

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

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13 **ABSTRACT**

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

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

27

28 **1. INTRODUCTION**

29 Biodiversity offsets aim to achieve no net loss of biodiversity by counterbalancing residual
30 biodiversity loss from development with equivalent gains at an offset location (ten Kate et al.
31 2004). While their use is increasing globally (Maron et al. 2016), detailed evaluations of offset
32 policies remain few. Indeed, in most cases, their outcomes will only be evident after several
33 decades (Maron et al. 2012; Gibbons et al. 2015), limiting our ability to assess directly whether
34 no net loss is being achieved. Thus, ex-ante evaluation of alternative offsetting approaches is
35 crucial for pinpointing how offset scheme design influences biodiversity outcomes and
36 achievement of no net loss (Sonter et al. 2014).

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

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

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

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

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

71 *Quadrilátero Ferrífero* mining region, allocating offsets to highly threatened ecosystems would
72 likely avert nine times more biodiversity loss than allocating the same area of offsets to
73 ecosystems deemed biologically equivalent to those damaged by development (Sonter et al.
74 2014).

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

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

92 **2. MATERIAL AND METHODS**

93 **2.1. Study region**

94 Our study region is defined by the northern extent of pre-clearing brigalow woodlands (Fig. 1; SI
95 Table 1). This ecosystem has been extensively cleared over the past century (Seabrook et al.
96 2006) and continues to face pressures from multiple competing land uses. They also are
97 characterised by a capacity to regrow following disturbance (Butler 2007), where habitat
98 structural complexity and species richness of birds improve with regrowth age (Scanlan 1991;
99 Johnson 1997; Bowen et al. 2009), until 30 years post-disturbance when the richness and
100 structure of regrowth resembles those of remnant woodland. Remnant brigalow is currently
101 protected under state and federal legislation (Queensland Government 1999; DSEWPC 2008);
102 however, clearing for extractive projects is still permitted. Recently-approved projects in our
103 study region fall within the Abbot Point and Galilee Basin State Development Areas (DDIP
104 2014) (Fig. 1). These projects will require some form of offsetting under state and federal
105 policies (Commonwealth of Australia 2012; Queensland Government 2014) and thus these areas
106 were used as our case study development.

107 **2.2. Modelling counterfactual scenarios**

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

111 We mapped land cover (remnant vegetation, regrowth, cleared land) in years 2006, 2009, 2011 at
112 100 m resolution. Remnant vegetation was identified from Regional Ecosystem databases

113 (Queensland Herbarium 2015). Regrowth was distinguished from cleared land using annually
114 derived foliage projective cover (FPC) (DSITI 2015) and a FPC threshold of 12% (Lucas et al.
115 2006). Land cover maps were overlaid to quantify vegetation change (Table 1) during two time
116 periods (2006–2009, 2009–2011). We used annual regrowth clearing maps (DSITI 2015) to
117 correct areas we incorrectly detected to transition from regrowth to cleared land. Resultant
118 clearing rates were similar to those reported by government agencies (DSITI 2015).

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

127 The model was used to simulate future counterfactual vegetation change between years 2011 and
128 2040. Annual vegetation clearing rates were set to those observed between 2006 and 2011 (Table
129 1). We used this time period to avoid influence of different regulatory settings prior to 2006,
130 when broad-scale vegetation clearing was not prohibited (Queensland Government 1999).
131 However, transition rates also differed between 2006–2009 and 2009–2011, so we simulated and
132 compared counterfactual scenarios for each time period. Since FPC is sensitive to seasonal and
133 inter-annual factors, we fixed annual regrowth rates at regrowth clearing rates (Table 1). This did

134 not influence our results, as our primary question related to averted loss of existing vegetation
135 (remnant and regrowth), not locations in which regrowth appeared through time.

136 **2.3. Simulating offsets and quantifying biodiversity outcomes**

137 We quantified vegetation clearing by development by overlaying land cover maps (Fig. 1; DDIP
138 2014). We assumed that, in accordance with the Queensland government's offsets policy, four
139 hectares were protected for each hectare cleared (Queensland Government 2014), and we
140 spatially allocated these offsets (using a second model developed in Dinamica EGO; Sonter et al.
141 2014) to reflect two scenarios: (1) offsets protect remnant vegetation ("remnant offsets"), and (2)
142 offsets protect regrowth ("regrowth offsets"). To mimic likely decisions about offset location and
143 size, we allocated half the offsets adjacent to existing protected areas at a minimum size of 25 ha.
144 The remainder were allocated elsewhere as new patches, of greater than 50 ha.

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

155 habitat type (ha x richness; Table 1; Bowen et al. 2009). We assumed regrowth offsets would
156 reflect a similar proportion of each of the regrowth age classes as recorded by Bowen et al.
157 (2009), and that regrowth offsets would continue to mature following protection.

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

163 **3. RESULTS**

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

171 Proposed development was estimated to clear 1,480 ha of remnant vegetation and 1,460 ha of
172 regrowth, requiring 11,760 ha of offsets under current policy. No net loss of biodiversity was not
173 achieved under any combination of counterfactual or offsetting scenario, but the level of averted
174 loss differed markedly among scenarios (Fig. 2). Using 2009–2011 clearing rates to inform the
175 counterfactual scenario and allocating offsets to remnant vegetation averted 997 ha of clearing

176 by 2025 and 2,098 ha by 2040 (representing 71% of that required to achieve no net loss). Using
177 equivalent clearing rates, but allocating offsets to regrowth, reduced averted loss to 863 ha by
178 2025 and 1,567 ha by 2040. Using 2006–2009 clearing rates further decreased averted loss by
179 remnant offsets to 198 ha and by regrowth offsets to 898 ha by 2040.

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

183 Accounting for counterfactual regrowth greatly reduced biodiversity gains across all scenarios
184 (Fig. 2). Most notably, averted loss by remnant offsets decreased from 2,098 ha to 558 ha (from
185 71% to 19% of that required to achieve no net loss) by 2040, once the potential for regrowth to
186 occur following counterfactual clearing was factored in. Accounting for this counterfactual
187 regrowth also altered relative differences in biodiversity gain among scenarios (Fig. 2). For
188 example, averted loss by regrowth offsets became greater when using 2006–2009 transition rates
189 (806 ha by 2040) than 2009–2011 transition rates (367 ha by 2040).

190 **4. DISCUSSION**

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

196 **4.1. Sensitivity to counterfactual vegetation clearing**

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

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

213 We found biodiversity outcomes were also influenced by differences in clearing pressures among
214 vegetation types used for offsetting. During 2006–2009, regrowth clearing was 3.6 times greater
215 than remnant clearing (Table 1), thus regrowth offsets averted 4.5 times more loss than remnant
216 offsets (Fig. 2). However, using 2009–2011 clearing rates, this finding reversed. Remnant

217 clearing was greater than regrowth clearing, and thus remnant offsets averted 1.3 times more loss
218 than regrowth offsets. Historically, regrowth clearing has surpassed remnant clearing because
219 young regrowth had limited legal protection (Neldner 2006); however, high-value regrowth was
220 protected between 2008 and 2013, causing a relative shift in clearing pressures. That protection
221 was removed in 2013, but another change of government has led to proposals to reinstate it. Such
222 changes in clearing pressures among vegetation types can drastically shift offsetting priorities.

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

232 **4.2. Considering counterfactual habitat quality improvements**

233 In comparison to vegetation extent, the biodiversity gains from offsets were improved when
234 considering habitat quality for woodland birds, with mean species richness as a proxy (Fig. 2).
235 For example, averted loss by regrowth offsets increased from 53% to 63%, using 2009–2011
236 clearing rates. Additional biodiversity gains achieved via habitat improvements could be further
237 increased by prioritising offsets to younger regrowth, since it is not protected under legislation

238 and have greater potential for biodiversity gains as it ages. However, biodiversity outcomes of
239 such prioritisation are also riskier, considering recovery uncertainties associated with young
240 regrowth (Maron et al. 2012) and the likely divergent responses of other taxa to regrowth age. In
241 addition, while Brigalow regrowth takes 30 years to return to remnant habitat structure and bird
242 species richness, other ecosystems may take longer and many may never naturally return to their
243 pre-clearing biodiversity levels. In these cases, averted loss offsetting will be much more limited
244 in its ability to achieve biodiversity gains via habitat quality improvements.

245 **4.3. Accounting for counterfactual regrowth and re-clearing**

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

253 Second, some counterfactual regrowth was re-cleared by 2040. For example, 25% of the loss
254 averted by regrowth offsets (after adjusting for regrowth) transitioned from cleared land, to
255 regrowth, to cleared at least once, using 2009–2011 clearing rates. This dynamic explains why
256 regrowth offsets averted more loss during the first 15 years of simulation (2011–2025) than the
257 second (2025–2040) (Fig. 2) and illustrates potential for double counting when quantifying
258 averted loss. Our method assessed vegetation clearing iteratively (on an annual basis), and this

259 only counted averted loss at the first time it occurred. However, quantifying all averted loss
260 through time, regardless of previous clearing, would have incorrectly overestimated biodiversity
261 outcomes.

262 **4.4. Implications for offset policies**

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

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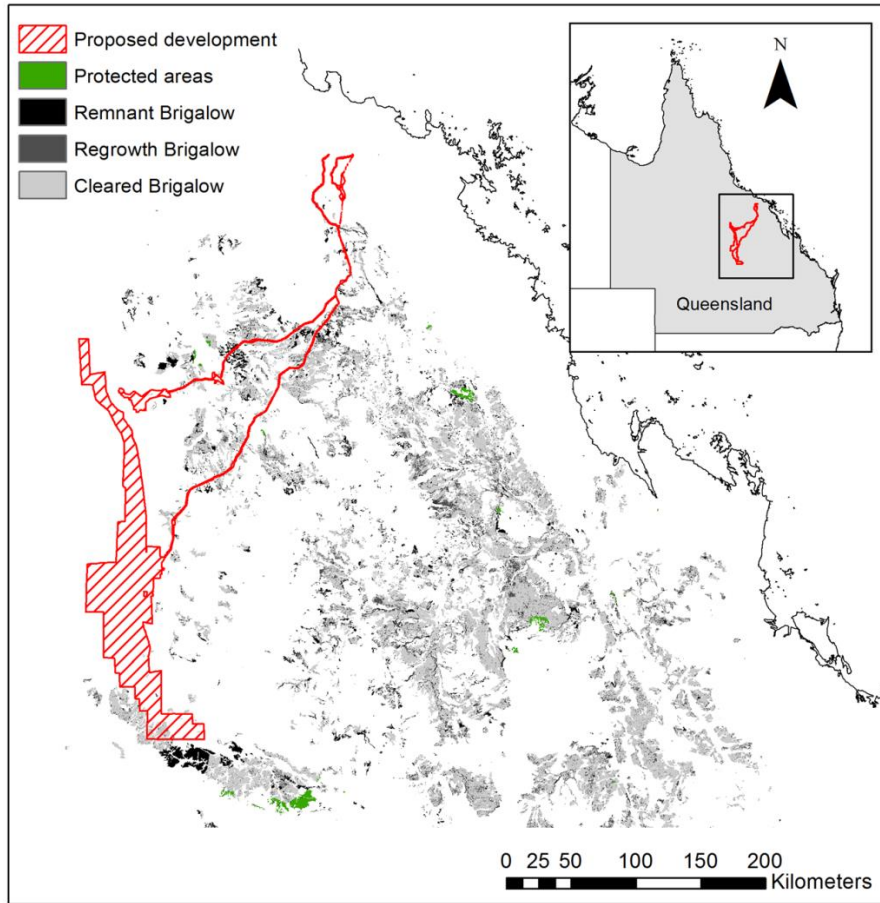
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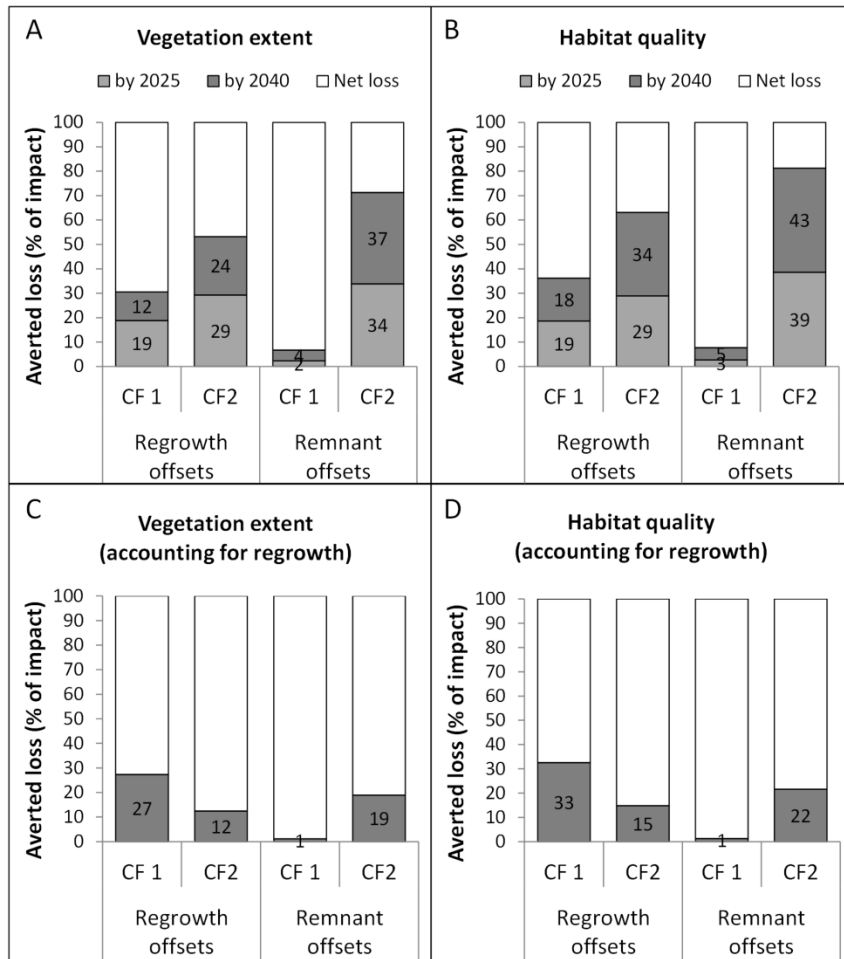
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360 **FIGURES**



361

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



365

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

375 **TABLES**

376 **Table 1:** Age class classification and habitat quality traits for brigalow woodlands. Adapted from
377 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

378

379 **Table 2:** Observed annual land cover transition rates. Table shows transition rates as absolute
 380 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

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