Conservation Letters
A journal of the Society for Conservation Biology
Open Access

LETTER

A Loss-Gain Calculator for Biodiversity Offsets and the Circumstances in Which No Net Loss Is Feasible

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Keywords
Biobanking; biodiversity offset; biodiversity; compensatory habitat; metric; mitigation banking; no net loss.

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Received
8 September 2014
Accepted
7 September 2015

doi: 10.1111/conl.12206

Abstract

Offsetting is a policy instrument intended to provide flexibility for development. We developed a simple calculator to predict when no net loss is feasible using biodiversity offsetting. Assuming offset ratios ≤10:1 are indicative of operational feasibility and employing a discount rate of 3%, we predicted that no net loss is feasible where biodiversity can be restored within 55 years, which restricts the impacts on biodiversity that can be offset using restoration. Alternatively, no net loss is feasible by avoiding loss to biodiversity that is declining under the counterfactual at an annual rate ≥6%. However, this is considerably higher than typical background rates of biodiversity loss so restricts where avoided-loss offsets are feasible. No net loss is theoretically feasible in the broadest range of circumstances if biodiversity gains are provided in advance of development. However, these gains are procured by restoration or avoided loss, so constraints presented by these approaches also apply. We concluded that no net loss is feasible in a limited range of development scenarios unless offset ratios greater than 10:1 are more widely tolerated.

Introduction

Global population growth and increasing per capita consumption (Lenzen *et al.* 2012) has led to the loss of 2.3 million km^2 of forest between 2000 and 2012 (Hansen *et al.* 2013). Habitat degradation and loss remains the key threat to biodiversity (McLellan *et al.* 2014). Thus, solutions that decouple economic development from biodiversity loss are required.

Biodiversity offsetting—the process of generating gains in biodiversity to compensate for losses from development—is a policy instrument that seeks to achieve no net loss of biodiversity against a background of ongoing development. Offsetting, it is argued, represents a flexible alternative to command and control regulation because it theoretically allows development impacts to continue or expand without detrimental net effect on the environment (Jenkins *et al.* 2004; Fromond *et al.* 2009; Reid 2011). However, the converse has also been argued with respect to biodiversity offsetting. Issues such as low success rates for ecological restoration, the slow rates at which some biodiversity gains accrue, and challenges representing the complexity of biodiversity in a fungible metric, limit the circumstances in which no net loss of biodiversity is feasible using offsetting as a policy instrument (Gibbons & Lindenmayer 2007; Bekessy *et al.* 2010; Maron *et al.* 2012; Curran *et al.* 2013; Overton *et al.* 2013).

We are lacking simple, generic methods that enable biodiversity losses and gains to be quantified in the context of biodiversity offsets that, in turn, can be used to transparently identify or audit development scenarios in which no net loss is feasible. Here, we: (1) develop a simple calculator to quantify the amount of biodiversity gain that is required to compensate for a known amount of biodiversity loss and (2) use this calculator to quantify development scenarios in which no net loss of biodiversity is most likely to be feasible.

Methods

Defining no net loss

No net loss of biodiversity is achieved when the gain in biodiversity generated by an offset is equal to, or greater than, the loss of biodiversity from the impacts of a development. However, calculation of no net loss is sensitive to the baseline specified (Bull *et al.* 2014). The conceptual model for no net loss we use in this article is illustrated in Figure 1. Loss and gain are calculated as the difference between: (1) the amount of biodiversity that would exist with a change in management (i.e., with development and with the offset) and (2) the amount of biodiversity that would exist under the counterfactual (i.e., without development and without the offset; Maron *et al.* 2013).

A method to calculate no net loss

Here, we describe a simple method to calculate whether an offset proposal achieves no net loss as defined in Figure 1. We illustrated each part of the calculator with a hypothetical example in which a protected plant species (species A) and bird species (species B) are impacted by a proposed development (Table 1). An Excel spreadsheet that implements the calculator using data in our example is provided in the Supplementary Material.

Calculating loss from development

We defined the present value of loss (*PVL*) for a biodiversity attribute ($i = 1$ to k) from a development as

$$PVL_i = \frac{(I \times P_I)_i}{(1+r)^{t_n}} \tag{1}$$

where I is the predicted impact, or amount of biodiversity that will be lost on the development site over t_n years in Figure 1, P_I is the proportion of this loss that can be attributed to the impact from development, and r is the discount rate. We estimated the impact (I) of biodiversity from a proposed development separately for each biodiversity attribute of interest ($i = 1$ to k) and using the most appropriate units for that attribute. Examples of different attributes used to characterise losses to biodiversity include the amount of habitat lost, the number of individuals lost, the change in reproductive success, or change in patch or landscape indices (e.g., perimeter of area ratio). In our hypothetical example (Table 1), $I = 100$ individuals of species A, $I = 50$ nesting cavities for species B and $I = 10$ ha of feeding habitat of species B will be impacted because of the proposed development.

The proportion of the estimated impact from development on a biodiversity attribute is given by P_I in Equation (1). For example, a species on a site may be declining because of a threat unrelated to the proposed development (e.g., disease), in which case only a proportion of the estimated loss of this species at the development site can be attributed to the development. In our example (Table 1), $P_I = 1$ for all attributes.

Development of a building site might be rapid while the development of a mine, and the associated impacts on biodiversity, might take several years. We therefore discount the loss of biodiversity from a development over the number of years the development occurs (t_n). Here, we make all estimations for the *PVL* using a discount rate of 3% as recommended for Habitat Equivalency Analysis in the United States (NOAA 1999), which reflects the approximate average rate of social time preference for public goods (Dunford *et al.* 2004).

Calculating gain from offsets

The present value of gain (*PVG*) generated from an offset for each separate attribute of biodiversity (i) that is impacted by the proposed development can be given as

$$PVG_i = \frac{(O \times P_O \times E)_i}{(1+r)^{T_n}} \tag{2}$$

where O is the gross quantity of attribute i that is provided as the offset, P_O is the proportion of O that is additional to what would have been provided under the counterfactual scenario, E is the rate of effectiveness or success of the proposed management action for attribute i at T_n years in Figure 1 and r is the discount rate. We explain each of these terms below.

The gross quantity of a biodiversity attribute that will be provided as an offset is denoted by O, which must be expressed in the same units used to enumerate the *PVL* for the same biodiversity attribute ($i = 1$ to k) from development. In our hypothetical example (Table 1), the proposed offset for the impact on 100 individuals of plant species A is to plant 500 individuals of the same species, and the proposed offset for the impact on 50 nesting cavities for species B is to erect and maintain 300 artificial nesting cavities.

The proportion of the offset that is additional to what would have occurred under the counterfactual (without development and without offsets) is given as P_O. In our example (Table 1), where the proposed offset is to plant 500 individuals of plant species A, $P_O = 1$ because all plants will be established specifically for the offset and there is no existing obligation for the land owner to do

Table 1 Loss and gain calculations for hypothetical impacts from a proposed development on a protected plant species (species A) and a protected bird species (species B)

		Loss				Gain				No net loss	
Attribute impacted by proposed development (*i*)	Estimated impact (*I*)	Years over which *I* is realised (t_n)	% of *I* that is due to development (P_L)	Net *PVL* from development (*PVL*)	Proposed offset (*O*)	% of offset that is additional (P_O)	Years between loss and gain (t_0 to T_n)	Effectiveness of offset at T_n (*E*)	Net *PVG* from offset (*PVG*)	Has no net loss been achieved (i.e., $PVG \geq PVL$)?	Min. offset required (*O*) such that $PVG = PVL$
Protected plant (species A)	100 individuals	2	100%	94.3 individuals	Plant 300 individuals of species A	100%	2 years	0.4 survival rate	113 individuals	Yes	250 individuals (2.7:1)
Nesting cavities for protected bird (species B)	50 cavities	2	100%	47.1 cavities	Erect and maintain 300 artificial nest boxes	100%	3 years	0.2 occupancy rate by target species	55 cavities	Yes	257 cavities (5.5:1)
Feed trees for protected bird (species B)	10 ha of tree species that are used for feeding	2	100%	9.4 ha	Protect and manage 10 ha of appropriate habitat	50%	10 years	1.0 survival rate (any planted trees that die will be replaced)	3.7 ha	No	25.3 ha (2.7:1)

The *PVL* and *PVG* are calculated using Equations (1) and (2). The minimum amount of offset (*O*) that must be established to achieve no net loss (i.e., $PVG = PVL$) is calculated using Equation (3). A discounting rate of $r = 3\%$ is used for all calculations.

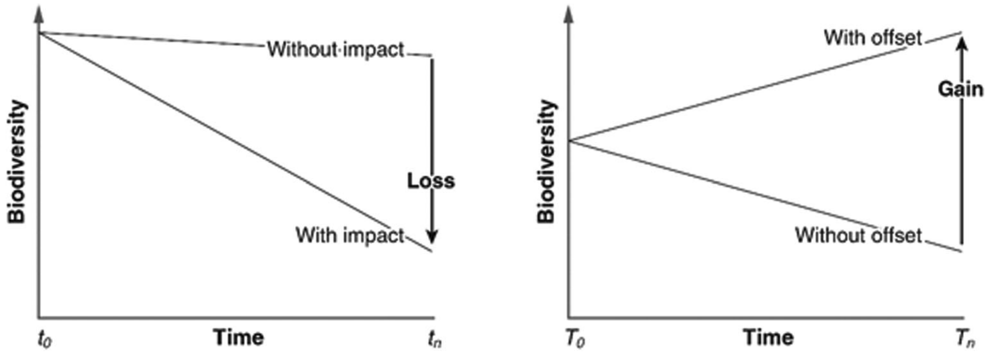

Figure 1 Our conceptual model for defining the loss of biodiversity from development (left) and gain in biodiversity generated from an offset (right). Net present values for loss and gain were calculated using time discounting.

this. However, in Table 1 where the proposed offset is to establish 10 ha of feeding habitat for species B, $P_O = 0.5$ because 5 ha (50%) of feeding habitat already exists on the proposed offset site and we assume this would persist irrespective of the offset.

Actions to restore biodiversity (Hilderbrand *et al.* 2005; Maron *et al.* 2012; Curran *et al.* 2013) or avoid threats to biodiversity (Hockings 2006; Joseph *et al.* 2009; Bottrill *et al.* 2011) have varying levels of success, so E is an explicit measure for the rate of effectiveness or success of the proposed offset at T_n (Figure 1). In our hypothetical example (Table 1), the value of E for planting species A is 0.4 because this is the survival rate of plants at $T_n =$ 2 years (the age of reproductive maturity for the species). The value of E for erecting nest boxes for species B is 0.2 because this is the known occupancy rate of nest boxes by this species. The value of E for the offset to establish trees as replacement feeding habitat for species B is 1.0 because the offset includes a provision to monitor mortality and replace any planted trees that are required to meet the objective.

In our calculator, we used discounting to account for the lag between the loss of biodiversity from development and the gain generated by an offset. The raw gain generated by the offset for each biodiversity attribute ($i = 1$ to k) is discounted over the number of years between t_0 and T_n in Figure 1 to give the *PVG* generated by the offset.

Calculating no net loss

A development proposal results in no net loss if $PVG \geq PVL$ for each and every biodiversity attribute ($i = 1$ to k) under consideration. The total offset (O) that must be established for a specified amount of loss (*PVL*), such that $PVL = PVG$ can be calculated by combining Equations (1) and (2) as

$$O_i = \frac{PVL_i \times (1 + r)^{T_n}}{(E \times P_O)_i} \tag{3}$$

Simulations under different loss-gain scenarios

We used Equation (3) to identify offset ratios that are required to achieve no net loss (i.e., units of biodiversity gain required for every unit of *PVL*) under the two most common offset strategies: restoration offsets (offsets based on restoring biodiversity) and avoided-loss offsets (offsets based on avoiding loss to existing biodiversity under current threat of loss) delivered over different time frames. We simulated restoration offsets assuming the product of effectiveness for ecological restoration (E) and the proportion of the gain in biodiversity from restoration that is additional (P_O) range from 0.1 to 0.5 (this is based on the assumption that typical rates of effectiveness for ecological restoration are ≤ 0.5; Maron *et al.* 2012) and restoration can compensate for losses from development with delays ranging from 0 to 100 years. We simulated avoided-loss offsets by assuming the product of effectiveness (E) and the proportion of biodiversity lost under the counterfactual (or "without offset" scenario in Figure 2; P_O) is 0.1-1.0, and that biodiversity subject to the offset will be lost under the counterfactual over time frames ranging from 0 to 100 years. For these scenarios, we fixed the discount rate (r) at 3%. However, we also simulated scenarios under a range of discount rates (1-4%) that have been proposed for compensatory habitat (Dunford *et al.* 2004) while holding values for effectiveness (E) and additionality (P_O) at their maximum (i.e., 1.0).

In all simulations, we interpreted offset ratios $\leq 10{:}1$ as indicative of greatest potential for operational feasibility given offset ratios employed in 10 out of 11 biodiversity offset policies we reviewed were $\leq 10{:}1$ (see Supplementary Material). However, we acknowledge that offset ratios below (e.g., Queensland State Government, Australia) and above (e.g., South African Government) 10:1 represent an upper limit in different offset policies.

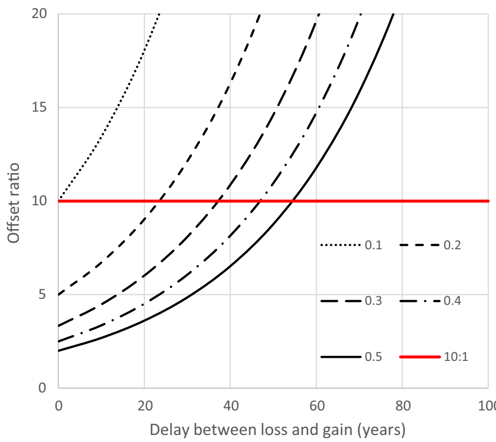

Figure 2 Simulations indicating offset ratios required to achieve no net loss of biodiversity for scenarios representing restoration offsets. The different curves represent values for the product of additionality (P_O) and effectiveness (E) ranging from 0.1 to 0.5 to reflect the potential for restoration offsets to have typical rates of effectiveness up to 0.5 and values for additionality up to 1.0. The discount rate is fixed at 3%. The horizontal (red) line represents an offset ratio of 10:1.

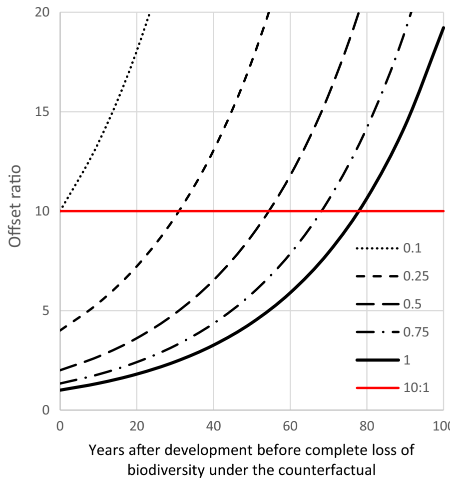

Figure 3 Simulations indicating offset ratios required to achieve no net loss of biodiversity for scenarios representing avoided-loss offsets. The different curves represent values for the product of additionality (P_O) and effectiveness (E) ranging from 0.1 to 1.0 to reflect the potential for avoided-loss offsets to have values for additionality (P_O) and effectiveness (E) up to 1.0. The discount rate is fixed at 3%. The horizontal (red) line represents an offset ratio of 10:1.

Results

Restoration offsets

The range of scenarios in which no net loss is most likely to be feasible (i.e., offset ratios ≤10:1) using restoration offsets is illustrated below the red line in Figure 2. Assuming the maximum typical rate of effectiveness for ecological restoration is 0.5 and maximum value for additionality is 1.0, no net loss using restoration offsets is most likely to be feasible where the biodiversity impacted by development can be restored within 55 years. Where biodiversity takes longer than 55 years after the impact to be restored, no net loss cannot be achieved with offset ratios ≤10:1 based on our underlying assumptions. No net loss is feasible across a broader range of values for effectiveness and additionality for biodiversity that can be restored within 55 years, or where delays between the loss of biodiversity from the impact and the gain in biodiversity from restoration can be reduced below 55 years by establishing the offset in advance of the impact.

Avoided-loss offsets

Assuming complete loss of biodiversity under the counterfactual (i.e., $P_O = 1.0$) and actions to reverse this loss will be 100% effective (i.e., $E = 1$), no net loss is most likely to be feasible (i.e., offset ratios ≤10:1) using avoided-loss offsets where biodiversity subject to management from the offset would otherwise have been entirely lost within 78 years (Figure 3). This equates to an annual rate of loss ≥6% under the counterfactual. Where existing threats to biodiversity at the offset site will result in only partial losses of biodiversity (i.e., $P_O < 1.0$) under the counterfactual, and/or values for effectiveness for abating threats to biodiversity on the offset site are <1.0, then avoided-loss offsets are only likely to be feasible where losses to biodiversity under the counterfactual occur at higher rates, or where avoided-loss benefits accrue in advance of impacts to biodiversity from development.

Discount rates

With values for effectiveness (E) and additionality (P_O) held at their maximum (i.e., 1.0), the scenarios in which no net loss is feasible when employing discount rates from 1% to 4% are illustrated below the red line in Figure 4. At discount rates of 1%, 2%, 3%, and 4%, no net loss is likely to be feasible with delays between biodiversity losses and gains up to 231, 117, 78, and 59 years, respectively. That is, greater delays between impacts on biodiversity from development and commensurate gains from offsets are tolerable where lower discount rates are employed.

Discussion

We used our calculator to predict the circumstances in which no net loss is most likely to be feasible under the

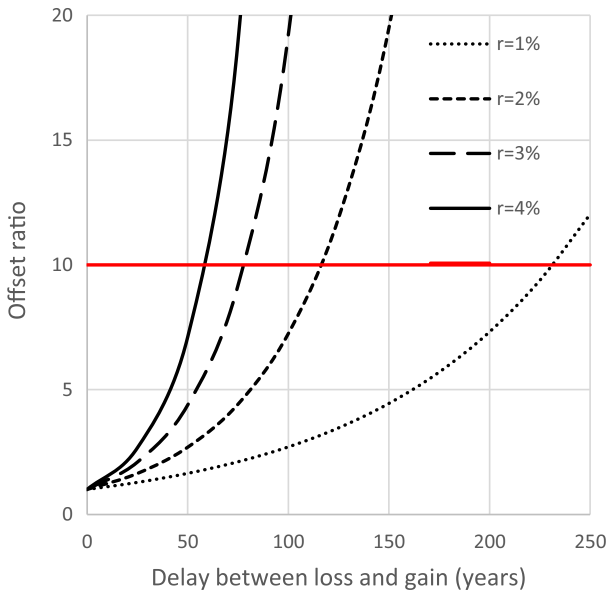

Figure 4 Simulations indicating offset ratios required to achieve no net loss of biodiversity for discount rates (*r*) between 1% and 4%. Additionality (P_O) and effectiveness (*E*) were each fixed at 1.0 (their maximum values). The horizontal (red) line represents an offset ratio of 10:1.

two main offsetting strategies that are employed: restoration and avoided loss.

Employing a discount rate of 3% (the approximate average rate of social time preference for public goods; Dunford *et al.* 2004), typical rates of effectiveness for ecological restoration of ≤0.5 (Maron *et al.* 2012) and assuming all actions are 100% additional, we predicted that not net loss using ecological restoration is likely to be feasible (i.e., using offset ratios ≤10:1) where delays between losses and gains are ≤55 years (Figure 2). That is, restoration offsets are unlikely to be feasible where delays between development and compensation of these losses will take longer than 55 years. This is likely to preclude offsets aiming to restore old-growth or late successional habitats (e.g., a meta-analysis of 108 studies indicates that secondary-growth habitats achieved species richness comparable with old-growth habitats within 100 years in 40% of cases; Curran *et al.* 2013) or habitat elements (e.g., mature trees; Gibbons *et al.* 2008; Maron *et al.* 2010); and plant species diversity on sites that are highly degraded or have been fertilized (Wilkins *et al.* 2003; Prober *et al.* 2005). Because many forms of ecological restoration have low rates of success (Maron *et al.* 2012; Curran *et al.* 2013), this also means that restoration offsets must typically be established in areas with high additionality, which means that the use of restoration offsets is further restricted to areas where there is little or no existing obligation to conserve biodiversity. Thus, circumstances in which no net loss can be achieved using restoration offsets are restricted.

It has been suggested that offsets based on avoided loss are more suited to achieving no net loss where development impacts on biota that are difficult to redress through restoration, such as old-growth habitats (Gibbons & Lindenmayer 2007). Employing a discount rate of 3%, and assuming actions to remove threats to biodiversity are 100% effective, no net loss is most likely to be feasible (i.e., using offset ratios ≤10:1) where biodiversity at the offset will be completely lost within 78 years under the counterfactual. This equates with an annual rate of loss ≥6%. Since we cannot assume that actions to abate threats to biodiversity are always 100% effective (Hockings 2006; Joseph *et al.* 2009; Bottrill *et al.* 2011), the required rate of loss to biodiversity under the counterfactual that is necessary to achieve no net loss is realistically higher. The rate of global biodiversity loss (2% per annum; data from McLellan *et al.* 2014) and rate of global deforestation (0.15% per annum; data from Hansen *et al.* 2013) are well below the annual rate of loss that we predict is necessary for no net loss to be feasible using avoided-loss offsets and none of the assumed rates of biodiversity decline under the counterfactual in Australian biodiversity offset policies are ≥6% (Maron *et al.* 2015). Indeed, Bull *et al.* (2014) caution that a perverse incentive exists to overestimate declines under the counterfactual when employing offsets. Our results therefore indicated that avoided-loss offsets are only feasible for achieving no net loss where biodiversity is declining much faster than typical background rates of biodiversity loss.

Providing biodiversity offsets in advance of impacts from development is preferred by several authors (Bekessy *et al.* 2010; ten Kate *et al.* 2014). Offsets (whether based on restoration or avoided loss) that generate benefits prior to development reduce or eliminate delays between losses and gains in biodiversity and therefore make no net loss theoretically feasible in a broader range of scenarios (Figures 2 and 3). However, because advanced offsets are procured using restoration or avoided loss, they impose practical constraints on development for similar reasons that restoration offsets and avoided-loss offsets impose constraints on development. That is, the restricted range of biodiversity gains that can be generated from ecological restoration and the long time frames needed to generate biodiversity gains from restoration or avoided loss will restrict the development scenarios where advanced offsets are feasible.

In conclusion, no net loss is likely to be feasible in a restricted range of circumstances when applied to biodiversity and thus may not be a more flexible alternative to command and control regulation. The principal reasons for this are that the effectiveness for ecological restoration and threat abatement are often well below 100%, that it takes a long time for ecological restoration to realise sufficient gains for many forms of biodiversity and that the rate of biodiversity loss under the counterfactual must be higher than typical background rates of biodiversity loss. No net loss is likely to be feasible under a greater range of circumstances where offset ratios greater than 10:1 are more widely tolerated—a conclusion also made by Laitila *et al.* (2014) and Moilanen *et al.* (2009)—and where discount rates less than 3% are deemed appropriate when calculating gains in biodiversity through time.

Acknowledgments

This research was funded by the Australian Government's Environmental Decisions Hub of the National Environmental Research Program and the Australian Research Council (ARC) Centre of Excellence for Environmental Decisions. We thank colleagues in the Australian Department of the Environment for many meaningful discussions about biodiversity offsets. MM is supported by ARC Future Fellowship FT140100516. Figure 1 was prepared by Clive Hilliker.

Supporting Information

Additional Supporting Information, including extensive text responding to VMEA's arguments, as well as the following tables and figures, may be found in the online version of this article at the publisher's web site:

Supporting Text
Supporting Text

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