Categories of flexibility in biodiversity offsetting, and the implications of out-of-kind ecological compensation

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Abstract

Biodiversity offsets ('offsets') are an increasingly widespread conservation tool. Often, offset policies have a like-for-like requirement, whereby permitted biodiversity losses must be offset by gains in similar ecosystem components. Some have suggested that flexibility might be desirable (e.g. out-of-kind offsets, that channel compensation towards priority species, potentially using conservation budgets more efficiently). But there has been little formal exploration of different types of flexibility, and the possible ecological consequences.

Building upon an existing framework for analysing conservation interventions, we first categorise types of flexibility relevant to offsetting. We then explore flexibility using an offset simulation model. This non-spatial model tracks biodiversity value (*'habitat condition' x area*) over time, for multiple vegetation communities. We simulate offset policies that are flexible in time (i.e. offsets implemented before or after development) and flexible in type (i.e. losses in one habitat compensated for by gains in another).

Our categorisation of flexibility in offsetting identifies categories previously not explicitly considered during policy development. We demonstrate, using model outputs, that flexibility can have material ecological consequences. Simulated offsets that were flexible in time resulted in biodiversity declines happening sooner or later than they would otherwise – important, as conservation priorities change with time. Flexibility in type resulted in the relative threat status of different habitat types changing.

We emphasize the importance of considering the full spectrum of flexibility in biodiversity offsets during policy development. As offset policies become increasingly prevalent, insufficient consideration of the consequences of flexibility could lead to undesirable biodiversity outcomes.

1. Introduction

1.1 *Biodiversity offsetting*

Biodiversity offsets (henceforth 'offsets') have emerged as an important tool in conservation practice worldwide (Madsen et al., 2011), and continue to form part of policy development in an increasing number of geographical regions (e.g. Tucker et al., 2013; Saenz et al., 2013). Offset policies fundamentally involve exchanging biodiversity losses for equivalent gains, with the objective that 'no net loss' of biodiversity is achieved overall alongside development. Whilst this premise might seem simple, it gives rise to a range of complications (Bull et al., 2013a). Not least of these is that 'biodiversity' is itself a vague concept, and any measure of biodiversity as a whole (which can be defined as the "sum total of all biotic variation from the level of genes to ecosystems") cannot be based upon a single number or metric (Purvis & Hector, 2000). Indeed, the concept of complementarity (Kukkala and Moilanen 2013), central to systematic conservation planning, implies that all different components of biodiversity should be catered for individually. Thus, in creating policies that aim for no measurable net loss of biodiversity, and consequently developing metrics to evaluate success, we must accept that these metrics will not capture every element of biodiversity at a site and therefore, fundamentally, remain only surrogate measures for biodiversity as a whole.

Current best-practice recommendations for implementing offsets suggest that they should be "in-kind" (BBOP, 2012; IFC, 2012), meaning that the gains from the biodiversity offset are for the same or very similar biodiversity components to those impacted. In practice, no two components of biodiversity (e.g. individuals of a given species, areas of the same habitat type) are ever precisely equivalent and fungible (Salzman & Ruhl, 2000). Thus all offsets are technically "out-of-kind" to some degree. But the simplifying assumption is made that trades that can be shown to be similar enough in terms of either overall biological diversity, or in terms of associated ecosystem functions, can be treated as equivalent (Quétier & Lavorel, 2012).

1.2 *Flexibility in biodiversity offsets*

In some cases, out-of-kind offsets (e.g. those that allow 'flexible' trade in biodiversity components) might be preferable, by allowing offsets to focus upon the priority conservation species within a region in a cost-effective manner (Wilcox & Donlan, 2007; Habib et al., 2013). To elaborate, Habib et al. (2013) found using a Canadian example that non-flexible offset policies required 2 – 17 times more funding to achieve the same conservation objectives as flexible offsets; and Wilcox & Donlan

(2007) found that a flexible offset mechanism was 23 times more effective at achieving the objective of invasive predator removal than other approaches.

It should be noted that what we call flexibility in this context has been called by other names elsewhere. For example, consider the terms ‘strong’ and ‘weak’ sustainability, which have been used in ecological economics and green accounting (Gowdy 2000; Dietz & Neumayer 2007). In biodiversity offsetting, these terms have been used to indicate the degree to which different biodiversity components can be exchanged – e.g. levels of ‘sustainability’ (i.e. flexibility) permitted in the newly developed ‘RobOff’ software range from treating different biodiversity components as completely fungible (i.e. weak sustainability) through to requiring no loss in any one biodiversity component (i.e. strong sustainability) (Pouzols & Moilanen 2013). The terms ‘substitutability’, ‘interchangeability’, ‘replaceability’, and ‘fungibility’ also link to flexibility, and have been used in various contexts (Parris & Kates, 2003; Dietz & Neumayer, 2007).

From a policy perspective, offsets are considered flexible in relation to a number of different policy characteristics. Offsets could involve the trade of one component or type of biodiversity for a different type (i.e. flexibility by type), or, for offset sites that are distant in space from the development for which they provide compensation (i.e. flexibility in space). Implicitly, permitting flexibility in time is also commonly discussed – e.g. by allowing time lags between development impacts and gains from associated offsets – although this is not generally explicitly recognized as a form of flexibility, and is allowed by many policies.

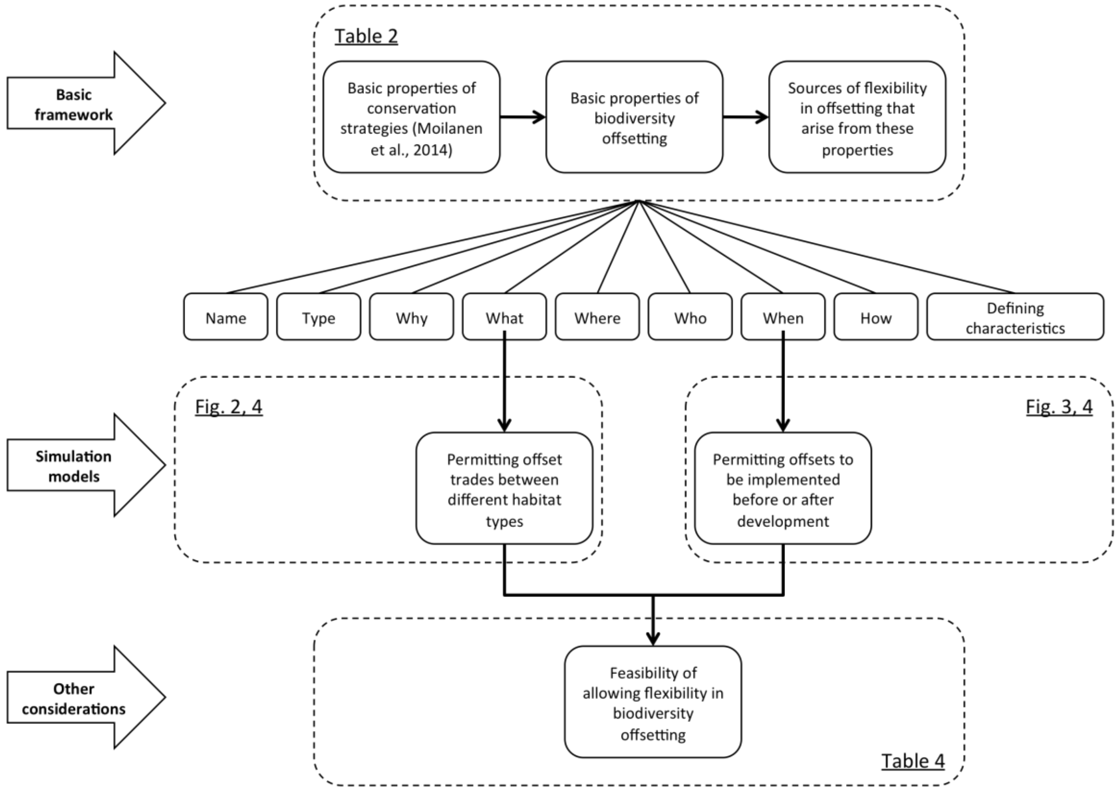
There has been almost no detailed exploration in the literature as to what the implications of flexible offsetting might be from an ecological perspective, i.e. the potential responses of a given ecosystem in absorbing internal exchange between different biodiversity components. Whilst mentioned by Habib et al. (2013), they focus rather on economic efficiency and a static analysis of flexible offsetting – so the ecological outcomes in relation to ecosystem dynamics are not considered. Otherwise, the degree to which existing problems with any biodiversity offset scheme are further complicated by allowing flexibility have yet to be understood (e.g. required longevity in the face of ecosystem change, the existence of ecological thresholds, potential for reversibility, complications around time lags and extinction debt, etc; Bull et al., 2013a). In terms of conservation science and the acceptability of flexible offsets to different stakeholders, such considerations are open to exploration.

A comprehensive categorization of flexibility in offsets would be useful for developing conservation policy, in terms of both identifying and managing the different forms of flexibility that might arise in on-the-ground offsetting applications. We attempt to summarize the various ways in which offsets can be flexible. To date, the only empirical assessments of the ecological implications of a spatially flexible offsetting policy have been at the landscape scale and implemented using the Marxan conservation planning software to prioritize offset locations (Kiesecker et al., 2009; Habib et al., 2013). Here, building upon our categorisation of flexibility in offsets, we consider the ecological implications of a flexible policy through time. To do so, we extend an existing theoretical biodiversity offset model (developed by Bull et al., 2014a), and so explore some of the categories of flexible offsetting identified.

2. Material and methods

In order to explore the application of a flexible offsetting policy, we first classify different types of flexibility that could theoretically arise in offset policies, using a framework based upon a top-down literature synthesis (Moilanen et al., 2014; see below). Then, we explore the consequences of allowing flexibility by adapting the simulation model originally created for evaluation of biodiversity offset projects against different frames of reference (i.e. counterfactuals – the trajectory that an ecosystem would have followed under different management scenarios to the one implemented) (Bull et al., 2014a; Fig. 1).

Fig. 1: Flow diagram illustrating the logic of the methods applied in this paper.



2.1 *Different types of flexibility*

A framework recently developed for the structured analysis of conservation strategies, among other things, specifies questions that can be answered to summarize the properties of such strategies (Moilanen et al., 2014). We utilise this framework to categorise flexibility in offsets. This involved the creation of two tables: the first table concerns nine “basic properties” of offsetting as a strategy (e.g. ‘why’ offsets are used, ‘what’ they involve, etc). We considered the ways in which flexibility could arise in each of these basic categories. The second table draws upon the first and upon simulation model outcomes, relating to a set of topics that capture “fundamental properties” of conservation strategies (e.g. what are their major underlying assumptions, risks, etc). In the discussion, we explore how feasible flexible offsetting is as an approach given these properties.

In order to evaluate how these various properties manifest themselves as forms of flexibility in actual biodiversity offset policies, we draw upon recent assessments in the literature, concerning the global development of biodiversity offset policies.

2.2 *Theoretical biodiversity offset model*

The theoretical offset model (henceforth the ‘model’) is based on a model originally developed to explore issues around evaluation of offset performance (Bull et al., 2014a). Here, we extend this model to consider multiple different biodiversity sub-components that together constitute the total biodiversity in a region, which in turn allows the modelling of flexible offset trades (see Section 2.3). The model is based on analytic equations and is deterministic and non-spatial. It simulates the evolution of the total hypothetical biodiversity value in a region over time, which is broken down into biodiversity impacted by development, biodiversity managed as an offset, and the remaining biodiversity (which is assumed unmanaged). Conceptually, we considered our biodiversity surrogate to be a metric that measures the condition and area of different vegetation communities, as this is a common metric used in biodiversity offset policies (Quétier & Lavorel, 2012). For example in Victoria Australia, the Habitat Hectares metric used to measure *condition x area* of vegetation, where condition is measured relative to a pristine example of that vegetation community (Parkes et al., 2003). As an illustration of the consequences of flexible offsets, we use real data for three different vegetation communities under threat from development around Melbourne, Australia which are labelled as ecological vegetation classes (EVCs): Plains Grassy Woodland, Damp Heathland, and Blackthorn Scrub (Table 1). Biodiversity in each of these three EVCs can have a different trajectory over time depending on its status in the model which can be one of the following: developed (all vegetation removed), offset (vegetation assumed managed) or unmanaged (vegetation potentially available for offsetting or development, but unmanaged and gradually declining in condition).

The base quantity in the model is the total biodiversity value at a time *t*, given by *B(t)*, which is determined by three basic functions: *dev(t)*, the amount of biodiversity lost to development over time; *off(t)*, the gain in biodiversity from offsets over time (in response to development); and *T(t)*, which describes the underlying biodiversity trajectory that occurs when biodiversity is not developed or managed. It is split into three different EVCs as mentioned above, and for each EVC, *B(t)* can be considered analogous to the condition of the vegetation community multiplied by its area (“condition-area”) as measured by the Habitat Hectares metric (Parkes et al., 2003). In the absence of development and offsetting the biodiversity trajectory is given by:

$$B(t) = T(t) \times B_0$$

[Eqtn 1]

where B_0 represent the initial amount of biodiversity and *T(t)* represents the decline trajectory of unmanaged vegetation (further information below).

With both development and offsetting, the biodiversity trajectory can be written as:

$$B(t) = T(t) \times [B_0 - dev(t)] + [p(t) \times off(t)].$$

[Eqtn 2]

Here *dev(t)* represents the area of biodiversity lost to development each year and *off(t)* represents the area protected and managed as offsets each year in response to development. The term *m* is the offset multiplier which determines the size of the offset for each unit of impact. The function *p(t)* specifies how the (protected) biodiversity contained in offset locations changes over time in response to offset actions. For ease of interpretation we assumed that biodiversity managed within the offset remained constant in constant condition (i.e. *p(t)* = 1). Once created, we assumed that offsets are managed indefinitely, and make the simplifying assumption that the ecosystem returns to its pristine condition as soon as the offset are implemented and that they stay in this condition due to effective management irrespective of whatever form *T(t)* takes.

In the absence of any intervention, we assume that biodiversity in the region is characterised by a slow logistic deterioration in condition, which approximately reflects the reality in the Melbourne region (Gordon et al., 2011a). It should be noted that in the null counterfactual scenario – i.e. without development or offsetting – biodiversity will nevertheless decline, and so offsetting aimed at achieving “no net loss” with respect to this counterfactual biodiversity trajectory would need only to achieve this same trajectory (which represents a gain with respect to biodiversity declines and development). Thus, all results will involve some overall loss of biodiversity, however successful the approach to offsetting. The model could also be parameterised such that the unmanaged biodiversity trajectory is flat or even increasing, but as this is not relevant to the Melbourne region, we do not consider this further here (c.f. Bull et al., 2014a). The decline trajectory was modelled as a logistic curve based upon the functional form described in Mace et al. (2008) for population decline:

$$T(t) = 0.5 + \frac{1}{(1 + e^{k_1 \times t})}.$$

[Eqtn 3]

Here the coefficient k_1 determines the shape of the logistic function and positive values determine how quickly the biodiversity component decreases (negative values of k_1 result in improving biodiversity trajectories, but are not considered here). As this model is primarily theoretical and used to illustrate our points about flexibility in offsets, we do not use different relative decline rates for each EVC and set $k_1 = 0.03$ for all results presented below. We do not focus upon degradation rates here, but note that the rate of decline used in designing and evaluating offsets is in practice a key consideration, as discussed in detail elsewhere in this Special Issue (Maron et al., in review).

We assumed development causes linearly increasing biodiversity losses with time, at a constant rate determined by the parameter k_2:

$$dev(t) = k_2 \times t.$$

[Eqtn 4]

Different types of development could be modelled by substituting different functional forms into the above equation. Offsets associated with development were expressed as:

$$off(t) = m \times dev(t) = m \times k_2 \times t.$$

[Eqtn 5]

The factor m in the above equation multiplies the size of offset implemented for a given development, in terms of offset per unit of development. In some policies such a ‘multiplier’ is used to increase the size of the offsets to account for uncertainties (Moilanen et al., 2009). Here, m is set to 2 for all simulations.

2.3 *Extension of the model for flexible offsetting*

General

Again, previously the model focus was upon evaluating the performance of offset policies in achieving no net loss of biodiversity value in a landscape against different frames of reference (Bull et al., 2014a). Here, total biodiversity $B(t)$ was instead split into a set of different components $B_i(t)$, which correspond to the three different ecosystem types (EVCs; Table 1), with $B(t)$ representing the Habitat Hectares score (condition x area) of each vegetation community (EVC). The total biodiversity score is given by:

$$B(t) = \sum_i B_i(t)$$

[Eqtn 6]

where the index *i* runs over the three EVC types. Each EVC was assigned an initial Habitat Hectares score based upon real data for the extent and condition of the these EVCs in Port Phillip and Western Port Catchment area around Melbourne, Australia. A linear development rate of was applied to $B_i(t)$, as in previous versions of the model, but applied to each different subcomponent (EVC) of $B(t)$ separately. For the results presented here, k_2 in in equation 4 was set to 0.16. For simplicity, we used the same development rate for all three EVCs, to focus on the impacts of different types of flexible offsetting. When running the model, condition scores for each different component waere recorded though time. We then used the minimum Habitat Hectares score at any point, and final Habitat Hectares score, as a basis for evaluating the consequences of flexibility.

<u>Types of flexibility</u>

Of the types of flexibility we categorized (c.f. Results), we modelled flexibility in time (delaying offsets or development relative to each other) and flexibility in type (out-of-kind). We explored 6 scenarios, including a baseline scenario with neither development nor offsetting, and scenarios variously combining flexibility in time and type as described below.

Previously, the optimistic model assumption was made that offsets occur simultaneously with development and create new biodiversity immediately. Biodiversity in any state could be offset and is assumed to revert to pristine condition once offset. In this version, we modelled flexibility in time by including scenarios with (i) offsets implemented 25 years before the associated development; (ii) offsets implemented at the same time as associated development; and, (iii) offsets implemented 25 years after the associated development. Delayed development corresponds to the use of habitat ‘banking’ (i.e. policies that require offsets to be implemented in advance of associated development impacts; Bekessy et al., 2010). Offsets implemented concurrently with development represent the idealized case where offsets gains occur at the same time as development. Delayed offsets represents the more realistic case, in which it takes time (after development) for biodiversity gains to accrue. Note that in some cases 25 years might be an unusually long timescale for either habitat banking or for implementing delayed offsets after development: this extended timescale was deliberately chosen used so that the functional influence on biodiversity outcomes was clear.

Flexibility in type was modelled by allowing all offsets to flow to the most threatened habitat type available for offsets at any one point in time. EVCs then become unavailable for additional offsets or development once “locked up” (i.e. all habitat in that EVC was either developed or managed as offsets). Once the most threatened EVC is locked up, offsets then flow to the second most threatened EVC, and then the least threatened EVC. By way of contrast, when flexibility was not permitted, offsets could only provide compensation in the same EVC in which development losses were incurred.

The 7 scenarios modelled consist of:

- **S1 (Baseline**, or null counterfactual**)** No development or offsetting occurs. All vegetation is unmanaged;
- **S2 (Like-for-like)** Development and completely non-flexible offsetting occur simultaneously;
- **S3 (Out-of-kind)** Development and offsetting occur simultaneously, but offsets are flexible by type;
- **S4 (Like-for-like, offsets delayed)** Same as S2 except offsets are implemented 25 years after development occurs (flexible in time);
- **S5 (Like-for-like, development delayed)** Same as S2 except development is delayed until 25 years after offsets are implemented (flexible in time);
- **S6 (Out-of-kind, offsets delayed)** Same as S3 except offsets are implemented 25 years after development occurs.

Table 1: empirical data on each EVC, including overall threat status, as well as area and Habitat Hectare score in the study area

EVC name	Overall threat status	Initial area (ha)	Initial Habitat Hectares score
1. Plains Grassy Woodland	Endangered	36.35	1817.5
2. Damp Heathland	Rare	41.65	2082.5
3. Blackthorn Scrub	Least concern	20.69	1034.5

It should be noted that we did not model flexibility in space in this exploration, as flexibility in space is relatively well understood (Wilcox & Donlan, 2007; Moilanen 2013; Habib et al., 2013), and because our theoretical model is non-spatial. Flexibility in space can be implemented in any spatial prioritization software, by tuning the extent at which spatial data layers are entered into prioritization (Moilanen 2013). The expectation is that when localized compensation is required, options for offsetting are fewer and cost-efficiency suffers, compared to the case in which offsetting is allowed over a larger spatial scale.

3. Results

3.1 *Flexibility in existing regional biodiversity offset policies*

There are approximately 50 regional offset policies and programmes worldwide (Madsen et al., 2011), although many of these are relatively new. Some permit flexibility. This includes, for instance, the *Biotopwertverfahren* offset scheme in Germany, and the application of Habitat Equivalency Analysis to mitigation banking in the US – both of which permit flexibility in type (Quétier & Lavorel, 2012). The Victorian offset scheme (Australia) has been in place for over a decade, and permits “trading up” (i.e. flexible trading of biodiversity components by type, if the gain is in a habitat with higher conservation value than losses). However, recent reforms to Victoria’s regulations also allow flexible offsetting in space, to a much greater extent (DEPI, 2013). In addition, relatively new Canadian biodiversity offset policy potentially permits flexible biodiversity trades in both type and space (Poulton, 2014), whilst the Western Cape policy in South Africa allows some flexibility in space (Brownlie & Botha, 2009). A new offset policy has been piloted in the UK, which would also permit flexible trades between different biodiversity components (Defra, 2011).

Since all offset policies, as far as the authors are aware, either involve biodiversity banking or permit biodiversity benefits associated with offsets to accrue over time (i.e. during and after development occurs), they all implicitly allow flexibility in time. This has not been recognised previously in the offsetting literature. All policies also implicitly allow flexibility in type, for those species and habitats that are not represented by data in the analysis.

3.2 *Categorisation of flexibility in offsets*

Applying the structured framework from Moilanen et al. (2014) permits a more comprehensive picture of flexibility in offsets, as detailed below (Table 2).

Table 2. Categorization and basic properties of flexible biodiversity offsets, drawing from a top-down question-based framework for analysis of conservation strategies (Moilanen et al., 2014), indicating where the outcomes of each category of flexibility are known to have been explored.

Category of flexibility	**Example of this type of flexibility in biodiversity offsets** (note that allowing flexibility in offsets is atypical)	**Outcomes explored in the literature**
Name and aliases	Biodiversity offsets can also be known as ‘mitigation’, ‘set asides’, etc. Exchanges are allowed between conservation interventions which have different names. Note that there are difficulties in translation. For instance, direct translation of “biodiversity offsets” into both Swedish and Russian is ‘ecological compensation’, although in English they are actually a very specific subset of ecological compensation	No
Type	Physical biodiversity losses (e.g. habitat clearances) could be exchanged for e.g. gains in information (e.g. biodiversity research) The obligation for biodiversity lost due to development and biodiversity gained due to offsets to have the same resilience to environmental change (c.f. for instance issues around requiring offsets to endure “in perpetuity”) is relaxed	No
Why	The drivers and subsequently the philosophy behind offset policy varies: e.g. in the US it is to create a big market in biodiversity credits, in the UK it based around streamlining development and adding transparency. Exchanges are permitted between offset markets that are driven by different philosophies (e.g. in different countries)	No
What	One type of biodiversity component can be exchanged for another e.g. one habitat type for a different habitat type, or habitat losses exchanged for gains in specific fauna species. This is ‘flexibility in type’. Trades are permitted between an offsets scheme that is part of a broader ‘no net loss’ policy (i.e. reduced losses against the counterfactual), and one that is part of a ‘net gain’ policy (i.e. ecological recovery against the counterfactual).	Wilcox & Donlan, 2007 Habib et al., 2013 This article
Where	Development losses and offset gains can be measured on different scales e.g. losses and gains at the project scale (i.e. just incorporating the impact and offset sites) versus losses and gains at the landscape scale incorporating multiple offset and impact sites as well as the matrix between them. Large distances are permitted between development sites and the associated offset project sites.	Kiesecker et al., 2009 Bull et al., 2014a
Who	Biodiversity components owned or controlled by one group can be exchanged for components owned by another (e.g. biodiversity value on public vs. private land)	Gordon et al., 2011b
When	Offset gains are often acceptable even if they postdate development impacts (i.e. the time lag problem). If it is treated as desirable if offsets are implemented before associated development impacts i.e. through mitigation banking mechanisms – even if conservation priorities are changing in the interim.	This article
How	Different means for achieving additional biodiversity value are treated as interchangeable e.g. restoration vs. protection resulting in gains from avoided loss.	No
Defining characteristics	Biodiversity offset credits can be exchanged between schemes that have slightly different defining characteristics, e.g. a No Net Loss policy and a ‘Net Positive Impact’ policy	No

Biodiversity offsets can be given various different names, such as for instance 'habitat credit trading' or 'complementary remediation' (Madsen et al., 2011). Further, biodiversity offsets might be translated only approximately into other languages: e.g. the phrase translates into both Swedish and Russian as "ecological compensation". Labels such as these, when used to describe biodiversity offsets, might also encompass other conservation interventions, and therefore introduce ambiguity. So, 'flexibility by name' could arise if exchanges are permitted between offset-type interventions with slightly different labels ('Name' in Table 2).

Offset projects can involve various compensatory activities, from active habitat creation or restoration through to preventing near-certain losses of biodiversity unrelated to the development ('avoided loss' offsets), on to provision of resources to existing protected areas, or financial support for ecological research activities (Madsen et al., 2011; Bull et al., 2013b). The exchange of direct biodiversity losses through e.g. habitat clearance, for gains in anything other than active biodiversity creation, represents a form of flexibility ('Type' and 'How' in Table 2).

Different offset policies are created for different reasons – but the philosophy behind an offset policy is not necessarily made explicit. For instance, Australian offset policies are essentially designed to add additional costs to clearance of native vegetation, thus discouraging development in such habitats. Conversely, the idea of placing any barrier to development whatsoever is anathema in the UK, where the pilot biodiversity offset policy was rather intended to simplify compensation for development impacts, and make it more transparent. If offset trades were permitted between regions with different drivers for developing offset policy, this would represent a form of flexibility ('Why' in Table 2).

As outlined in the Introduction, the concepts of biodiversity offsets being flexible in type (i.e. 'What' in Table 2) and in space (i.e. 'Where' in Table 2) have already been discussed in the literature (Kiesecker et al., 2009; Quétier & Lavorel, 2012; Habib et al., 2013). Conversely, the subject of who owns the land upon which offsets are delivered has received only limited attention (Gordon et al., 2011b). Yet the land tenure situation determines who controls any value associated with the biodiversity contained within that region. If, for instance, biodiversity losses occurred on public land, but were permitted to be compensated for by gains in biodiversity on privately owned land, then the associated offset policy would be implicitly allowing flexibility in terms of the control of biodiversity value ('Who' in Table 2).

We have already indicated that offsets can be flexible in time under existing offset policies: if a development occurs and is then compensated for with an offset, such policies permit ecological benefits from the offset to accrue over time, so there is a time lag between development losses and gains. Such temporal discrepancies are often dealt with through the use of multipliers, increasing the size of the offset required for a given development (Laitla et al., 2014). It has been argued that time lags in biodiversity gains from offsets should necessitate the use of conservation banking mechanisms, and biodiversity gains achieved in advance of development (Bekessy et al., 2010). But conservation priorities can change with time, so the implementation of an offset in advance of the development impacts for which it compensates may target different priorities than one implemented simultaneously with development. Both conservation banking and the use of temporal multipliers (note: which might in practice be one component of the variable m in Equation 5) can therefore be generalized as a form of flexibility in time ('When' in Table 2).

Finally, offset policies can have different defining characteristics, for instance: whether the fundamental objective of the policy is to achieve No Net Loss or a Net Gain in biodiversity; whether the target of the policy is one specific biodiversity component or many; whether the policy targets biological diversity, ecosystem services or ecosystem function; and so on (IFC, 2012; Bull et al., 2013a). Any attempt to allow trades of offset credits between regions whose offset policies have different characteristics would represent another form of flexibility ('Defining Characteristics' in Table 2).

3.3 *Model outcomes*

To reiterate, in principle, the aim of offset policies such as the one we model here is generally to achieve no net loss of biodiversity (here, treated as *condition* x *area* of three EVCs) relative to a given baseline. For all results presented here we show trajectory of the Habitat Hectares score for each of the three EVCs, as well as the trajectory of total biodiversity which comprised the sum of the Habitat Hectares score for the three EVCs. S1 was the baseline, comprising neither development nor offsetting, with all EVCs unmanaged and consequently declining in condition. We compared the other scenarios to S1 to determine the extent to which they resulted in no-net-loss, or a net gain relative to this baseline.

Fig. 2a shows the results of the S1, with declines due solely to background habitat deterioration. The results of non-flexible (like-for-like) offsetting are presented in Fig. 2b. Fig. 2c shows a breakdown of different model components for EVC1, with separate lines for the HH score of vegetation developed, offset, and available for development or offsetting. Along with background deterioration, these processes together result in the overall condition trajectory (i.e. solid line in Fig. 2c). Offsetting that is non-flexible by type (like-for-like) results in gains relative to the baseline S1 (Table 3).

Flexibility in type

Allowing trades to be flexible between EVCs resulted in different ecological outcomes. Under a non-flexible policy, losses and gains are exchanged within type, so the proportion of each habitat ends up remaining approximately constant (Fig. 2b). In Fig. 2d the flexible (out-of-kind) scenario is shown (S3) where all offsets first flow to EVC2, and when EVC2 is locked up after approximately 30 years offsets flow to EVC1, and finally to the least threatened EVC3. In distributing offset gains across different habitat types, EVC2 and EVC3 suffered proportionally greater losses, while EVC1 benefited (Fig. 2d, Table 3). Even though the impacts on individual EVCs differed between S2 and S3, the impact on summed HH score across all EVCs in terms of both the minimum score reached and score at the 150 years was similar (Table 3).

Flexibility in time

The results for allowing flexibility in time, but not type, are shown in Fig. 3 – that is, delaying offsets relative to development (Fig 3a) and delaying development relative to offsets (Fig 3b). These delays did not affect final HH score of all EVCs combined at 150 years (Table 3), however, did effect the minimum HH score that occurred. Delaying offsets resulting in a lower minimum score compared to delaying development (Fig 3; Table 3). This same trend was reflected in the trajectories of the individual EVCs. This result is partly intuitive, as creating biodiversity gains to pre-empt losses provides gains in advance of development, resulting in a lessening of the impact of development over time. However, the final score for each EVC was the same irrespective of whether offsets or development were delayed, becuase our model assumes the same offset benefits can accrue irrespective of the vegetation condition when the offsets are implemented. Thus, while delayed offsets means an initially greater overall impact from development, the offset eventually results in the same gains, meaning that the net result over time is the same. However, delaying offsets in this way could result in a bottleneck, where EVC condition score drops to a low value before the offsets gains can increase it again.

Fig. 2: Results from the offset model showing (a) the baseline scenario (S1) with no offsetting and no development (b) like-for-like offsetting (c) the individual component that comprise the trajectory for EVC1 for like-for-like offsetting (c) out-of-kind offsetting of permitting flexibility in type.

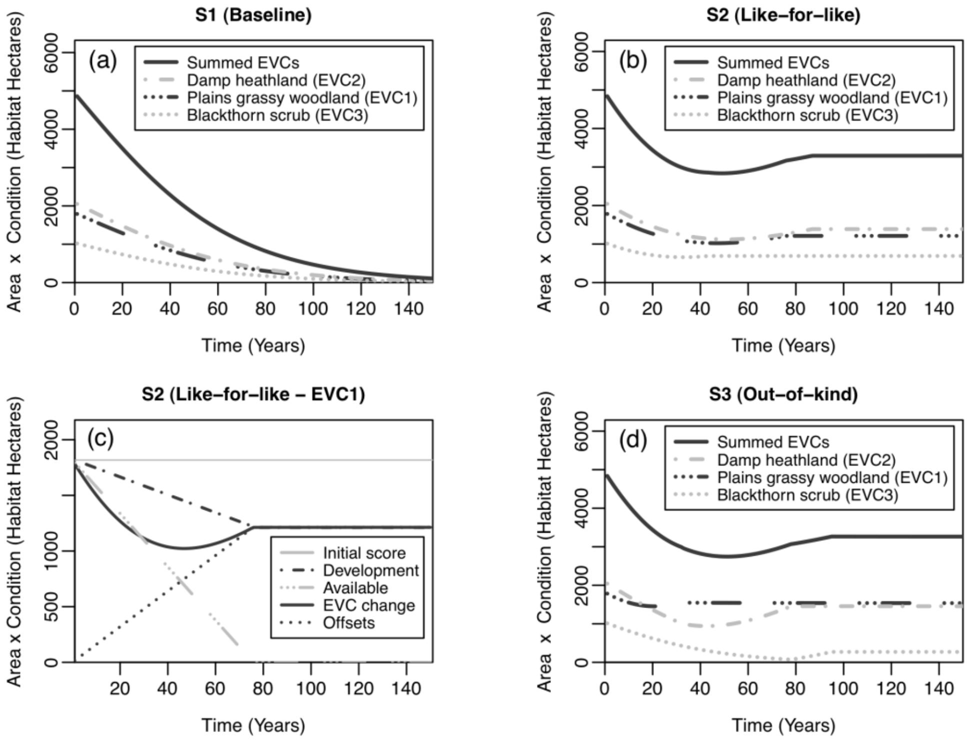
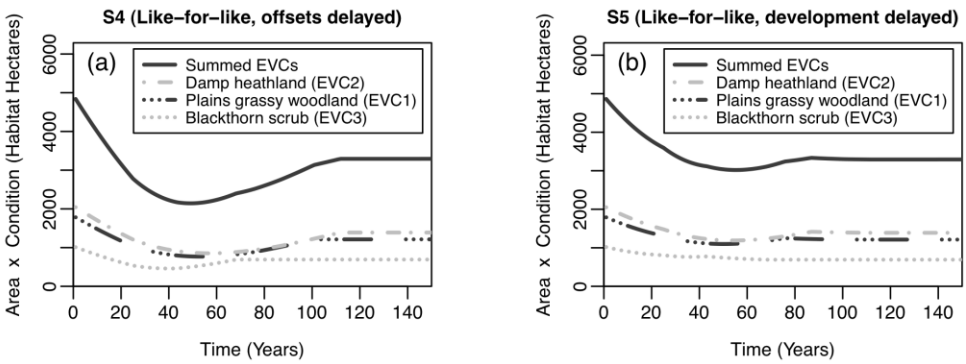


Fig. 3: Like-for-like offset trades that flexible in time but not type. (a) offsets delayed by 25 years relative to development (b) development delayed by 25 years relative to offsets.



Flexibility in both time and in type

Figure 4 show the situation S6 where offsets are permitted to be flexible in both type and time, i.e. out-of-kind offsetting where offsets are delayed relative to development (Fig. 4). When flexibility in both type and time was permitted in the model, varied in terms of the final score and minim scores for each EVC and summed score over all EVC. (Fig. 4; Table 3).

Fig. 4. Combining flexibility in both type and time. Out-of-kind offsetting, with offsets delayed by 25 years relative to development.

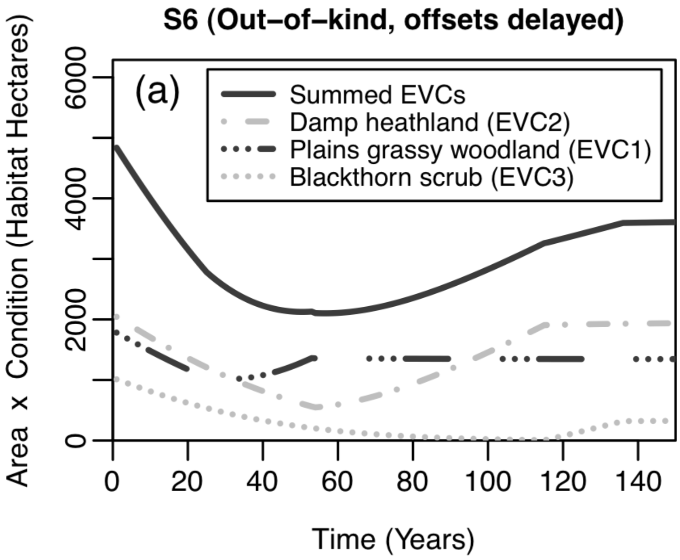


Table 3. Summary results for all 6 scenarios, individual EVCs and summed EVCs. Min score = minimum Habitat Hectare score reached during the 150-year simulation period. End score = Habitat Hectares score after the 150-year simulation period.

Scenario	**EVC 1**		**EVC2**		**EVC3**		**All**	
	Min score	**End score**	**Min score**	**End score**	**Min score**	**End score**	**Min score**	**End score**
S1 (Null counterfactual)	39.9	39.9	45.8	45.8	22.7	22.7	108.4	108.4
S2 (Non-flexible)	1022.6	1212.8	1121.6	1388.8	659.4	691.1	2837.1	3292.7
S3 (Flexible by type, non-flexible by time)	1453.9	1536.5	941.5	1456.0	72.1	270.5	2744.0	3263.0
S4 (Non-flexible by type, offsets delayed)	768.3	1212.8	853.4	1388.8	459.7	691.1	2143.9	3292.7
S5 (Non-flexible by type, development	1098.3	1212.8	1189.9	1388.8	690.7	691.1	3019.4	3292.7

delayed)								
S6 (Flexible by type, offsets delayed)	1013.1	1344.9	547.5	1937.7	7.0	324.2	2101.2	3606.9

<u>Influence of degradation rates</u>

Different degradation rates were explored in simulation runs. Due to the functional form of the equations used in the model, the rate of degradation did not qualitatively influence final simulation outcomes for each EVC, as all impacts were eventually fully offset. However, the degradation rate was found to alter the severity of the decline in the interim.

4. Discussion

The primary objectives of this paper were to provide a structured categorisation of different types of flexibility in biodiversity offsets and begin exploring the ecological outcomes of allowing flexibility in time and type. We find that there are a number of categories of potential flexibility in offsets that have not to date been explicitly considered in the literature on offsetting, and that allowing flexibility can have important consequences from the perspective of biodiversity conservation.

4.1 *The importance of classifying different types of flexibility in offsetting*

There are a number of reasons why it is beneficial to understand different types of flexibility in offsetting. From a policymakers perspective, it allows a methodical consideration of flexibility in developing new offset policy, and clarifies where existing policies implicitly permit allow certain types of flexibility (e.g. habitat banking). The categorisation provided here highlights those topics necessary for consideration as offsets become more widespread (e.g. 'Who' - public versus private ownership of biodiversity value). Further, the topics identified here should become focal areas for offset policy if and when offset credits begin to be traded internationally (e.g. 'Name', 'Why', 'Defining Characteristics'). Finally, our categorisation of flexibility here suggests the need for an explicit consideration of change and resilience in biodiversity offsetting (c.f. Table 2), which, despite having been partly explored in theory via new methodological approaches (e.g. Pouzols & Moilanen, 2013) remains something of a gap in offset implementation (Bull et al., 2013b).

Beyond the interest from a policy perspective, it is necessary to categorize flexibility for the research community as well. For instance, in order to progress robust evaluation of the use of habitat banking and the achievement of biodiversity gains in advance of development (Bekessy et al., 2010), it is important to recognize that habitat banking arguably represents a specific type of offset trade, in which there is flexibility though time and possibly across space and type.

4.2 *Implications of flexible offsetting*

According to existing research and its extension here, there could be both pros and cons of allowing flexibility in offsetting. In terms of pros, flexibility in space can lead to more efficient implementation of offset activities across a landscape, as shown by Kiesecker et al. (2009) and Habib et al. (2013). That is to say, flexible offsets could allow better incorporation of ecological considerations into offsetting such as including species' behaviour across their full range, interactions with other species including top-down and bottom-up processes, population or genetic dynamics through time, and so forth. Equally, Wilcox & Donlan (2007) pointed out the potential efficiency gain and increased conservation benefits of implementing offsets that are flexible in space and effectively in type. Bekessy et al. (2010) implicitly point not just to the benefits, but to the *necessity* of allowing flexibility in time, as ecological value can take a long time to accrue. It is pointed out in the context of the RobOff software, that comparatively higher offset ratios (multipliers) are needed when a stronger form of sustainability, implying less flexibility, is assumed in the offsetting model (Pouzols & Moilanen 2013).

We have also highlighted some pitfalls associated with flexible offsetting. For instance: allowing flexibility by 'type' could lead to some habitat types losing out, if not adequately coordinated across the landscape. In particular, trading up could result in relatively heavy losses of more common habitat types overall (Fig. 2, Table 3), which could perversely result in those becoming more limited in spatial extent and hence threatened over time. Equally, allowing flexibility in time can either lead to undesirable time lags in the compensation of lost biodiversity value (Fig. 3), or potentially to compensation via outdated conservation priorities – because ecosystems are inherently dynamic and subject to change, and so conservation targets may change over the course of decades. The former issue can be managed through temporal discounting (c.f. Overton et al., 2012; Pouzols et al. 2012; Laitila et al. 2014), but the latter is a more subtle issue and perhaps difficult to circumvent. Allowing flexibility in space can lead to more coordinated conservation area networks at the landscape level. It can also facilitate avoidance of threats to biodiversity.

However, it could also lead to problems in those areas where maintaining highly localised access to habitat patches is a key concern for stakeholders (e.g. the UK).

The categorisation we provide here draws attention to further considerations, including that flexible offsetting could permit nature to flow out of one region and into another, which may not be a desirable outcome. Flexible offsetting (in terms of "Who") could permit the flow of biodiversity value from public ownership to private ownership or between different jurisdictions, which would represent a loss in ecosystem service provision in a region. And, if offsets are traded between jurisdictions that differ in terms of "Why", then biodiversity value could flow from a society that has a certain philosophy concerning nature conservation to one that has a different philosophy (Bull et al., 2014b). Such an exchange would not be justifiably tradeable, would concern a type of flexibility that would be difficult to communicate, and would require an even more ambiguous concept of No Net Loss.

We endeavour to capture concepts and results discussed throughout this article, again in the framework suggested by Moilanen et al. (2014), related to the overall feasibility of implementing flexible biodiversity offsets (Table 4).

Table 4. Fundamental properties, and feasibility of implementation, for flexible offsetting (following Moilanen et al., 2014)

Topic	**Flexibility in biodiversity offsets**	**Relevant publications**
Major underlying assumptions	Flexible offsetting assumes that different components of biodiversity can be treated as fungible, if not physically then in terms of importance to society	Salzman & Ruhl, 2000
Direct and opportunity costs	Direct costs: recent research shows that flexibility can allow more efficient use of conservation funds Opportunity costs: not applicable	Wilcox & Donlan, 2007; Bull et al., 2013b; Habib et al., 2013
Data needs and availability	Demonstration of no net loss when allowing flexibility in time, type or space requires sufficient data to apply detailed biodiversity metrics. This information is not always available. When using a refined set of biodiversity features in analysis, data would rarely be available. More flexible offsetting demands more data, because data is required to specify the tradeoffs and preferences that allow flexibility. Conversely, flexibility is in practice is sometimes permitted in terms of carrying out research in exchange for impacts upon those biodiversity components for which no data are available. Data availability is not required in this instance.	Walker et al., 2009 IFC (2012)
Other constraints	Biodiversity offsets require technical expertise and ecological knowledge. Those implementing offsets do not always have access to these resources.	-
Risks, unintended consequences	As illustrated by the simulation modelling results presented here (Figs. 2 - 4), flexible offsetting could potentially lead to unintended changes in the conservation status of certain biodiversity components e.g. more common habitats. In addition, the offsetting approach in general can lead to a variety of unintended consequences through perverse incentives.	This article Gordon et al., in review
Uncertainty	Extensive uncertainties exist with the implementation of even non-flexible biodiversity offsetting, hence the need for multipliers. Allowing flexible offsetting requires an additional level of value judgements to be made (e.g. in defining exchange rules), bringing in additional elements of human decision uncertainty.	Moilanen et al., 2009; Kujala et al., 2013; Pouzols & Moilanen., 2013
Conflicts (with other land uses or strategies)	As outlined in a forthcoming paper, biodiversity offsetting in general can lead to competition in terms of both land and financial resources available for other conservation strategies. However, it is not clear if competition is increased by allowing flexibility in offsetting.	Gordon et al., in review
Synergies (with other land uses or strategies)	Biodiversity offsets that are flexible have been argued to potentially present a useful framework for relatively novel, 'dynamic' approaches to conservation, such as mobile protected areas. Can be used to buffer existing protected areas, and in this and similar ways support conservation networks.	Bull et al., 2013b
Overall feasibility	Given sufficient resources (expertise, finance, space, data) flexible offsets are feasible. However, feasibility depends upon relevant stakeholders being sufficiently convinced that creating an artificial fungibility in biodiversity trades is acceptable.	-
Related alternatives	(a) Earlier stages in the mitigation hierarchy (i.e. avoidance, minimization or restoration of biodiversity impacts), (b) non-flexible biodiversity offsetting, (c) prevention of development that results in significant biodiversity impacts.	-

4.3 *Further work*

As far as we are aware, this paper categorises flexibility in biodiversity offset schemes specifically for the first time. It also illustrates elements of flexibility using a theoretical model of offsetting. There are a number of further research directions that are suggested in relation to the modelling work. First, in this simple exploration, we present results involving only three habitat types. The analysis could feasibly be extended to show outcomes for a larger range of EVCs, representing a more realistic landscape, of even for cases where out-of-kind offsetting results in trades between gains and impacts on vegetation communities and individual fauna species.

As discussed, spatial flexibility in offsetting has been recently explored in other papers (e.g. Moilanen, 2013; Habib et al., 2013). The notion is not complicated in implementation, but the outcomes will likely be highly case-specific. Here provide an exploration of temporal flexibility and flexibility in type, but our model is non-spatial. The interaction between all three types of flexibility would be interesting to explore.

To reflect the situation in Victoria, we assumed in this version of the model that there was background trajectory of deterioration in EVC condition across the landscape. It is not the case in all regions that offsets are implemented for habitat types that are degrading with time, e.g. Europe, where offsets are implemented for impacts upon protected areas (Tucker et al., 2013). As such, the simulations could be repeated using different background trajectories, including those that are qualitatively stable or even improving. It should be noted that this has already been partly explored for offsetting, although not in the context of flexibility (Bull et al. 2014a).

The issue of whether to allow flexibility links not only to conservation value, but also to the social objective of the offset scheme, which has not been explored here. For instance, a common requirement of conservation interventions might be ensuring human access to nature. Such an objective might provide a different argument for requiring spatially constrained (non-flexible) offsets, if that means that offset locations are closer to transport infrastructure or urban centres.

Finally, it would be useful to extend the modelling work we have undertaken here to critically assess outcomes of other types of flexibility. Of particular relevance to contemporary debate in the offset field would be to analyse the consequences of implementing trans-jurisdictional trades i.e. those between different countries (c.f. Bull et al., 2014b).

Trans-jurisdictional trades are one of a number of new directions being informally discussed in the current development of biodiversity offset initiatives worldwide, although this has not been discussed in the literature. We have shown here how this would reflect just one of a range of categories of flexibility in offsetting. In our view, flexibility has not been fully considered in practical offset policy and project development so far. The dangers of not giving sufficient consideration to flexibility include that some ecosystem components could be much more heavily impacted than others, that offset projects could target out-of-date conservation priorities, that the value received from the existence of biodiversity could flow from one stakeholder group to another, and more. Our overarching recommendation for conservation is that all forms of flexibility be explicitly considered during the development of offset policies. We believe that we provide one useful framework for doing so.

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