus controlled and nongrazed. We used LOOIC (Watanabe 2010; Gelman et al. 2014; Vehtari et al. 2015) for model selection and chose the simplest model (smallest number of terms) within two LOOIC units of the best fitting model.

We modeled bird and reptile species richness with Poisson regression with a random effect for farm as with vegetation. We modeled the presence/absence of five individual bird species (presence over the six point counts) and one species of reptile (any occurrence of the species detected using the various field survey methods)—Rufous Songlark (*Megalurus mathewsi*), Superb Fairy-wren (*Malurus cyaneus*), Willie Wagtail (*Rhipidura leucophrys*), White-plumed Honeyeater (*Lichenostomus penicillatus*), Australian Magpie (*Cracticus tibicen*), and Boulenger's Skink (*Morethia boulengeri*)—with logistic regression using farm as a random effect. These six taxa were the six most common species with sufficient data to underpin robust path analyses.

We used the same site-level characteristics used in the vegetation analysis as predictors in the Poisson and logistic regression models and also used standardized versions of the six vegetation cover variables. Due to the number of predictor variables under consideration at this stage, we did not use an all possible subsets strategy. Instead, we considered the 16 models (Table S2) for the site characteristics combined with the 42 models (Table S3) for the vegetation variables where, at most, three vegetation variables were considered at any one time. We used LOOIC using a similar strategy as described previously.

We used a Bayesian approach, which was implemented using the brms (Bayesian Regression Model Stan) package (Bürkner 2016) in R (R Core Team 2015). Continuous predictor variables were standardized prior to entry in the models. We used the brms default priors for the beta and Poisson modeling, and we employed Cauchy priors (location = 0, scale = 5/2) to control the potential effects of complete separation (see Gelman 2008).

Results

We recorded 89 species of birds (Table S1) and 15 species of reptiles (Table S2). Of these, no reptile species and two bird species (House Sparrow [*Passer domesticus*] and Common Blackbird [*Turdus merula*]) are exotic taxa.

Covariate Effects on Vegetation Cover

Descriptive information for all the variables used in the analysis is given in Table S3. In the initial step of our path analysis, we modeled relationships between planting attributes (age, width, and type of grazing [viz: none, controlled, and uncontrolled]) and the various vegetation cover variables. We uncovered evidence of a negative effect of uncontrolled grazing on the amount of leaf litter, a negative effect of grazing compared to no grazing for native tussocks, and a negative effect of planting width (log) on the amount of midstory cover (Tables S4 & S6). The null model was the most parsimonious model (within two LOOIC units of the best fitting model) for all other vegetation cover variables and combinations of covariates (Table S4). Notably, there was only limited correlation between the six vegetation cover variables (the amount of cover in the understory, mid-story, overstory, native tussock, exotic tussock, and leaf litter) (see Table S7).

Planting Attribute and Vegetation Cover Pathway Effects on Bird and Reptile Species Richness

We found that bird species richness increased with understory cover and the amount of leaf litter (Fig. 2). There also was a negative effect of midstory cover on bird species richness (Tables S8 & S9). In addition, there was a direct positive effect of planting width (log) on bird species richness (i.e. an effect not mediated through vegetation attributes) (Fig. 2). In the case of reptile species richness, there was evidence of negative effects of uncontrolled grazing and the amount of vegetation cover in the overstory. There was also a positive relationship between the amount of leaf litter and reptile species richness (Tables S8 & S9; Fig. 3). The causal model for the bird species richness fitted the observed data well (Fisher's $C = 36.66$, $df = 28$, tail area = 0.129); however, there is some evidence that the reptile species richness model did not fit the observed data well (Fisher's $C = 48.01$, $df = 30$, tail area = 0.020). The lack of fit of the causal model was caused by a correlation between overstory and midstory (controlling for planting width) (Bayesian tail area = 0.001, Table S10).

Planting Attribute and Vegetation Cover Pathway Effects on Individual Bird and Reptile Species

We completed path analysis for five bird and one reptile species (Tables S8 & S9). The Rufous Songlark was negatively associated with grazing (uncontrolled grazing vs. no grazing) and positively associated with exotic tussocks (Table S9; Fig. S1). The White-plumed Honeyeater was negatively associated with grazing and overstory cover and positively associated with leaf litter (Table S9; Fig. S2). The Superb Fairy-wren was positively associated with leaf litter (Table S9; Fig. S3). The Australian Magpie and Willie Wagtail were not associated with any covariates. We found that the Boulenger's Skink was positively associated with leaf litter and the age of planting (see Table S9; Fig. S4). The causal (path) models fit reasonably well for all species with the exception of Rufous Songlark (Fisher's $C = 50.97$, $df = 32$, tail area = 0.018) and White-plumed Honeyeater (Fisher's $C = 37.37$, $df = 24$, tail area = 0.040) (Table S10). The main contribution to the lack of fit of the causal models for these species is correlation between vegetation variables: leaf litter and exotic tussocks controlling for grazing for Rufous Songlark and midstory and overstory cover controlling for planting width for White-plumed Honeyeater.

Discussion

We found differences in bird and reptile biodiversity between grazed and ungrazed plantings. Moreover, using path analysis, we identified both: (1) indirect effects of grazing on various elements of biodiversity as mediated by changes in vegetation condition and (2) direct effects of grazing (irrespective of modification in vegetation attributes). Thus, we were able to identify some of the mechanisms by which grazing can influence the occurrence of bird and reptile biota in plantings. We also uncovered evidence of direct effects on bird and reptile biota of other planting attributes such as planting width and planting age. We further discuss these findings in the remainder of this article and conclude with some commentary on their implications for restoration management and biodiversity conservation.

Grazing Effects

The most prevalent grazing effect identified in our study was an indirect one in which grazing (and particularly uncontrolled grazing) reduced the amount of leaf litter. This, in turn, led to depressed bird species richness, reduced reptile species richness, and reduced occurrence of the White-plumed Honeyeater and Superb Fairy-wren. Earlier studies have shown that livestock grazing leads to a significant loss of leaf litter, albeit in temperate woodland remnants rather than plantings (e.g. Robertson & Rowling 2000; Yates et al. 2000). Leaf litter is, in turn, an important foraging substrate for many woodland birds (Antos et al. 2008; Barrett et al. 2008) and also reptiles (Valentine et al. 2007). Grazing-related modification of the suitability of habitat and foraging substrate suitability is therefore a plausible explanation for the indirect pathway linking grazing and altered bird and reptile occurrence.

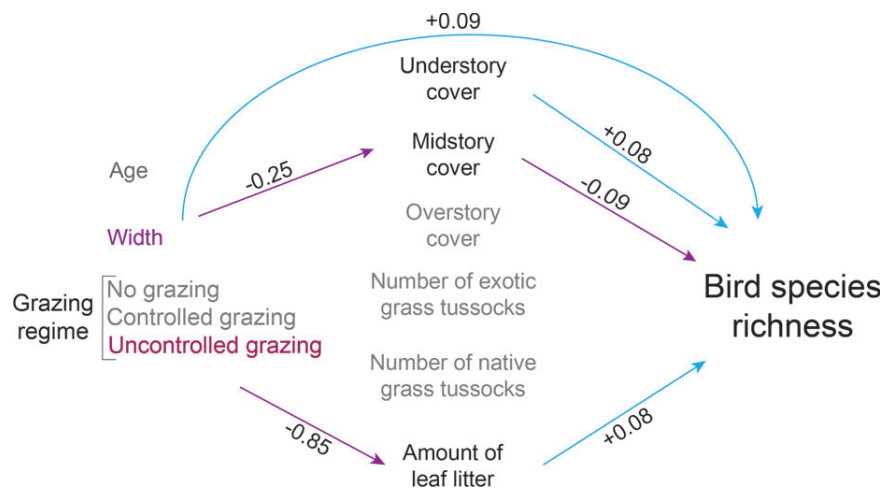


Figure 2. Directed acyclic graph depicting which planting attributes, grazing, and vegetation variables are important in the path analysis of bird species richness. Path coefficients are deemed important if their 95% credible intervals do not overlap zero (see Table S4). Coefficients whose credible intervals overlap zero or were excluded from the final model via LOOIC model selection are omitted from the path diagram. The larger the absolute value of the coefficient, the stronger the effect.

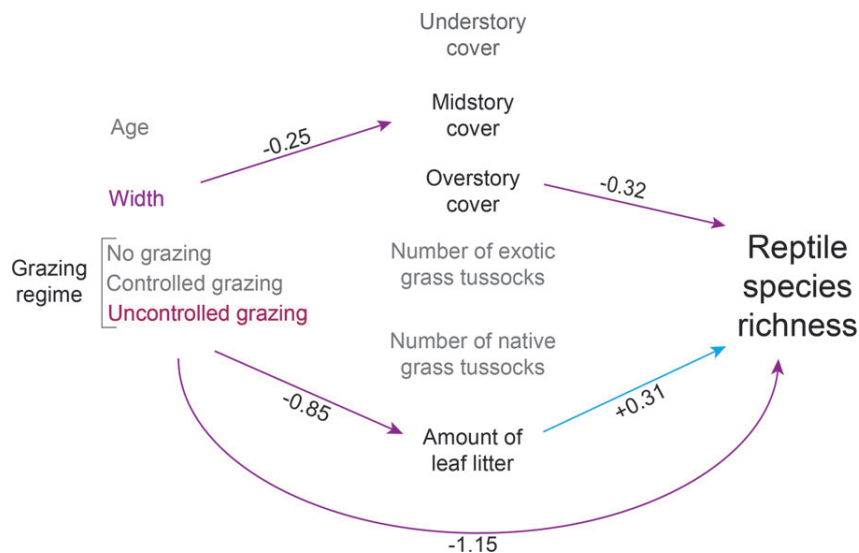


Figure 3. Directed acyclic graph depicting which planting attributes, grazing, and vegetation variables are important in the path analysis of reptile species richness. Path coefficients are deemed important if their 95% credible intervals do not overlap zero (see Table S4). Coefficients whose credible intervals overlap zero or were excluded from the final model via LOOIC model selection are omitted from the path diagram. The larger the absolute value of the coefficient, the stronger the effect.

We also uncovered evidence of direct effects of grazing not mediated through modification in vegetation condition. Such effects may manifest through trampling and perturbation of the ground and affect nests, for example. Such a mechanism is plausible for species including the Rufous Songlark, which nests on the ground. This effect is consistent with work by (Ford 2011) who recognized that ground foraging and ground nesting woodland birds were prominent among those declining across temperate woodland biomes in south-eastern Australia. However, trampling-related perturbation may not explain the direct effects of grazing on the White-plumed Honeyeater, the

abundance of which was reduced depending on whether plantings were grazed or not. The White-plumed Honeyeater only infrequently forages on the ground and other factors may be important for this species. It may nest as low as 1 m above the ground and mechanical disturbance by livestock might influence nesting success. The White-plumed Honeyeater also uses spider web to construct its nests (Higgins et al. 2001) and work elsewhere in south-eastern Australia has shown that abundant (albeit native) populations of herbivores can cause significant mechanical damage on the webs constructed by spiders (Foster et al. 2015).

Planting Width Effects

We uncovered evidence of a direct positive effect of planting width on bird species richness. This suggests that geometry is important for birds in restored environments; for example, landscape ecology theory predicts that wider plantings will have more interior versus edge habitat suitable for animal occupancy of sites (Lindenmayer & Hobbs 2007; Collinge 2009).

An unexpected outcome of our path analysis was that wider plantings were characterized by vegetation with lower values for midstory cover. The reasons for this relationship remain unclear but such paths had subsequent links with reduced overall bird species richness and, conversely an increased occurrence of the Rufous Songlark. Midstory vegetation can add an important layer in the vertical structure of a stand of woodland and can, in turn, add to the number of niches available for different species of birds—the vegetation structure hypothesis underpinning overall bird species richness (MacArthur & MacArthur 1961). However, some ground-associated species may be disadvantaged by additional layers of vegetation cover as observed for the occurrence of the Rufous Songlark.

Planting Age

Only one species, Boulenger's Skink, exhibited a direct positive response to the age of plantings. That is, the species was more likely to occur in older plantings. One explanation for this was that the longer plantings have been established, the greater the amount of natural self-thinning of trees and, in turn, the more light penetrating to the woodland floor, thereby creating more suitable habitat for this generalist reptile species. However, we found no indirect relationships between planting age, vegetation structure, and condition and bird or reptile response. This result was unexpected given that vegetation structure and composition of planted areas changes over time with vegetation succession and maturation (e.g. Vesik et al. 2008) and this can influence the availability of potential food sources such as invertebrate prey (Majer et al. 2001; Gibb & Cunningham 2010) as well as the abundance of flowers, pollen, nectar, and seeds. Although our plantings were between 6 and greater than 20 years old at the start of our investigation, it may be that more time is required for the ecological maturation of restored areas (Munro et al. 2009) and, in turn, the emergence of indirect planting effects on birds and reptiles.

Management Implications

This study and several previous investigations by us (Lindenmayer et al. 2007, 2010b; Munro et al. 2011; Pulsford et al. 2017) and other researchers (e.g. Ryan 2000; Robinson 2006; Barrett et al. 2008; Kinross & Nicol 2008; Selwood et al. 2008) have highlighted the value of revegetated areas for biodiversity in the temperate woodland environment of eastern Australia. The study we report here indicates that the benefits of restored areas may be undermined when they are grazed, especially by uncontrolled grazing. These findings and others from this investigation have important implications for the management of restored areas.

First, our results suggest that where the objective of vegetation restoration is to enhance biodiversity conservation, it may be appropriate to limit the amount of grazing within established plantings. This recommendation has, in turn, important ramifications for the maintenance of key infrastructure such as fencing as this is currently the primary method to control the intensity, frequency, and periodicity of livestock grazing on farms (Spooner & Briggs 2008). Indeed, our work showing the negative effects of grazing on bird and reptile species richness is timely given that 20 or more years after many plantings were established within (but also beyond) our study, fences are deteriorating as a result of natural attrition and need to be replaced or subject to substantial maintenance.

A second important implication from our study concerns the width of plantings. We suggest that where possible, wide plantings should be established given that such areas support higher levels of bird species richness (see also Kinross 2004; Munro et al. 2007). Many past restoration programs in our study region have resulted in the creation of narrow strips of planted woodland. These areas are not without value, but we suggest that there can be greater biodiversity gains if plantings are widened when fences need to be replaced.

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Supporting Information

The following information may be found in the online version of this article:

- Figure S1.** Directed acyclic graph depicting which planting attributes, grazing, and vegetation variables are important in the path analysis for the occurrence of Rufous Songlark.
- Figure S2.** Directed acyclic graph depicting which planting attributes, grazing, and vegetation variables are important in the path analysis for the occurrence of White-plumed Honeyeater.
- Figure S3.** Directed acyclic graph depicting which planting attributes, grazing, and vegetation variables are important in the path analysis for the occurrence of Superb Fairy-wren.

Figure S4. Directed acyclic graph depicting which planting attributes, grazing, and vegetation variables are important in the path analysis for the occurrence of Boulenger's Skink.

- Table S1.** Occurrence of individual bird species in grazed and ungrazed restoration plantings.
- Table S2.** Occurrence of individual reptile species in grazed and ungrazed restoration plantings.
- Table S3.** Descriptive information by type of grazing for the vegetation variables and site planting characteristics.
- Table S4.** Delta LOOIC values for each of the 16 models fit to estimate path coefficients for the vegetation component of the path analysis.
- Table S5.** Listing of the 42 vegetation models.
- Table S6.** Model coefficients for midstory, native tussock, and leaf litter, which were modeled with a beta and zero-inflated beta distribution with a random effect for farm, except for midstory, which was modeled as a beta distribution.
- Table S7.** Pearson correlation coefficients between vegetation variables and site planting characteristics.
- Table S8.** List of the models within two LOOIC units of the best fitting model for the following response variables: bird species richness, reptile species richness, Australian Magpie, Rufous Songlark, Willie Wagtail, White-plumed Honeyeater, Superb Fairy-wren, and Boulenger's Skink.
- Table S9.** Model coefficients of the most parsimonious model from Table S6 for each of the response variables.
- Table S10.** Tests of conditional independence claims in the basis sets implied by the path models for the various response variables.

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