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

REVIEW

Implementation Gap between the Theory and Practice of Biodiversity Offset Multipliers

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Keywords
Compensation ratio; ethics, governance; no net loss; prospect theory; taboo trade-off.

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Received
20 April 2016
Accepted
27 November 2016

Editor
Jonah Busch

doi: 10.1111/conl.12335

Abstract

Emerging policies worldwide require biodiversity gains as compensation for losses associated with economic development, seeking to achieve "no net loss" (NNL). Multipliers – factors by which gains are larger than associated losses – can be crucial for true NNL. Here, we review the theoretical literature on multipliers. Then, we collate data on multipliers implemented in practice, representing the most complete such assessment to date. Finally, we explore remaining design gaps relating to social, ethical, and governance considerations. Multiplier values should theoretically be tens or hundreds when considering, for example, ecological uncertainties. We propose even larger multipliers required to satisfy previously ignored considerations – including prospect theory, taboo trades, and power relationships. Conversely, our data analyses show that multipliers are smaller in practice, regularly <10.0, and have not changed significantly in magnitude over time.

We recommend that NNL policymakers provide explicit multiplier guidelines, require larger multipliers where appropriate, and ensure transparent reporting of multipliers used. Further research is necessary to determine reasons for the implementation gap we have identified. At the same time, there is a need to explore when and where the social, ethical, and governance requirements for NNL reviewed here can be met through approaches other than multipliers.

Introduction

Economic development delivers societal benefits, but also incurs costs through negative biodiversity impacts. A balance must be found between development and biodiversity conservation. The "no net loss" (NNL) policy principle could help achieve this balance. NNL policies are those under which developers – having mitigated biodiversity impacts where possible – fully offset residual losses through quantified, commensurate gains (Gardner *et al.* 2013). When losses and gains are summed, development then theoretically results in NNL of biodiversity, against some reference point (Bull, Gordon *et al.* 2014). NNL biodiversity policies have existed since at least the 1970s and continue to emerge (Maron *et al.* 2016), with an expanding associated technical literature (Calvet *et al.* 2015).

An important component of NNL policy is determining the ecological gains required to deliver full compensation for residual losses. Doing so involves choosing, for instance: biodiversity value metrics; counterfactuals against which net outcomes are evaluated; and, exchange rules between biodiversity components (Quétier & Lavorel 2012; Bull *et al.* 2013; Bull, Milner-Gulland *et al.* 2014; Gibbons *et al.* 2015). Among such considerations is whether to require "multipliers" – i.e., factors by which gains are larger than losses (Bull *et al.* 2013). While drivers motivating multiplier use and methods for their calculation have been discussed (e.g., Laitila *et al.* 2014; Pilgrim & Ekstrom 2014), there is no global assessment of multipliers used in practice. Consequently, it is difficult to assess whether multipliers are being used appropriately. More generally, NNL research often focuses upon technical challenges, with insufficient treatment of social and ethical concerns. This is problematic when NNL policies are sometimes deemed unethical (Ives & Bekessy 2015).

Here, we review the relevant literature, then collate and analyze data on multipliers used in practice, discussing whether implementation corresponds with theoretical requirements. Subsequently, we review gaps in multiplier design related to social and ethical considerations. We finish with policy recommendations related to multipliers and NNL more broadly.

Multipliers in theory

Reasons for using multipliers

Multipliers are employed for multiple reasons (Table 1), including: (I) to achieve broader biodiversity conservation objectives (Brownlie & Botha 2012); (II) to overcome poor information or predictive capability (Moilanen *et al.* 2009); (III) to manage risks of complete failure for biodiversity offsets (Maron *et al.* 2012); (IV) to account for temporal issues (Overton *et al.* 2012); and (V) to account for imperfect exchange currencies (McKenney & Kiesecker 2010).

Pilgrim & Ekstrom (2014) propose that categories I, II, and IV represent appropriate motivations for multiplier use, whereas categories III and V merely mask inadequate biodiversity offset design. Others warn against resorting to multipliers when: there is no ecological justification; insufficiently accounting for temporary biodiversity losses; and when offset activities might fail due to ecological correlation (Moilanen *et al.* 2009; Gardner *et al.* 2013). Multipliers are often but not always associated, to some degree, with managing uncertainties.

Maron *et al.* (2016) explore unresolved controversies in NNL policies, grouping considerations into technical, social, ethical, and governance issues. Referring to this framework, alongside Table 1, multipliers currently manage a combination of: technical challenges (categories II, III, V); social challenges (categories III, IV); and governance challenges (categories I, III). They are not yet designed to incorporate ethical considerations, which we discuss later.

Use of multipliers

The Sydney Olympic Park development provides an illustrative case study (Pickett *et al.* 2013). Lost pond habitat for a threatened frog species was offset by creating new ponds nearby. Subsequent monitoring over a decade found that guaranteeing NNL for frog populations required new ponds 19 times larger by area than those removed. Pickett *et al.* suggest this multiplier (= 19) was necessitated by time lags (category IV), habitat quality being insufficiently captured in project metrics (category V), and frog populations not always establishing (category III). Multipliers in this case appear to have been useful in meeting NNL objectives (maintaining frog populations), despite category III and V multipliers being cautioned against by Pilgrim & Ekstrom (2014) – perhaps due to lack of correlated restoration failure between ponds (Moilanen *et al.* 2009).

Sydney Olympic Park aside, there has been little exploration concerning multipliers implemented in practice. Some provide examples of proposed multipliers (McKenney & Kiesecker 2010; Quétier & Lavorel 2012; Laitila *et al.* 2014), without assessing multipliers realized under these policies. Substantive regional research was undertaken by Quigley & Harper (2006; Canadian Fish Habitat) and Matthews & Endress (2008; US Wetland Banking). A *lack* of specific multipliers has been recorded for Germany, New Zealand, and Sweden (Darbi & Tausch 2010; Persson 2013; Brown *et al.* 2014;). No global assessment exists regarding the actual use of multipliers in NNL policies (by which we mean guidelines for achieving NNL commitments) or projects (by which we mean specific development sites attempting to achieve NNL) – a gap we address in the "Multipliers in Practice" section. Conversely, there is considerable theoretical literature on multiplier design.

Theoretical literature on multipliers

A key theoretical work deriving biodiversity offset multipliers (Moilanen *et al.* 2009) incorporated consideration of uncertainty in: magnitude and value of realized biodiversity losses and gains; spatial correlation of restoration outcomes; and discount rates, i.e., time preferences. Moilanen *et al.* proposed a bet-hedging strategy across multiple sites, aligned with general recommendations to manage risk in conservation through diversification (Hummel *et al.* 2009).

Subsequently, Overton *et al.* (2012) further incorporated time preferences into multipliers, addressing: the chance that offset gains never occurs; lost option value associated with biodiversity; and, conversely, potential economic returns received from biodiversity (i.e., ecosystem services). Notably, the authors state that they do not address "social problems behind the effectiveness of offsets," without defining social problems.

Laitila *et al.* (2014) extended the theory on appropriate multipliers, combining the preceding literature to develop "minimum practical multipliers." They note the connection between risk and time preferences ("discount rate can also model the offsetting risk, as an immediate certain gain may be preferable to a risky delayed gain").

Table 1 Rationale and drivers for using multipliers in practice (Pilgrim & Ekstrom 2014), alongside related categories of uncertainty

Category	Reason	Description	Example regulatory framework	Relevant uncertainties
I	Achieving biodiversity objectives	Multipliers designed to ensure compensation meets landscape level conservation objectives. When development causes cumulative impacts, or to leverage conservation funding (e.g., higher multipliers for more threatened habitats, or to achieve net gains).	South Africa; New Zealand	Human decision
II	Limited information, or predictive power	Multipliers used to ensure NNL is achieved by accounting for epistemic uncertainties. When there is limited information on either impacts or offsets (e.g., development disturbing species movements), or predictions are uncertain (e.g., response of habitat to management).	Australia; UK	Epistemic
III	Risk of failure	Multipliers used if conservation gains might not succeed. When ecological measures implemented under NNL to achieve biodiversity gains may not be successful (e.g., restoration measures might fail, a reintroduced species might not establish) or other factors might prevent offsets (e.g., commercial viability, changing legislation).	Canada; US	Epistemic
IV	Temporal issues	Multipliers used to manage temporal challenges. When future biodiversity gains may need to be larger than realized current losses in order to account for: • Human time preferences (e.g., incorporate discount rates) • Time lags between impacts and gains • The degree of permanence that can be assured for offsets.	UK	Human decision
V	Inexact NNL trading	Multipliers used by regulators to ensure ecological equivalence when NNL metrics do not. So, when policy is based upon imperfect currencies (e.g., those that are nonreflective of broader biodiversity or functionality), or exchanges based entirely on expert opinion (i.e., rather than purely quantitative measures).	Germany	Linguistic; human decision

Moilanen & Laitila (2016) argue for an additional multiplier to manage leakage (i.e., when "environmentally damaging activity stopped by avoided loss offsetting . . . is not really stopped but relocates elsewhere"). The additional factor would be $= 1/(1 - L)$, where $L =$ the proportion of activities displaced (e.g., leakage of 90% of such activities could necessitate an additional multiplier = 10).

The existing literature on multipliers focuses upon technical considerations, also incorporating time preferences and leakage (social and governance considerations, respectively). All considerations relate to categories proposed by Pilgrim & Ekstrom (2014; Table 1). Multiplier values consequently considered necessary for NNL, in theory, are in the order of unity to hundreds (Laitila *et al.* 2014). More recently, however, Gibbons *et al.* (2015) propose that realized multipliers will likely be ≤10.0 for development projects seeking NNL, due to "operational feasibility." How large, then, are multipliers used in practice?

Multipliers in practice

Methodology

Our approach was simple, yet labor-intensive – we systematically collated all accessible information on multipliers used in practice. An assumption was that NNL projects are primarily enabled through three policy types: (1) government policies; (2) project cofinance; and (3) corporate commitments. We explored all NNL guidelines arising from these policies, and projects implemented accordingly. The following resources were used: (1) a global policy database (Maron *et al.* 2016); (2) key lenders requiring NNL (ICMM & IUCN 2012); and (3) corporate NNL-type commitments (Rainey *et al.* 2014). Every country, organization, and corporation mentioned in these resources was within scope, and no information could be found on multipliers for those not included in the Results.

Information sources

The literature on each NNL policy was searched (Google, Google Scholar) for papers reporting multipliers specified in guidelines or in practice. Search terms were "multiplier" and "ratio," combined with "biodiversity offset," "biodiversity compensation," "compensatory mitigation," and "NNL."

For Australia Capital Territory and New South Wales (Australia), data on the area of development and accompanying offsets were obtained with the relevant multipliers not specified. We calculated the effective multiplier in each state as the mean offset:development ratio by area for all projects, reporting the standard deviation. Although good practice NNL requires compound metrics, e.g., combining area and habitat condition (Quétier & Lavorel 2012), this simplification provides the best multiplier estimate given available data. The multiplier was similarly calculated for three individual projects where explicit values were not found (San Francisco-Mocoa Road, Ambatovy, Etileno Petrochemical), and this limitation should be considered when interpreting the results.

Where no online information was available regarding known policies or projects, experts were contacted for clarification ("experts" being researchers publishing related literature, or practitioners developing projects), and listed in Figure S1. Details on specific sources for all reported data are included in Figure S1.

Information collected

We primarily sought numerical values for multipliers specified by any policy or project. Beyond this, to understand comparability, we subcategorized multipliers. First, we divided multipliers into "proposed" (specified, but not implemented in practice) and "realized" (implemented). Second, we categorized multipliers specified by national policy, and by individual development projects. Finally, we categorized multipliers based upon motivation for use (Table 1). In addition, we considered whether multipliers have changed in magnitude over time. Multipliers were dated to the year in which enabling regulations were put in place, the necessary policy interpretation published, or project details published.

Results

Absolute size

Quigley & Harper (2006; Canadian Fish Habitat) found that multipliers required by regulators were 6.8:1 and realized multipliers were 1.5:1, or 1.2:1 and 0.8:1 (in-channel and riparian habitat, respectively). Matthews & Endress (2008; US Wetlands, Illinois) found that proposed multipliers were 1.55, and realized multipliers 1.1 (22 of 37 projects studied). Pickett *et al.* (2013) report a multiplier of 19 at the Sydney Olympic Park. Some information on proposed multipliers is available through public policy documentation and gray literature. No online data sets explicitly quantify multipliers used on projects (Figure S1). Few multiplier values are obtainable for offsets implemented through cofinance agreements or corporate commitments.

The majority of proposed multipliers are >1.0 but <10.0 (Table 2; Figure 1), the maximum is 90 (certain UK habitats; Defra 2011). Realized multipliers are generally at the lower end of the range proposed by policy. There is little difference in absolute magnitude between multipliers proposed through policies or projects (Figure 1). The largest realized multiplier for an individual project = 30.0 (Shaw's Pass, South Africa; Jenner & Balmforth 2015). Some countries with NNL policies do not specifically require multipliers, in which case we assume the multiplier realized in practice by developers = 1.0 (Table 2). This assumption could skew the results downward – however, national studies available for New Zealand and Sweden show the assumption to be valid (i.e., an effective multiplier ~1.0 was implemented when none was specified in policy; Persson 2013; Brown *et al.* 2014). Where policy noted the need for multipliers but values were left to expert opinion, the multiplier could not be assumed to be = 1.0 (Germany).

Comparability

Since multipliers are employed to address different NNL challenges, those collected here are not directly comparable (Tables 1 and 2). Most can be classified under more than one motivational category (Table 2), although South Africa exemplifies category I, and proposed multipliers in the United Kingdom explicitly reflect categories II–IV. Our aim was not to compare multipliers directly, but rather capture absolute multiplier values used, and discuss drivers. Nonetheless, the fact that multipliers are often motivated by more than one driver, and so may be incomparable, deserves attention.

Multipliers through time

We plotted absolute size of proposed multipliers against the year in which the associated policy or project began, finding no statistically significant trend. While the lower bound of proposed multipliers remained constant at ~1.0, the upper bound of proposed multipliers trended slightly upward (Figure 2a). The scientific literature on appropriate design of offsets has grown substantially since the early 2000s (Calvet *et al.* 2015), reflected in more detailed multiplier requirements under recent offset policies

Table 2 multipliers proposed and realized as part of offsetting under NNL policies and projects

Category	Country (Region)	Multiplier *Proposed*	Multiplier *Realized*	Source	Category (see Table 1)	Year
Required by policies or guidelines at a regional or national level	Australia (Australian Capital Territory)	1.0–10.0	2.9 ± 1.2	ACT (2015)	I–III	2007
	Australia (Victoria)	1.0–2.0	–	DSE (2002)	I–III	2002
	Australia (Queensland)	1.0–10.0	–	NELA (2014)	I–III	2008
	Australia Koala Habitat (Queensland)	>5.0	–	Ecosystem Marketplace (2010)	I–III	2006
	Australia (South Australia)	1.0–10.0	<10.0	Gibbons *et al.* (2015)	I–III	2003
	Australia (West Australia)	1.0–10.0	2.8 ± 5.6	WA (2015)	I–III	2006
	Brazil	1.0	1.0–4.0	Villarroya *et al.* (2014); Sonter *et al.* (2014)	–	1965
	Canada (In-channel HADD)	6.8	1.5	Quigley & Harper (2006)	I, II	1986
	Canada (Riparian HADD)	1.2	0.8	Quigley & Harper (2006)	I, II	1986
	Canada (South East Alberta Pilot)	3.0–5.0	–	Noga (2014)	II, V	2013
	Canada (British Columbia)	–	0.78	Carter *et al.* (2012)	I, II	2012
	China	>1.0	–	Ecosystem Marketplace (2010)	–	2002
	Columbia	1.0	–	Villarroya *et al.* (2014)	–	1994
	Denmark	1.0	–	Expert (Figure S1)	–	1979
	France	1.0-5.0	–	Morandeau & Vilaysack (2012)	I, III	2007
	Germany	*Not specified*	*Expert opinion*	Darbi & Tausch (2010)	V	1976
	Mexico	1.0	–	Villarroya *et al.* (2014)	–	1989
	New Zealand	1.0	*Not measured*	Brown *et al.* (2014)	–	1987
	Peru	1.0; 3.0–5.0	–	Villarroya *et al.* (2014); Pilla (2014)	–; ?	2013
	South Africa	5.0–30.0	0.5–30.0	Laitila *et al.* (2014); Expert (Figure S1)	I	2007
	Sweden	1.0	1.0	Persson (2013)	–	1995
	UK Biodiversity Offset Pilot	1.2–90.0	–	Defra (2011)	II–IV	2012
	US (Wetland Banking)	1.0–10.0	–	Laitila *et al.* (2014)	II–IV	1983
	US (Wetland Banking, Illinois only)	1.55	1.1	Matthews & Endress (2008)	II–IV	1983
Category	**Country (Project)**	**Multiplier *proposed***	**Multiplier *realized***	**Source**	**Category (see Table 1)**	**Year**
Specific development projects subject to NNL policy	Australia (Sydney Olympic Park)	0.7–19.3	19.0	Pickett *et al.* (2013)	III, IV, V	2009
	Australia (Whitehaven Coal Mine)	4.46–8.50	–	Gibbons *et al.* (2015)	I–III	2010
	Canada (Trans Mountain Legacy Fund)	1.0	*Not measured*	Bull & Sandom (2016)	–	2004
	Canada (Pipestone Creek Habitat Bank)	–	10.0	Hunt *et al.* (2011)	?	1986
	Columbia (San Francisco-Mocoa road)	–	1.65	Vicetini *et al.* (2009)	?	2009
	France (CNM Railway)	1.0	–	Aiama *et al.* (2015)	–	2007
	France (Bay of Brest)	4.0	–	Laitila *et al.* (2014)	II, III	2007
	Guyana (Guyana Goldfields)	–	2.4	Expert (Figure S1)	I, II	2013
	Madagascar (Ambatovy)	1.2–3.5	–	von Hase *et al.* (2014)	?	2012
	Madagascar (QMM)	2.0–4.0	–	Temple *et al.* (2012)	II, IV	2012
	Mexico (Etileno Petrochemical)	0.22	–	Braskem-Idesa (2011)	?	2011
	Mongolia (Oyu Tolgoi)	0.3–4.0	–	TBC & FFI (2012) [v]	II, IV	2012
	South Africa (Shaw's Pass)	–	30.0	Jenner & Balmforth (2015)	I	2007
	Sweden (Umeå Railway)	>1.0	–	Project documentation	–	1995
	Switzerland (Dry Grasslands)	1.5–8.0	–	Laitila *et al.* (2014)	II	1979
	UK (Streatham Common, Thameslink)	1.2–90.0	2.0	Baker (2013)	II–IV	2012

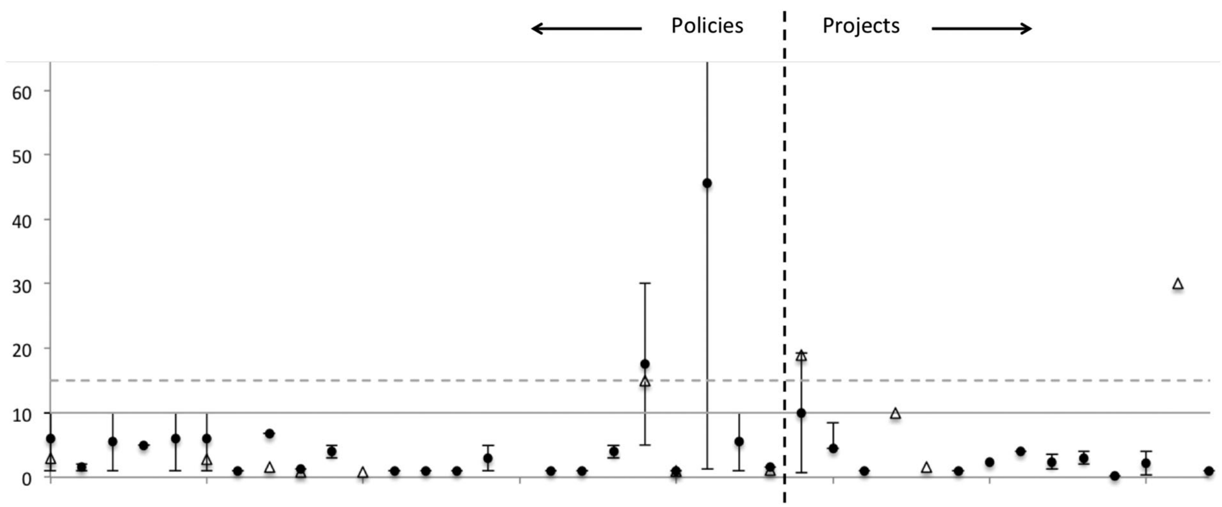

Figure 1 Magnitude of proposed and realized multipliers (*y*-axis), for a set of policies and projects. Black dots = proposed multipliers, where error bars represent possible range. Triangles = realized multipliers. Solid gray line = maximum multiplier that is operationally feasible (10) according to Gibbons *et al.* (2015). Dashed gray line = approximate minimum multiplier (15) according to Laitila *et al.* (2014), for a 30-year restoration lag and a 10% discount rate (see Overton *et al.* 2012).

(e.g., United Kingdom) and projects (e.g., Oyu Tolgoi). Even if our analysis of multiplier values through time shows no significant increase as of yet, we consider it likely that multiplier values will increase in the future as research findings are built into NNL projects and policies.

All categories (I–V) have motivated multiplier use since the 1980s (Figure 2b). We have insufficient data to show whether trends exist in these categories over time, but the data do show that all previously categorized drivers for using multipliers have existed for as long as modern NNL policies themselves.

Discussion of data analyses

The paucity of information on implemented multipliers suggests they are often not reported, or used at all. For some policies – Australia, Canada, South Africa, the United States – both proposed and realized multiplier estimates exist. These four cases are loosely comparable, being based upon numerous sites arising from regulatory policy. For these mature NNL policies, realized multipliers are smaller than policymakers propose, but generally >1.0. Regarding these four policies and some others (Germany, New Zealand, Sweden), certain considerations associated with multipliers are satisfied through different elements of NNL policy. So, Australia has a defensible metric, while Canada, South Africa and the United States require flexible but robust quantification of losses and gains (see category V). Australia, Germany, and South Africa require consideration of landscape context, and/or proximity between development and offsets – partly addressing broader objectives (category I). Germany and the United States enable habitat banking, realizing gains in advance of losses – partially removing the need to account for restoration failure or time lags (categories III, IV). Conversely, UK policy suggests multipliers to account for numerous considerations (categories II–IV).

Regarding projects – Ambatovy, QMM, and Oyu Tolgoi all belong to the global mining group Rio Tinto, which has a "Net Positive Impact" corporate policy (Rainey *et al.* 2014), and are arguably comparable. All three projects use detailed metrics and counterfactuals, obviating the need for related multipliers. The Whitehaven Coal Mine, Guyana Goldfields, and Etileno Petrochemical projects are similar (i.e., large extractive projects seeking "NNL or better") – all propose effective multipliers <10.0. The projects implemented in Australia, Canada, France, South Africa, Sweden, and the United Kingdom are associated with the NNL policies for those same countries listed in Table 2, so links exist between policy and project multipliers reported here. Information is publically accessible for these specific projects, suggesting ecological compensation is perhaps more extensive than on average for such projects. Sydney Olympic Park is the only project subjected to peer-reviewed analysis following implementation.

Gaps in multiplier design

Our analyses suggest that realized multipliers are motivated by various drivers (Tables 1 and 2), but are not large enough to meet theoretical requirements (Figure 1).

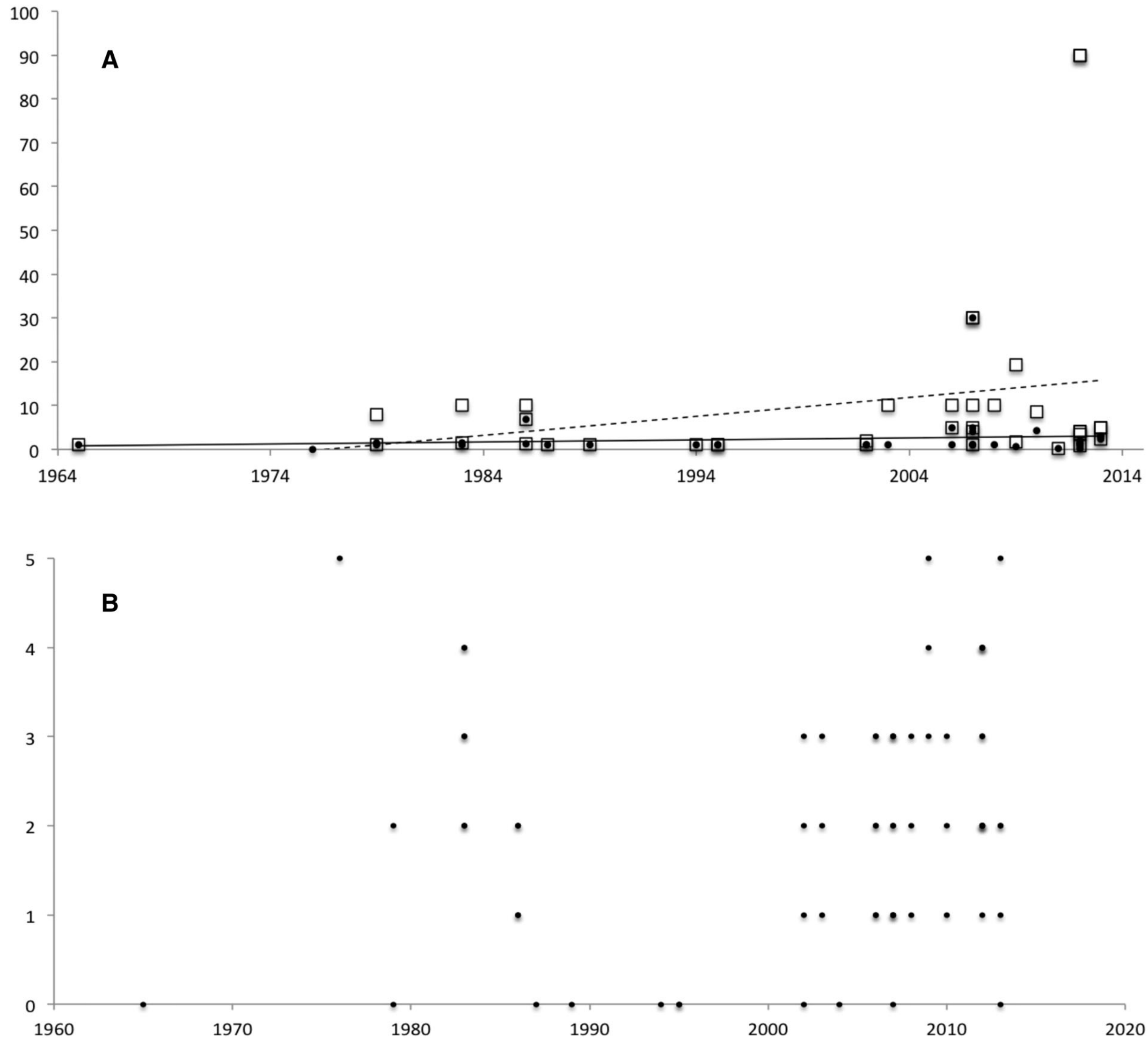

Figure 2 (A) Size of proposed multiplier against the year in which the relevant policy was developed. Black dots = lower bound of proposed multiplier (with solid line of linear best fit, $R^2 > 0.1$), squares = upper bound of proposed multiplier (with dashed line of linear best fit $R^2 \sim 0.1$). Where there is a single number specified, the upper and lower bounds are the same. (B) Category of multiplier represented over time, in both policies and projects. Categories I–V = as discussed in the main text (see Table 1), category 0 = no category specified.

Next, we consider whether additional gaps remain, in theory, for appropriately sizing multipliers. Since technical considerations have been covered in detail (Moilanen *et al.* 2009; Overton *et al.* 2012; Pickett *et al.* 2013; Laitila *et al.* 2014), this section is structured around the other categories proposed by Maron *et al.* (2016): social, ethical, and governance considerations. To emphasize, our intention is to highlight remaining gaps in the theoretical specification of multipliers, so technical multipliers already proposed in the literature for ecological reasons would need to be *combined* with those we propose below in seeking NNL.

Social considerations

In this subsection, we constrain our discussion to basic in-kind exchanges of losses and gains in NNL biodiversity trades. There are multiple possible categories of flexibility in NNL trades that constitute out-of-kind exchanges (Bull *et al.* 2015), which would bring in additional social considerations (e.g., changes in biodiversity tenure), which we have insufficient space to consider here.

Multipliers account for time preferences (category IV; Table 1), but not the degree to which people demonstrate bounded rationality in decision-making. Kahneman & Tversky (1979) provide a now established model for decision-making under uncertainty (prospect theory). Experiments revealed that people tend to be risk-averse, weighting losses higher than gains. Furthermore, people tend to underweight probable outcomes in comparison with certain outcomes, and put almost no weight on low probability outcomes. Note, risk and time preferences are intertwined (Andersen *et al.* 2008; Andreoni & Sprenger 2012) – the present is known, while the future is inherently risky. This is problematic when studying time preferences, since uncontrolled risk can generate behaviour biased toward the present (Andreoni & Sprenger 2012). Joint elicitation of risk and time preferences provides estimates of discount rates significantly lower than normal (Andersen *et al.* 2008).

Human risk aversion is relevant to biodiversity conservation (Hummel *et al.* 2009), especially where stakeholders are expected to accept losses of existing biodiversity in return for gains elsewhere. Not only do people place greater weight on losses as they are more certain – losses also naturally "loom larger." Consequently, an NNL multiplier incorporating prospect theory is justifiable. Hypothetical calculations based upon arbitrary parameter values for illustration (Figure S2), suggest a multiplier in the order of tens could reasonably be required to overcome human risk aversion, which has not previously been considered in NNL policy (Table 3). The assertion that prospect theory generates multipliers in the order of tens could partly explain the magnitude of realized multipliers (Table 2; Figure 1), or why multipliers <10.0 reflect "operational feasibility" (Gibbons *et al.* 2015). But if offsets are indeed being widely designed based on social preferences, without incorporating multipliers large enough to account for the academic literature on technical multipliers, then true NNL is likely not being achieved.

Ethical considerations

Ives & Bekessy (2015) explore ethical considerations for NNL, particularly: (1) acceptance of an outcomes-based ethical framework for nature conservation, rather than an actions-based framework like other environmental policies; (2) whether people assign multiple intrinsic values to nature that cannot be traded; and (3) whether NNL policies legitimize biodiversity loss. In this subsection, we do not suggest larger multipliers could resolve ethical concerns over the fundamental validity of NNL policy – rather, we explore whether different ethical framings of NNL trades permit multipliers.

If it is deemed inappropriate to use an outcomes-based framework or impossible to meaningfully exchange intrinsic values – extreme cases of points (1) and (2), respectively – then NNL trades are not ethically acceptable under any circumstances. This situation effectively represents an infinite multiplier, i.e., developers must either avoid all impacts, or not undertake the development. It is unrealistic to expect that *all* development impacts could be avoided, yet preventing *all* development is hardly desirable. Therefore, a more nuanced framework is necessary. One potential approach lies in treating NNL trades using the framework for conservation trade-offs outlined by Daw *et al.* (2015). Those authors explain that values underlying trades are either "sacred" (e.g., human life) or "secular" (e.g., money). Trading secular values is morally acceptable, representing routine trade-offs. Trading between secular and sacred values is morally incommensurable, resulting in "taboo" trade-offs. Trading different sacred values is less morally repugnant and sometimes virtuous, resulting in "tragic" trade-offs. Under NNL, perhaps different stakeholders perceive biodiversity trades associated with development as falling within different categories of trade-off, depending upon the values they themselves assign to biodiversity components, e.g., place-based values, intrinsic values (Figure 3).

From a utilitarian perspective, if nature had no intrinsic value or if only outcomes mattered, NNL trades represent a routine trade-off. Considering nature to have intrinsic value, NNL trades result in a loss of biodiversity in exchange for financial gains – an unacceptable taboo trade-off. Alternatively, some might consider nature to have intrinsic value, but perceive NNL as an acceptance of losses of nature in exchange for: (1) social welfare gains through development, i.e., different sacred values or (2) high-value nature conservation elsewhere – that is, difficult but acceptable tragic trade-offs. Departing from Daw *et al.*, the loss of biodiversity with low conservation value for high conservation value gains (i.e., "trading up") might be seen as trading secular losses for sacred gains, a more acceptable trade-off. NNL trades may affect many stakeholders with differing perspectives on where within this framework the trades sit.

Such a framework (Figure 3) could be used to discuss NNL multipliers alongside ethical considerations. For routine trades, ethical concerns are low, and multipliers can be derived based upon existing technical and social considerations. When secular values are traded up for sacred values, a low multiplier might be considered acceptable. Conversely, a taboo trade may result in the aforementioned infinite multiplier, ensuring sacred values are not exchanged for purely secular values. Finally, a tragic trade would be more complicated – as discussed by Daw *et al.*, the unavoidable loss of one sacred value in exchange for gain in another (e.g., fundamental societal needs provided by development) might be deemed ethically acceptable. Then, the form of such trades would depend on societal "willingness to accept" (WTA) losses for

Table 3 summary from this review of all potential types of driver for specifying additional multipliers in NNL trades, including the potential order of magnitude of those multipliers, and examples of alternatives to using those multipliers

Consideration	Category (Table 1)	Rationale	Description	Order of magnitude	Example alternative to using multipliers
Technical	II	Poor information or predictive power	See Table 1	$\sim 10^0 - 10^2$	More measurement, monitoring and research
Technical	III	Risk of failure	See Table 1	n/a	Diversification of compensation strategies
Technical	V	Imperfect exchange currencies	See Table 1	n/a	Better technical design, more research
Social	I	Broader biodiversity objectives	See Table 1	$\sim 10^1$	Complementary policies
Social	IV	Temporal issues	See Table 1	$\sim 10^0 - 10^2$	Biodiversity banking
Social	–	Prospect theory	Human risk aversion	$\sim 10^1$ [a]	Biodiversity banking
Ethical	–	Trade-offs	Routine trade-offs	=1	n/a
Ethical	–	Trade-offs	Taboo trade-offs ("trading down")	$=\infty$	Avoidance of impacts
Ethical	–	Trade-offs	Taboo trade-offs ("trading up")	=1	Avoidance of impacts (and forgone conservation benefit)
Ethical	–	Trade-offs	Tragic trade-offs	>1 (proportional to WTA/WTP)	Avoidance of impacts
Ethical	–	Utilitarianism	Removing ethical barriers to environmental destruction	n/a	[None – challenges the very validity of NNL policies]
Governance	–	Agency problems	Power imbalance	$\sim 10^0 - 10^2$ (Dictator Game)	Independent assessment; public scrutiny
Governance	–	Trust fund models	Lack of transparency; poor accounting	n/a	Independent assessment; public scrutiny; accounting systems
Governance	–	Monitoring and evaluation	Insufficient resources, political will, or guidelines	n/a	Independent assessment; public scrutiny; better guidelines for monitoring outcomes
Governance	–	Leakage	Spatial displacement of development activity	$\sim 10^1$	Diversification of compensation strategies

[a]Hypothetical (see Figure S.2).

gains. Any such assessment of trading losses and gains in biodiversity value would relate to reference points, like trades under normative economics: the WTA compensation for, in this case, environmental degradation; and, the willingness to pay (WTP) for improving environmental conditions or avoiding degradation (Pearce & Moran 1994; Tilman 2000). Tragic NNL trade-offs can be framed as a public WTA biodiversity loss, with compensation determined by developer WTP. WTA is asymmetric with WTP, so an additional multiplier potentially arises from the ratio of the two, increasing when substitution possibilities are smaller (Hanemann 1991; Shogren *et al.* 1994; Table 3).

The third ethical issue raised by Ives & Bekessy (2015) is whether the framing of NNL policies could make biodiversity loss more legitimate. A key concern here would be whether requiring lower multipliers sends a signal to stakeholders that biodiversity is more expendable, and the opposite for higher multipliers – until the multiplier is very high or infinite, at which point the signal is that any biodiversity loss is unacceptable. This valid concern must be taken into account when designing minimum multipliers for NNL.

Governance considerations

Governance considerations have been discussed at length in NNL literature. Challenges include: asymmetric access to information; uneven sharing of risks between developers and other parties (Salzman & Ruhl 2000); conservation interests not overcoming political motivations to relax environmental safeguards; market mechanisms being vulnerable to institutional dynamics (Walker *et al.* 2009); NNL policies having short lifespans (Bull *et al.* 2013); lack of will or resources to evaluate NNL projects (Brown *et al.* 2014); perverse incentives to reduce conservation volunteerism (Gordon *et al.* 2015); leakage (Moilanen & Laitila 2016); lack of compliance; overestimation of gains; and, cost-shifting (Maron *et al.* 2016). Our data corroborate concerns regarding lack of transparency, monitoring, and

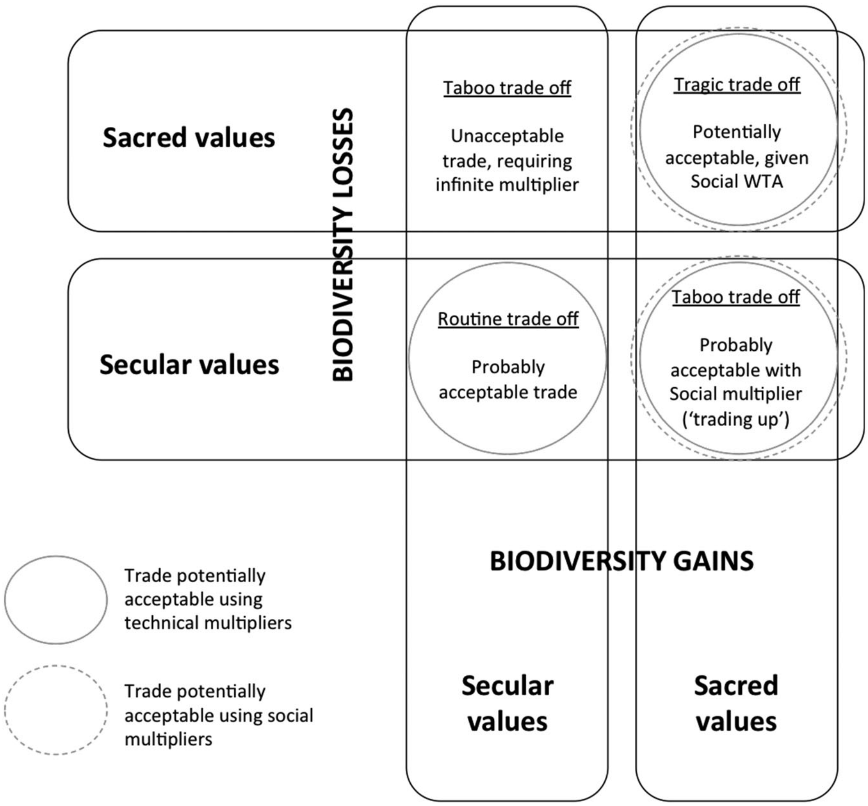

Figure 3 Different ethical perspectives on NNL trades, depending upon whether losses and gains are seen as secular or sacred. Framework modified from Daw *et al.* (2015).

evaluation of NNL – given the paucity of information available on multiplier use (Table 2) – a broader problem for NNL policies (Bull *et al.* 2013).

Overcoming governance challenges could involve increased independent assessment, public scrutiny, and more concrete guidelines for implementation (Walker *et al.* 2009; Maron *et al.* 2016; Table 3). But no governance considerations have been incorporated into multipliers, except perhaps leakage (Moilanen & Laitila 2016). Since weak governance would likely be associated with a high chance of offset failure, simply increasing multipliers would not ensure NNL, as for category III drivers (Table 1; Pilgrim & Ekstrom 2014). In such cases, again, diversification is a more appropriate strategy for reducing risk. However, a multiplier could feasibly be used to address any power imbalance between development and conservation interests.

To explain, implementing NNL in practice involves negotiation between parties: landowners, developers, conservation agencies, local government. The Dictator Game captures behaviour in such negotiations – an established experiment in which party A (the "dictator") is given money to distribute between itself and party B. Party B has no power over A, although A experiences social pressure. Research shows A gives on average 28.35 % of the money to B – more than might be expected given B's lack of power, but less than the 50% which might be deemed "fair" (Engel 2011). This game is analogous to a developer implementing a biodiversity offset, the size of which is to be determined through negotiation with conservationists. If the developer holds greater negotiation power and could therefore be treated as the "dictator," they may be able to negotiate down the compensation required by NNL policy (from 100% of necessary compensation, to as low a value as conservationists accept). Such an effect would be consistent with our multiplier data, i.e., realized multipliers are lower than proposed multipliers, and at the low end of the spectrum proposed by policy (Table 2). So, the proportional power differential between different parties involved in negotiating an NNL trade, derived via the Dictator Game, could feasibly be used to calculate an additional multiplier for compensation requirements, assuming that compensation measures would eventually be negotiated down to the amount required for true NNL (Table 3). Understanding the negotiation process for real NNL trades (through theory such as the Dictator Game) is an important topic in its own right, and relatively unexplored.

Policy recommendations

It is clear from the literature that multipliers are a necessary consideration for meaningful NNL trades. We have shown that multipliers required to achieve NNL could be larger than previously thought – by building upon the existing technical literature and incorporating important social, ethical, and governance considerations. But our data analyses also show that multipliers are often not explicitly specified in NNL policy, or by individual projects, and that those implemented are generally substantially smaller than theory dictates. Consequently, there is an implementation gap between the theory and practice of multipliers implemented through NNL policy.

A prerequisite for making detailed policy recommendations is better understanding of why this implementation gap exists. It is necessary to establish whether, for instance: project developers do not implement larger multipliers due to practical constraints; or, whether they choose methods other than multipliers; or whether those designing NNL measures are not sufficiently empowered to ensure robust measures are put in place; or whether the theory of NNL simply has to "catch up" with the practice (NNL policies have existed for ∼40 years, but the first detailed article on multiplier design was published recently; Moilanen *et al.* 2009). Further research is necessary to provide clarity, particularly in relation to the compensation negotiation process.

In the absence of evidence to explain the implementation gap between theory and practice of multipliers, we recommend that: first, every NNL policy should incorporate detailed guidelines on multiplier design and use. Second, policymakers should endeavor to incorporate theoretical research on NNL into policy, requiring developers to implement much larger multipliers than is currently the norm. This could be supported through institutional safeguards that protect against power imbalances during negotiations. However, it would be insufficient for policymakers to stop there, as multipliers may be insufficient in isolation to secure NNL. So, policymakers should also offer developers guidelines on additional, complementary approaches they can take to meeting the NNL requirements otherwise covered by multipliers – some of which we capture in Table 3. For instance, a multiplier in the order of tens might be implemented to manage ecological uncertainties, alongside: biodiversity banking that delivers gains in advance of losses (instead of temporal multipliers); increased investment in avoidance of impacts (reducing predicted losses and therefore necessary multiplier size); additional compensation measures (i.e., using diversification to account for possible restoration failure, rather than multipliers); and opening biodiversity compensation calculations up to public scrutiny (to reassure stakeholders that, e.g., governance-related multipliers are unnecessary).

In this way, gaps between multiplier values suggested by theory and those realized in practice could be accounted for. That is not to say developers should be enabled to avoid implementing large multipliers – rather, that alternative options (such as those mentioned in Table 3) must be implemented to manage any of the challenges reviewed in this article that are not managed through a multiplier. The signal is not that small multipliers are acceptable – rather, that true NNL necessitates large multipliers, to the extent that project proponents must likely also find accompanying alternative measures. We recognize that the latter assertion is contingent on ensuring developers demonstrably and transparently implement the necessary measures alongside multipliers in achieving NNL. That brings us to the final requirement: policy must encapsulate the need for reporting on the design and implementation of multipliers, enabling maintenance of transparent records of NNL accounting for all projects. The need for transparent regional, national, and international databases containing details concerning the implementation of NNL policy has been highlighted in the literature (Bull *et al.* 2013), but has yet to be met.

But again, we emphasize that more definitive recommendations will only be possible once further research is completed into this topic. That research is required to examine *why* multipliers are consistently low in practice (Table 2). In turn, this would enable us to determine whether requiring higher multipliers from NNL projects is overly optimistic or even unrealistic, and whether not requiring higher multipliers would send the wrong signal to developers. In summary, does the implementation gap we have identified arise from gaps in the theory or the practice of NNL? If the latter, we may need higher multipliers (raising the bar in practice so as to meet theoretical requirements) – if the former, we may need to focus upon implementing additional mitigation strategies as well as simply increasing the size of multipliers. Both are potential routes to achieving true NNL, but we recognize that determining which is the most appropriate is at least partly a political decision, and therefore beyond the remit of conservation science.

On a final note, biodiversity trades under NNL policy should be better framed in relation to ethical considerations. Some can reconcilably be incorporated into NNL calculations, others cannot. We recommend that, for any project, biodiversity losses and gains are categorized as "secular" or "sacred" values (or similar) based upon stakeholder consultation. Doing so would not be overly complicated for developers, as it is not too dissimilar from existing approaches to Environmental and Social Impact Assessment, which often lays the groundwork for NNL strategies. Furthermore, there is an incentive for developers to understand stakeholder perceptions, as these greatly influence the amount of resistance a project might receive – see, for instance, the Trans-Mountain Pipeline (Bull & Sandom 2016). Under such categories, NNL trades can be modified based on consideration of taboo trade-offs and public WTA losses (Figure 3; Table 3). Ultimately, social and ethical considerations are likely just as important to successful implementation of NNL policy as technical considerations, if not more so.

Acknowledgments

J.W.B. is funded by a Marie Skłodowska-Curie Action under the Horizon 2020 call H2020-MSCA-IF-2014 (grant number 655497). J.W.B. and N.S. acknowledge the Danish National Research Foundation for funding for the Center for Macroecology, Evolution and Climate (grant number DNRF96). We thank all experts consulted and named in the Supporting Information for their advice on specific biodiversity offset schemes. We would also like to acknowledge extensive and useful comments from three anonymous reviewers.

Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Figure S1: Illustrating the utility function of gains and losses assuming the scale loss-aversion coefficient is 2.25 and the utility of gains and losses are $U(x)^{0.5}$ and $-\mu U(x)^{0.5}$, respectively.

Figure S2: NNL multiplier (λ) estimated for various levels of loss and loss-aversion scenarios. It is assumed that $\alpha = 0.5$, and $\alpha \leq \beta$. When $\alpha < \beta$, it indicates that loss aversion increases disproportional to gains and that the multiplier increases with losses.

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