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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.

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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., 2016a, b), 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 and 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 and 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 and Ostertag, 2001) may gain biodiversity, both in terms of vegetation

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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., 2016a, b). For example, different ecosystems may be legally protected to various degrees, which in turn affect 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 was 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 recleared. 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

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