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Title: Biodiversity offsetting in dynamic landscapes: influence of regulatory context and counterfactual assumptions on achievement of no net loss

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ABSTRACT

Biodiversity offsets are used to mitigate the residual impacts of development on biodiversity. However, their ability to achieve no net loss is rarely evaluated, and factors leading to their success are mostly unknown. Here, we modelled the biodiversity outcomes of averted loss offsetting—in terms of vegetation extent and habitat quality—in the endangered brigalow woodlands of central Queensland, Australia. We found that biodiversity outcomes were highly sensitive to the time period used to inform counterfactual scenarios and to large differences in clearing pressures among vegetation types used for offsetting. Our results reveal major challenges for achieving no net loss of biodiversity in dynamic landscapes globally. Offsetting policies must develop plausible counterfactual scenarios—a difficult task in a volatile regulatory context—and allocate offsets according to spatially-explicit counterfactual biodiversity losses and gains. Failing to do so may drastically overestimate the expected outcomes of offsets and thus result in large net biodiversity losses.

Key-words: averted loss; brigalow; biodiversity offsets; mitigation; land clearing; regrowth.

1. INTRODUCTION

Biodiversity offsets aim to achieve no net loss of biodiversity by counterbalancing residual biodiversity loss from development with equivalent gains at an offset location (ten Kate et al. 2004). While their use is increasing globally (Maron et al. 2016), detailed evaluations of offset policies remain few. Indeed, in most cases, their outcomes will only be evident after several decades (Maron et al. 2012; Gibbons et al. 2015), limiting our ability to assess directly whether no net loss is being achieved. Thus, ex-ante evaluation of alternative offsetting approaches is crucial for pinpointing how offset scheme design influences biodiversity outcomes and achievement of no net loss (Sonter et al. 2014).

Almost all existing offset policies involve some component of averted loss (Gibbons & Lindenmayer 2007; Maron et al. 2015). This involves generating biodiversity 'gains' by protecting and/or maintaining biodiversity that would otherwise have deteriorated in condition or been lost, for example, due to deforestation or other pressures (that would not themselves trigger offset requirements; (Gibbons & Lindenmayer 2007; Maron et al. 2013)). To determine the biodiversity gains such protection and maintenance generates, the 'with protection' outcome must be compared to a counterfactual scenario—i.e. what would be expected to occur in absence of development and offsetting (Maron et al. 2013; Bull et al. 2014). Such counterfactual scenarios, although never observed directly, strongly influence the biodiversity outcomes from offset exchanges (Maron et al. 2015).

Despite their fundamental importance to achieving no net loss, counterfactual scenarios are often neglected in decision-making and rarely explicitly stated (Maron et al. 2015; Maron et al. 2012).

Nevertheless, all offset decisions imply a counterfactual, the nature of which can be inferred post-hoc. Both implicit and explicitly-stated counterfactuals used to calculate equivalence in offset schemes tend to assume that the ‘background’ rate of biodiversity change – that is, without the impacts and offsets – is one of biodiversity decline. This assumption may often be invalid, meaning that offsets do not avert enough loss, and thus enable ongoing biodiversity decline (Gordon et al. 2015; Maron et al. 2015).

Often, the assumed counterfactual trajectory of biodiversity loss is implausibly steep, meaning that the expected biodiversity gains from offsetting are unrealistically large (Maron et al. 2015). In some cases, trajectories of net biodiversity gain may be more realistic. For example, landscapes with regrowing native vegetation (sensu Guariguata & Ostertag 2001) may gain biodiversity, both in terms of vegetation extent and habitat quality (Bowen et al. 2007). Nevertheless, even in such naturally recovering ecosystems, biodiversity loss tends to occur in some places, so opportunities to avert loss probably still exist. In these cases, spatially-explicit counterfactual scenarios that account for heterogeneous biodiversity losses and gains are required, if averted loss offsetting is to be possible at all.

Because counterfactual scenarios are best-guess descriptions of future biodiversity trends, plausible counterfactuals must also account for their surrounding regulatory context—including both biodiversity management policies and offsetting requirements (Githiru et al. 2015; Maron et al. 2016). For example, different ecosystems may be legally protected to various degrees, which in turn affects biodiversity gains achieved through conserving a site as an offset. As such, a one-hectare offset can yield widely different biodiversity gains depending on where it is, what ecosystem it contains, and the set of regulations that apply to it. For example, in Brazil’s

Quadrilátero Ferrífero mining region, allocating offsets to highly threatened ecosystems would likely avert nine times more biodiversity loss than allocating the same area of offsets to ecosystems deemed biologically equivalent to those damaged by development (Sonter et al. 2014).

Such regulatory context is also often dynamic over time. For example, in Queensland, Australia, changes in land clearing regulations over the past decade and a half have altered the degree to which remnant vegetation and certain types of regrowth are protected from being cleared. As a consequence, land clearing declined dramatically from 2003 to historically low levels in 2009, followed by resurgence during 2012–2014 (DSITI 2015). In such a volatile regulatory environment, selecting appropriate counterfactuals is likely to be fraught. Understanding the sensitivity of offset outcomes to the regulatory context and accompanying policy settings is important for developing robust offset approaches that effectively achieve desired outcomes (Gordon et al. 2015).

In this study, we modelled expected biodiversity outcomes of averted loss offsetting in a dynamic ecosystem—the endangered brigalow (*Acacia harpophylla*) woodlands of central Queensland, Australia. This ecosystem underwent huge regulatory change over the past two decades, affecting vegetation clearing rates. It also has the capacity to recover following disturbance, resulting in natural biodiversity gains. Therefore, we used data on clearing rates to simulate offsets and their biodiversity gains—in terms of vegetation extent and habitat quality—under different counterfactual and offsetting assumptions. Our results reveal major implications for achieving no net loss of biodiversity in dynamic landscapes.

2. MATERIAL AND METHODS

2.1. Study region

Our study region is defined by the northern extent of pre-clearing brigalow woodlands (Fig. 1; SI Table 1). This ecosystem has been extensively cleared over the past century (Seabrook et al. 2006) and continues to face pressures from multiple competing land uses. They also are characterised by a capacity to regrow following disturbance (Butler 2007), where habitat structural complexity and species richness of birds improve with regrowth age (Scanlan 1991; Johnson 1997; Bowen et al. 2009), until 30 years post-disturbance when the richness and structure of regrowth resembles those of remnant woodland. Remnant brigalow is currently protected under state and federal legislation (Queensland Government 1999; DSEWPC 2008); however, clearing for extractive projects is still permitted. Recently-approved projects in our study region fall within the Abbot Point and Galilee Basin State Development Areas (DDIP 2014) (Fig. 1). These projects will require some form of offsetting under state and federal policies (Commonwealth of Australia 2012; Queensland Government 2014) and thus these areas were used as our case study development.

2.2. Modelling counterfactual scenarios

We developed a spatially-explicit land cover change model to simulate future vegetation change, using the modelling platform Dinamica EGO (Soares-Filho et al. 2013). Model calibration required information on historic vegetation change and explanatory landscape attributes.

We mapped land cover (remnant vegetation, regrowth, cleared land) in years 2006, 2009, 2011 at 100 m resolution. Remnant vegetation was identified from Regional Ecosystem databases

(Queensland Herbarium 2015). Regrowth was distinguished from cleared land using annually derived foliage projective cover (FPC) (DSITI 2015) and a FPC threshold of 12% (Lucas et al. 2006). Land cover maps were overlaid to quantify vegetation change (Table 1) during two time periods (2006–2009, 2009–2011). We used annual regrowth clearing maps (DSITI 2015) to correct areas we incorrectly detected to transition from regrowth to cleared land. Resultant clearing rates were similar to those reported by government agencies (DSITI 2015).

The Weights of Evidence method (Bonham-Carter 1994) was used to establish conditional probabilities of future vegetation change, based on the spatial distribution of 2006–2009 vegetation change and explanatory landscape attributes. Landscape attributes included elevation, soil type, protected areas, distance to roads, distance to watercourses, and distance to existing land cover categories (SI Table 2). To validate the model, we simulated annual vegetation change from 2009 to 2011 and compared simulated with observed vegetation change, using the reciprocal comparison metric (Soares-Filho et al. 2013). Accuracy was 30% at 10 ha resolution (SI Fig. 1).

The model was used to simulate future counterfactual vegetation change between years 2011 and 2040. Annual vegetation clearing rates were set to those observed between 2006 and 2011 (Table 1). We used this time period to avoid influence of different regulatory settings prior to 2006, when broad-scale vegetation clearing was not prohibited (Queensland Government 1999). However, transition rates also differed between 2006–2009 and 2009–2011, so we simulated and compared counterfactual scenarios for each time period. Since FPC is sensitive to seasonal and inter-annual factors, we fixed annual regrowth rates at regrowth clearing rates (Table 1). This did not influence our results, as our primary question related to averted loss of existing vegetation (remnant and regrowth), not locations in which regrowth appeared through time.

2.3. Simulating offsets and quantifying biodiversity outcomes

We quantified vegetation clearing by development by overlaying land cover maps (Fig. 1; DDIP 2014). We assumed that, in accordance with the Queensland government’s offsets policy, four hectares were protected for each hectare cleared (Queensland Government 2014), and we spatially allocated these offsets (using a second model developed in Dinamica EGO; Sonter et al. 2014) to reflect two scenarios: (1) offsets protect remnant vegetation (“remnant offsets”), and (2) offsets protect regrowth (“regrowth offsets”). To mimic likely decisions about offset location and size, we allocated half the offsets adjacent to existing protected areas at a minimum size of 25 ha. The remainder were allocated elsewhere as new patches, of greater than 50 ha.

We quantified and compared biodiversity outcomes—in terms of vegetation extent and habitat quality—for the four combinations of counterfactual (2006–2009 vs. 2009–2011 clearing rates) and offsetting (regrowth vs. remnant offsets) scenarios. For vegetation extent, we quantified averted loss as the area of counterfactual vegetation lost (ha) that occurred within the boundary of offset areas. We also quantified the proportion of this averted loss that, under the counterfactual scenario, naturally regrew, and the proportion of this that was re-cleared. To explore the gains achieved by averted loss offsets in terms of habitat quality, we used existing data for one taxon of conservation importance in the region: woodland-dependent birds. We multiplied vegetation extent values by mean woodland-dependent bird species richness for each of three, 15-year regrowth age categories, based on research in a nearby region in the same

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habitat type (ha x richness; Table 1; Bowen et al. 2009). We assumed regrowth offsets would reflect a similar proportion of each of the regrowth age classes as recorded by Bowen et al. (2009), and that regrowth offsets would continue to mature following protection.

Biodiversity gains of offsets accrue gradually over time, whereas the losses due to development were assumed to occur in 2011. To account for these time-lags, we adjusted all reported biodiversity outcomes using the standard time discounting approach of the Australian EPBC Act for Endangered ecological communities (discount rate of 1.2% p.a.; Miller et al. 2015). Non-discounted biodiversity outcomes are shown in SI Fig. 2.

3. RESULTS

Vegetation clearing rates more than doubled between 2006–2009 and 2009–2011 (Table 2). Remnant clearing increased from 356 to 3076 ha yr^{-1} and regrowth clearing increased from 1297 to 3055 ha yr^{-1}. Clearing rates also differed between vegetation types (Table 2). Regrowth clearing was nine times greater than remnant clearing during 2006–2009; while remnant clearing was greater than regrowth clearing during 2009–2011. Projecting counterfactual vegetation change to 2040 caused a decline in remnant vegetation by 9,850 ha under 2006–2009 clearing rates, and by 76,930 ha under 2009–2011 rates.

Proposed development was estimated to clear 1,480 ha of remnant vegetation and 1,460 ha of regrowth, requiring 11,760 ha of offsets under current policy. No net loss of biodiversity was not achieved under any combination of counterfactual or offsetting scenario, but the level of averted loss differed markedly among scenarios (Fig. 2). Using 2009–2011 clearing rates to inform the counterfactual scenario and allocating offsets to remnant vegetation averted 997 ha of clearing by 2025 and 2,098 ha by 2040 (representing 71% of that required to achieve no net loss). Using equivalent clearing rates, but allocating offsets to regrowth, reduced averted loss to 863 ha by 2025 and 1,567 ha by 2040. Using 2006–2009 clearing rates further decreased averted loss by remnant offsets to 198 ha and by regrowth offsets to 898 ha by 2040.

Compared to vegetation extent, biodiversity outcomes in terms of habitat quality for woodland birds increased averted loss across all scenarios by 2040 (Fig. 2); however, accounting for these additional biodiversity gains did not result in any scenario achieving no net loss of biodiversity.

Accounting for counterfactual regrowth greatly reduced biodiversity gains across all scenarios (Fig. 2). Most notably, averted loss by remnant offsets decreased from 2,098 ha to 558 ha (from 71% to 19% of that required to achieve no net loss) by 2040, once the potential for regrowth to occur following counterfactual clearing was factored in. Accounting for this counterfactual regrowth also altered relative differences in biodiversity gain among scenarios (Fig. 2). For example, averted loss by regrowth offsets became greater when using 2006–2009 transition rates (806 ha by 2040) than 2009–2011 transition rates (367 ha by 2040).

4. DISCUSSION

No-net-loss of biodiversity was not achieved under any combination of counterfactual and offsetting scenarios that we considered. However, biodiversity outcomes were highly sensitive to the time period used to inform counterfactual scenarios and to differences in clearing pressures among vegetation types used for offsetting. Our results illustrate major challenges for developing plausible counterfactual scenarios and quantifying averted loss potential in dynamic landscapes.

4.1. Sensitivity to counterfactual vegetation clearing

We used data on vegetation clearing rates from two recent time periods to inform counterfactual scenarios, and found biodiversity outcomes differed under each. Clearing rates were higher during 2009–2011 than 2006–2009 (Table 2) and thus averted loss by offsets was greater when using 2009–2011 counterfactual clearing rates (Fig. 2). Specifically, averted loss by remnant offsets was 10.6 times greater, and that by regrowth offsets was 1.7 times greater. Designing plausible counterfactual scenarios is essential to reasonably predict averted loss—using unreasonably high clearing rates may drastically overestimate outcomes—however, this task is difficult and fraught with uncertainty.

Regulatory volatility is a key driver of fluctuations in vegetation clearing rates. Queensland has seen several changes in government over the past six years, which has led to substantial swings in vegetation regulation (Evans 2016). This creates enormous uncertainty regarding the future of vegetation in the state, and renders any counterfactual scenario for offsetting almost meaningless. The use of longer-term historical data is similarly fraught, as prior to 2006, Queensland experienced some of the highest land clearing rates in the world; a return to such extreme loss seems implausible. Such uncertainty in counterfactual scenarios plagues most offset decisions, whether explicitly recognised (e.g. Sonter et al. 2014; Virah-Sawmy et al. 2014) or not.

We found biodiversity outcomes were also influenced by differences in clearing pressures among vegetation types used for offsetting. During 2006–2009, regrowth clearing was 3.6 times greater than remnant clearing (Table 1), thus regrowth offsets averted 4.5 times more loss than remnant offsets (Fig. 2). However, using 2009–2011 clearing rates, this finding reversed. Remnant clearing was greater than regrowth clearing, and thus remnant offsets averted 1.3 times more loss than regrowth offsets. Historically, regrowth clearing has surpassed remnant clearing because young regrowth had limited legal protection (Neldner 2006); however, high-value regrowth was protected between 2008 and 2013, causing a relative shift in clearing pressures. That protection was removed in 2013, but another change of government has led to proposals to reinstate it. Such changes in clearing pressures among vegetation types can drastically shift offsetting priorities.

Such temporal changes in vegetation clearing had considerable influence on biodiversity outcomes. This was most pronounced for remnant offsets, as illustrated by their averted loss being 2.4 times greater during the second 15 years of simulation (2026–2040; 129 ha) than the first (2011–2025; 69 ha), using 2006–2009 clearing rates (Fig. 2). We found that remnant vegetation protected as offsets became increasingly threatened in the counterfactual scenario, due to three interrelated factors: we allocated 50% of offsets adjacent to protected areas, remnant clearing occurred preferentially near regrowth, and regrowth increased within protected areas (SI Table 2). As a result, averted loss by remnant offsets increased over time. While difficult to predict, such changes in spatially-explicit clearing pressures affect the rate of biodiversity gains.

4.2. Considering counterfactual habitat quality improvements

In comparison to vegetation extent, the biodiversity gains from offsets were improved when considering habitat quality for woodland birds, with mean species richness as a proxy (Fig. 2). For example, averted loss by regrowth offsets increased from 53% to 63%, using 2009–2011 clearing rates. Additional biodiversity gains achieved via habitat improvements could be further increased by prioritising offsets to younger regrowth, since it is not protected under legislation and have greater potential for biodiversity gains as it ages. However, biodiversity outcomes of such prioritisation are also riskier, considering recovery uncertainties associated with young regrowth (Maron et al. 2012) and the likely divergent responses of other taxa to regrowth age. In addition, while Brigalow regrowth takes 30 years to return to remnant habitat structure and bird species richness, other ecosystems may take longer and many may never naturally return to their pre-clearing biodiversity levels. In these cases, averted loss offsetting will be much more limited in its ability to achieve biodiversity gains via habitat quality improvements.

4.3. Accounting for counterfactual regrowth and re-clearing

Our results revealed two additional challenges for quantifying biodiversity outcomes in dynamic landscapes that experience both biodiversity losses and gains. First, we found that accounting for counterfactual regrowth greatly influenced biodiversity outcomes. This effect was most notable for remnant offsets, where averted loss was reduced from 71% to 19% of that required to achieve no net loss by 2040 (Fig. 2). Regrowth is rarely considered in counterfactual scenarios. However, averted loss must be additional, and so if cleared land regrows, averted loss calculations must be adjusted accordingly.

Second, some counterfactual regrowth was re-cleared by 2040. For example, 25% of the loss averted by regrowth offsets (after adjusting for regrowth) transitioned from cleared land, to regrowth, to cleared at least once, using 2009–2011 clearing rates. This dynamic explains why regrowth offsets averted more loss during the first 15 years of simulation (2011–2025) than the second (2025–2040) (Fig. 2) and illustrates potential for double counting when quantifying averted loss. Our method assessed vegetation clearing iteratively (on an annual basis), and this only counted averted loss at the first time it occurred. However, quantifying all averted loss through time, regardless of previous clearing, would have incorrectly overestimated biodiversity outcomes.

4.4. Implications for offset policies

Biodiversity offset policies must explicitly define plausible counterfactual scenarios, rather than use arbitrary mitigation ratios, if they are to genuinely achieve their no net loss objectives. Such counterfactuals should account for spatially-explicit biodiversity losses and gains (e.g. vegetation clearing and regrowth), and capture differences among vegetation types. Although a difficult and uncertain task in dynamic landscapes governed by volatile clearing policies, our results show that assuming unrealistically high clearing rates and ignoring counterfactual regrowth drastically overestimates expected biodiversity gains from averted loss offsets, and results in large net biodiversity losses.

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FIGURES

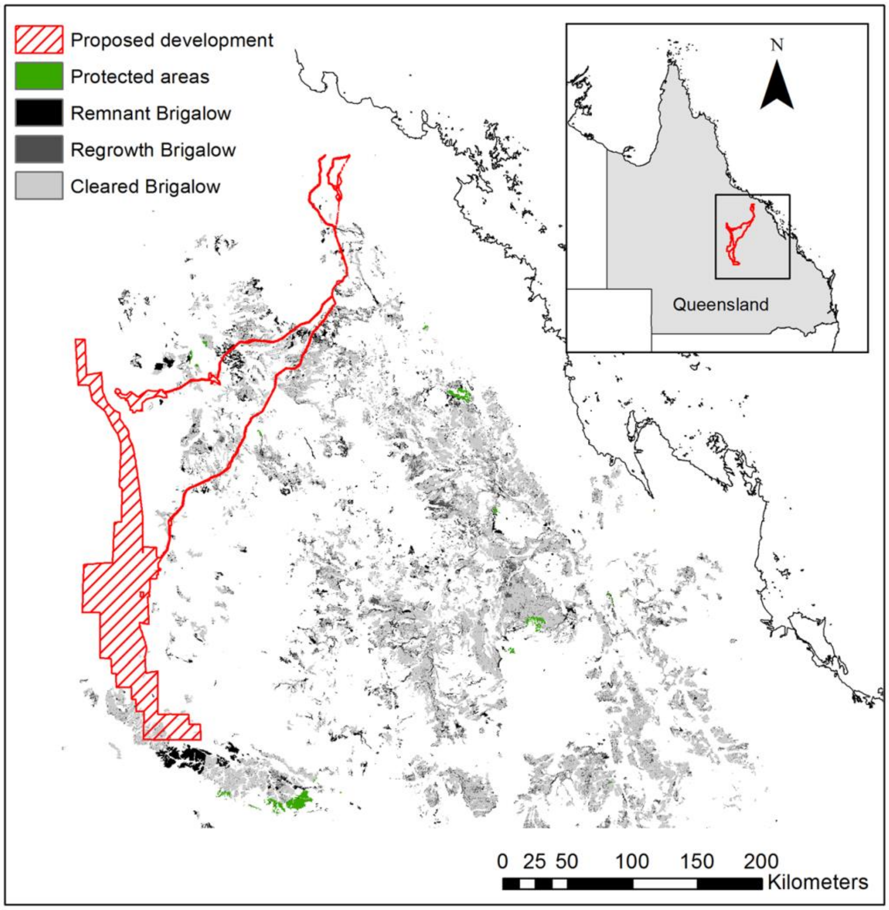

Figure 1: Study region (grey shading), showing location of protected areas, Abbot Point and Galilee Basin State Development Areas (DDIP 2014), and mapped remnant, regrowth and cleared brigalow woodland in 2011. Inset shows study region within Queensland, Australia.

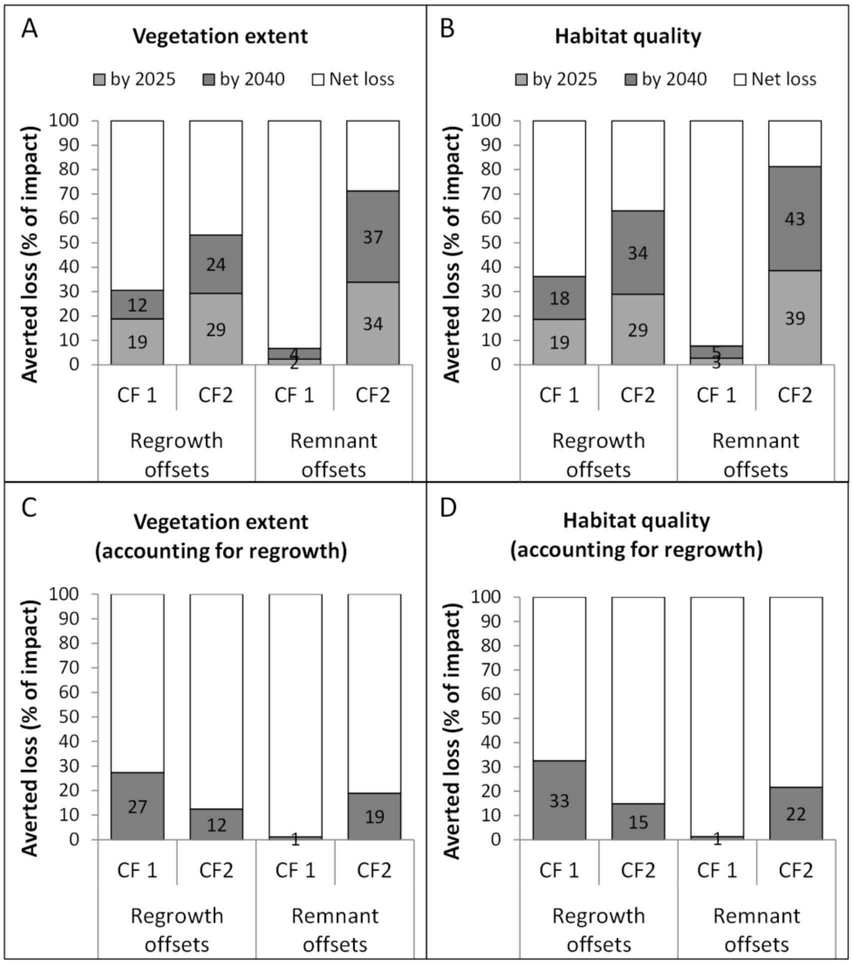

Figure 2: Biodiversity outcomes of averted loss offsets. Figure shows the percent of biodiversity that was lost to development that was averted by offsetting, considering vegetation extent (panels A and C) and quality (panels B and D). Rates of vegetation change were set to two time periods (CF1: 2006–2009, CF2: 2009–2011; CF = “counterfactual”) and offsets were allocated to regrowth vegetation (regrowth offsets) or remnant vegetation (remnant offsets). Stacked bars show the level of averted loss achieved after 15 years (by 2025) and after 30 years (by 2040). Panels A and B show biodiversity outcomes without accounting for counterfactual regrowth, panels C and D show outcomes when accounting for counterfactual regrowth. All results are time discounted—see SI Fig. 2 for non-discounted outcomes.

TABLES

Table 1: Age class classification and habitat quality traits for brigalow woodlands. Adapted from Bowen et al. (2009).

Classification	**Vegetation age (years)**	**Percentage of regrowth**	**Woodland bird species richness (bird/ha ± SD)**
Regrowth			
Young	0-15	30.5	3.0 ± 2.4
Intermediate	15-30	18.3	4.6 ± 2.6
Old	30-100	51.2	10.3 ± 4.0
Remnant	100+	n/a	9.9 ± 4.2

Table 2: Observed annual land cover transition rates. Table shows transition rates as absolute areas (ha) and percent of initial land use that transitioned during the time period.

Transitions	**2006–2009**		**2009–2011**	
	ha	**%**	**ha**	**%**
Remnant to Regrowth	210	0.07	1796	0.58
Remnant to Cleared	146	0.05	1280	0.42
Regrowth to Cleared	1297	0.41	3055	0.73
Cleared to Regrowth*	1297	0.06	3055	0.16

*Shows corrected cleared to regrowth rates when assuming the absolute area of cleared to regrowth equals that of regrowth to cleared.