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ABSTRACT

Loss of habitats or ecosystems arising from development projects (e.g. infrastructure, resource extraction, urban expansion) are frequently addressed through biodiversity offsetting. As currently implemented, offsetting typically requires an outcome of 'no net loss' of biodiversity, but only relative to a baseline trajectory of biodiversity decline. This type of 'relative' no net loss entrenches ongoing biodiversity loss, and is misaligned with biodiversity targets that require 'absolute' no net loss or 'net gain'. Here, we review the limitations of biodiversity offsetting, and in response, propose a new framework for compensating for biodiversity losses from development in a way that is aligned explicitly with jurisdictional biodiversity targets. In the framework, targets for particular biodiversity features are achieved via one of three pathways: Net Gain, No Net Loss, or (rarely) Managed Net Loss. We outline how to set the type ('Maintenance' or 'Improvement') and amount of ecological compensation that is appropriate for proportionately contributing to the achievement of different targets. This framework advances ecological compensation beyond a reactive, ad-hoc response, to ensuring alignment between actions addressing residual biodiversity losses and achievement of overarching targets for biodiversity conservation.

INTRODUCTION

The 196 Parties to the Convention on Biological Diversity (CBD) are currently setting ambitious post-2020 biodiversity targets (Mace et al., 2018; Visconti et al., 2019). Yet, despite widespread recognition of the need to slow and ultimately halt biodiversity loss, transformation of the natural world for infrastructure, industry, commercial agriculture, urbanisation and resource extraction (hereafter, 'development') continues to drive declines (IPBES, 2019). Ceasing all such transformation is not feasible in the face of desirable development imperatives (Griggs et al., 2013; United Nations, 2018). Governments, developers and civil society therefore need tools for reconciling development and conservation to reduce the rate of biodiversity loss.

The mitigation hierarchy is an approach for responding to biodiversity losses arising from development. It has been embedded into numerous government, lender and corporate policies (BBOP, 2012; Gardner et al., 2013; IFC, 2012; IUCN, 2018a; Rainey et al., 2014). Proponents of development projects—where these are mandated by policy ('regulated sectors')—are required to reduce adverse biodiversity outcomes through sequentially following four steps. Only after completing avoidance, and then restoration/rehabilitation of disturbed areas onsite, should the fourth step be taken – compensating for any residual losses through biodiversity offsetting. When applied as the final step of the mitigation hierarchy, biodiversity offsets are typically intended to achieve an outcome in which there is (at least) 'no net loss' of the impacted biodiversity due to a particular project (BBOP, 2012; Bull, Gordon, Watson, & Maron, 2016; IUCN, 2016).

Biodiversity offsetting, however, is almost never designed to align with the achievement of national or sub-national ('jurisdictional') biodiversity targets that aim to halt species and ecosystem decline, or achieve biodiversity recovery. In large part, this is because no net loss of biodiversity at the level of individual development projects can mean something quite different to no net loss at the jurisdictional level (Maron, Brownlie, et al., 2018). When framed in relation to a jurisdictional biodiversity target, no net loss implies that the amount of a particular biodiversity feature (e.g.

forest) should not fall below what we have now; in other words, it means no net loss relative to a 'fixed reference scenario' (Maron, Brownlie, et al., 2018). Under such a scenario, any lost forest (for example) would need to be replaced to achieve absolute no net loss – that is, to maintain the amount of forest at its current level (Figure 1).

This is rarely the intended meaning of no net loss in offset policies which guide compensation for residual losses at the *development project level*, not the jurisdictional level. Project-level no net loss is often framed relative to a counterfactual scenario of decline, in which biodiversity is expected to be lost even without the development (and its offset) (Maron, Bull, Evans, & Gordon, 2015; IUCN, 2016). The rationale is that the protection provided by the offset action achieves a benefit by averting a loss or decline that would otherwise have occurred. Such 'averted loss' offsetting (also called avoided loss or protection offsetting) is one of the two main forms of biodiversity offsetting (the other being restoration). It is referenced as a key approach to offsetting in policies and standards espoused by financial institutions (IFC, 2012; World Bank Group, 2016), multistakeholder platforms (BBOP, 2012; IUCN, 2016) and jurisdictions (Australia, Columbia and Chile (Maron, Brownlie et al., 2018)). In a global review of over 12,000 individual offsets projects, Bull and Strange (2018) found that approximately 66% used averted loss offsetting, either exclusively, or in combination with other measures.

When framed this way, even best-practice offsets result in less biodiversity over time, as protection of already-existing biodiversity, which is expected to decline in the future, can be exchanged for biodiversity losses at the development site(s) (Bekessy et al., 2010; Buschke, Brownlie, & Manuel, 2017; Maron, Brownlie, et al., 2018; Moilanen & Laitila, 2016). Across multiple projects, offsetting that achieves no net loss relative to a counterfactual scenario of biodiversity decline maintains the declining trend, and corresponds with a net loss at the jurisdictional level (Figure 1) (Gibbons & Lindenmayer, 2007; Quétier, van Teeffelen, Pilgrim, von Hase, & ten Kate, 2015).

<**Figure 1**>

Relative no net loss of biodiversity at the project level does not equate with the achievement of absolute no net loss at the jurisdictional level. This mismatch causes conceptual confusion and ambiguity about the meaning and intention of no net loss as a policy objective. It also makes it hard to assess the contribution that project-level compensatory actions (e.g. biodiversity offsetting) are making to broader conservation goals, such as the achievement of jurisdictional biodiversity targets (Maron, Brownlie, et al., 2018). We are aware of only one national policy that links compensatory actions to the achievement of a target (limiting ecosystem loss to pre-defined thresholds) – South Africa's Draft National Biodiversity Offset Policy (Republic of South Africa, 2017). If offsetting continues to occur in isolation from broader conservation imperatives, the risk is that at best, offsetting will contribute minimally to conservation objectives, and at worst, will detract from achieving such goals (e.g. where counterfactual-based approaches entrench ongoing declines (Maron, Brownlie et al., 2018)). An overarching framework is therefore needed to align project-level actions under the mitigation hierarchy, particularly of ecological compensation for residual losses, with the biodiversity targets that a jurisdiction may strive to achieve.

Here, we propose such a framework, and review its suitability in applied conservation policy. We refer throughout to 'ecological compensation' to distinguish our proposed approach as an alternative to the narrower concept of biodiversity offsetting, which has strict rules about like-for-like trades in biodiversity and aims to achieve at least no net loss relative to a counterfactual scenario (BBOP, 2012; Bull et al., 2016; IUCN, 2016). We discuss the consequences of different approaches to ecological compensation, and provide guidance on how, where and when the framework we present could be operationalised. This framework entails several advantages over current practice. First, it makes explicit the contribution of ecological compensation towards meeting jurisdictional biodiversity targets. Second, it avoids the need for complex (and highly uncertain) calculations of the counterfactual scenario. Third, it strengthens the focus on avoidance, because it explicitly identifies instances where biodiversity losses require proportionate increases through actions like restoration, which will not always be a feasible option. Fourth, it provides conceptual clarity; the net outcome across impact and compensation sites for a particular project would align with the desired net outcome at the jurisdictional level.

Jurisdictional-level biodiversity targets

The framework we propose is general, and can apply to any biodiversity targets that describe a desired state of biodiversity ('outcome-based targets') at any jurisdictional scale. Target-setting is not a part of the framework, but the existence of quantifiable targets is a pre-requisite for its implementation. Indeed, the targets that we refer to in this framework should be set independently of, and have primacy over, policy relating to the mitigation hierarchy and compensation. This is to prevent targets being designed to facilitate a particular policy approach.

Biodiversity targets are a familiar concept. Under the CBD Strategic Plan for Biodiversity 2010-2020 (UN CBD, 2010), more than 160 Parties to the CBD already have targets for biodiversity conservation laid out in their National Biodiversity Strategy and Action Plans (a response to the 20 global Aichi Targets agreed in 2010) (UNEP, 2019). However, these are often not outcomes-based targets (IUCN, 2018b) – a reflection of the fact that the Aichi Targets themselves are predominantly non-quantifiable, and lack focus on desired outcomes (Barnes, Glew, Wyborn, & Craigie, 2018; Butchart, Di Marco, & Watson, 2016).

As Parties to the CBD negotiate the post-2020 global biodiversity framework, there are increasing calls for clear, quantifiable science-based targets for the retention and recovery of biodiversity and nature (Dinerstein et al., 2019; Mace et al., 2018; Maron, Simmonds, & Watson, 2018; Visconti et al., 2019; Watson & Venter, 2017). Such targets should be incorporated in national plans and actions, and linked to the achievement of broader global goals (IUCN, 2018b; Mace et al., 2018). Plentiful guidance on target-setting is available (Butchart et al., 2016; Carwardine, Klein, Wilson, Pressey, & Possingham, 2009; Di Marco, Watson, Venter, & Possingham, 2016; Doherty et al., 2018; Maron, Simmonds, et al., 2018; Maxwell et al., 2015; Watson & Venter, 2017). The framework we present requires that targets are measurable, and explicitly reflect the desired state (outcome) of the biodiversity feature (e.g. species population, ecosystem extent) on which the target focusses, rather than a desired rate of change, or a mechanism for achieving the target. Examples of such targets that already exist include the French Government's pledge to support and maintain a population of 500 wolves for the years 2018 to 2023 (Republique Francaise, 2018), and ecosystem-specific retention thresholds that are incorporated into South Africa's Draft National Offset Policy (Brownlie et al., 2017 (see Supporting Information 1)).

RESULTS

Aligning ecological compensation with biodiversity targets

In this framework, targeted conservation outcomes such as desired species populations or minimum ecosystem extents are set in absolute terms at the jurisdictional level. The required trajectory needed to achieve a target for a particular species, assemblage or ecosystem (hereafter, 'biodiversity feature') depends on the level (e.g. number, amount, area) of the biodiversity feature when the jurisdictional-level target for that biodiversity feature was set (Figure 2).

<**Figure 2**>

When a biodiversity feature is approximately at the target level ongoing 'No Net Loss' is required. All losses of the biodiversity feature need to be balanced by proportionate gains in order to maintain the biodiversity feature at the target level. It follows that when a biodiversity feature is below the target level, 'Net Gain' is needed to achieve the target, whereby the biodiversity feature increases in absolute terms to (at least) the point where the target is met. 'Managed Net Loss' may be appropriate in exceptional circumstances when a biodiversity feature is above its target. Setting a target below current levels might require that: (1) the particular biodiversity feature is very common and widespread; (2) some losses at the jurisdictional level can occur without compromising the ecological integrity and function of the feature (e.g. population viability, intactness); and (3) continued, strictly managed drawdown to a pre-determined target level is socially acceptable.

Once a jurisdiction has established targets, and thus specified the required trajectory for its biodiversity features, project-level actions under the mitigation hierarchy can be designed to contribute to achieving these targets. The approach to compensating for residual losses at the project level depends upon several factors. The *type* of compensatory action depends on whether achievement of the jurisdictional biodiversity target requires Net Gain, No Net Loss, or occasionally in specific situations allows for Managed Net Loss. The *amount* of compensation required for any given project is guided by the amount of residual loss, how much of the affected biodiversity feature remains relative to its particular target, and policy decisions regarding the share of responsibility among sectors. Below, we set out each consideration.

Achieving jurisdictional outcomes – Improvement, Maintenance and Avoidance

There are two broad types of ecological compensation in this framework: Maintenance and Improvement. By 'Maintenance' we mean preventing a threat to ensure persistence of a biodiversity feature at its *current* condition, extent or population (and conservation status), for example by legally securing existing biodiversity at a compensation site. The aim of Maintenance is to prevent existing biodiversity from being lost at a site in the future (i.e. avert future losses). The net result of Maintenance interventions across a jurisdiction is a reduction in the biodiversity feature, because the loss from development is compensated for by securing the persistence of the biodiversity feature at another site(s), where it already exists.

This contrasts with 'Improvement', which involves producing a quantifiable *increase* in the biodiversity feature. Improvement can take a range of forms, and result from a variety of interventions such as habitat enhancement (e.g. improving condition of native vegetation) or removal of pervasive pressures to allow populations to increase (e.g. invasive species control). In reality, the interventions that achieve Maintenance and Improvement at a site can overlap—legally securing a site and managing it at a moderate intensity might preserve that site's condition (Maintenance), but if management intensity is increased it might achieve Improvement; similarly, legal protection of a degraded site might over time allow its recovery (Improvement). Generally, Improvement will require complementary Maintenance as a necessary prerequisite (e.g. securing a site containing the focal biodiversity feature or its habitat, with a view to improving it).

Enhancing biodiversity, including via Improvement compensation actions, is ultimately essential for achieving jurisdictional-level No Net Loss or Net Gain—only by increasing the extent and/or condition or amount of a biodiversity feature can No Net Loss (or Net Gain) be achieved under this framework (Figure 3a and 3b). When carefully linked to biodiversity targets, Maintenance can be used to contribute to Managed Net Loss, until such time that the target is reached, after which Improvement becomes an essential response to any permitted losses (Figure 3c). Further, while Maintenance alone cannot achieve No Net Loss or Net Gain at the jurisdictional level, it may be a necessary transitional intervention to ultimately achieving these outcomes in the common situation where a biodiversity feature is (1) below its target; and (2) experiencing rapid and ongoing loss from unregulated pressures, where the mitigation hierarchy is not fully applied. In these circumstances, compensation through Maintenance may be appropriate for a transitional period alongside or in advance of compensation through Improvement (Figure 3d). However, for such an approach to be a step towards a No Net Loss or Net Gain, transition phases with strict limits must be set (see Supporting Information 1).

<**Figure 3**>

Because this framework explicitly links ecological compensation requirements with jurisdictional-level target outcomes, it strengthens the focus on rigorously applying the earlier steps of the mitigation hierarchy. Jurisdictional No Net Loss or Net Gain cannot occur without losses being compensated by Improvement actions such as restoration or increases in species' populations. However, for some biodiversity features, achieving such gains through actions like restoration is either hampered by great uncertainty, or is simply not possible (given, for example, substantial time lags) (Curran, Hellweg, & Beck, 2014; Gibbons et al., 2016; Maron et al., 2012; Moilanen, van Teeffelen, Ben-Haim, & Ferrier, 2009; Pilgrim et al., 2013). This reality limits considerably the types of biodiversity features for which No Net Loss or Net Gain are feasible. Losses of irreplaceable biodiversity features simply cannot be managed though a compensation approach, unless the jurisdictional target involves Managed Net Loss. If an outcome of further (managed net) loss is unacceptable, the only option is more rigorously to apply the earlier steps in the mitigation hierarchy, and avoid losses entirely.

The amount of compensation required for a given loss

This target-based framework no longer depends upon the complex and often counterintuitive process of defining dynamic counterfactual scenarios to establish what type of action, and how much, is required to compensate for a given loss (as offsetting does). This is because instead of a dynamic counterfactual scenario, a reference point fixed at a particular level—the target—is used. The *amount* of compensation required for any given project is determined by both how much residual loss a particular biodiversity feature experiences as a result of a development project, and the pathway (e.g. No Net Loss) required to achieve a target, along with several additional considerations (outlined below) that are factored into the calculation of a compensation ratio. The compensation ratios (sometimes called a ‘multiplier’) detailed here only need to be established once—at the inception of a compensation scheme—and should be applied consistently to all projects.

The compensation ratio sets the amount of Improvement or Maintenance required per unit of residual loss to contribute to the achievement of a target, as depicted in Figure 3. The first step in calculating the compensation ratio is to estimate how much of the affected biodiversity feature (x) exists relative to its target (at time $t = 0$, when the target, B, was set). The current amount of x comprises two parts: how much of what exists is already considered *effectively* protected from adverse impacts (e.g., fully resourced protected areas) or planned to be so protected ($x_p(0)$); and how much of what exists could still conceivably be lost (including because of development projects) ($x_a(0)$). Places identified as being under effective protection (x_p) are not available to be used for compensation.

Where No Net Loss or Net Gain is needed to achieve a target, the amount of compensation (gain via Improvement) required for a given unit of loss to a particular biodiversity feature is:

[Equation 1]

$$\boldsymbol{Compensation\,ratio\;(Improvement)} = \frac{\left(\boldsymbol{B - x_p(0)}\right)}{\boldsymbol{x_a(0)}}$$

Where Managed Net Loss is appropriate, the amount of compensation (securing existing biodiversity via Maintenance) required for a given unit of loss to a particular biodiversity feature is:

[Equation 2]

$$\boldsymbol{Compensation\,ratio\;(Maintenance)} = \left(\frac{\boldsymbol{B - x_p(0)}}{\boldsymbol{x(0) - B}}\right)$$

For the transitional approach (Figure 3d), Equation 2 is used to set Maintenance requirements to ensure that an interim target (threshold) of B_I is not breached, before switching to Improvement using Equation 1 to achieve the desired target. More details on calculating the Improvement and Maintenance compensation ratios (including for transitional approach) are provided in Supporting Information 1 and Supporting Information 2.

To exemplify these ratios, compensation for a project-level loss of 100 ha of habitat, consistent with Net Gain linked to a target of doubling the currently-available habitat for a species, requires an Improvement ratio of 2:1. This is based on assumptions that none of the biodiversity feature is currently protected, and all adverse impacts to this biodiversity feature are regulated (i.e. follow the mitigation hierarchy). Here, a ratio 2:1 requires that 200 ha of 'new' equivalent habitat must be successfully created (and maintained) to compensate for the loss. Similarly, Managed Net Loss in which 90% of a remaining ecosystem is to be retained would require a Maintenance ratio of 9:1, wherein nine times the area of residual loss is secured and retained into the future. Again, this assumes no current protection of the ecosystem, and no unregulated losses. If, say, half the remaining ecosystem was already effectively protected, the ratio would be 4:1.

These compensation ratios can vary with policy settings. For example, the ratios presented above are based on a proportionate contribution towards the achievement of the target. In other words, a unit of loss caused by a regulated sector requires the same amount of compensation as would a unit of unregulated loss (the liability for which accrues, in effect, to the jurisdictional government) in order to progress toward the target. However, in some instances a jurisdiction may require sectors that are regulated to contribute disproportionately towards a target's achievement. For example, the jurisdiction may require that some sectors make additional contributions towards a biodiversity target, beyond just compensating for their own impacts. Alternatively, the government may shoulder some of the responsibility for compensation to limit the requirements on certain sectors. Government decisions about proportionate or disproportionate responsibility and policy scope (which sectors or type of impact are regulated) can affect both compensation ratios for regulated sectors *and* the amount of responsibility that falls on governments to address losses that are contrary to the required trajectory needed to achieve target commitments. Therefore, they must be made and factored in at the point of policy development when ratios are calculated (i.e. prior to the policy's implementation) (Supporting Information 2). This allows for transparency and clarity about which actor must do what action, how much of it, and why, to compensate for residual impacts in line with meeting desired targets.

Time lags in and uncertainty about achievement of compensatory outcomes are also often dealt with by adjusting ratios. These factors can be incorporated in this approach by increasing the ratios as appropriate (Bull, Lloyd, & Strange, 2017; Laitila, Moilanen, & Pouzols, 2014; Moilanen & Kotiaho, 2018). This particularly applies to Improvement, where the unadjusted ratio assumes full and certain compensation instantly. The compensation ratio for Improvement thus gives the *minimum* compensation required for a particular unit of loss (to contribute to achievement of the target), and would need to be increased accordingly to account for time lags and uncertainties (e.g. restoration not being fully successful (Maron et al., 2012; Moilanen et al., 2009)).

Contrast with counterfactual-based offsetting

Both target-based ecological compensation, as described in this framework, and counterfactual-based offsetting, require strict adherence to the mitigation hierarchy, quantification of residual losses, and determination of compensatory requirements for these losses. The fundamental difference lies in *how* the compensation required for a particular biodiversity feature is calculated—now based on the overall jurisdictional biodiversity target and on policy choices for how to achieve it, rather than a project-specific assessment underpinned by complex counterfactual scenarios. This, and other differences, are summarised in Table 1. We note that some jurisdictions may lack the enabling environment to (1) develop and implement compensatory policy; and (2) determine and enact either targets for biodiversity conservation, or mechanisms for their achievement. In circumstances such as these, counterfactual-based offsetting may be more appropriate, although this should be considered a temporary solution given its inherent propensity for the uncapped drawdown of biodiversity. As long as appropriate, scientifically-robust biodiversity targets can be set, we propose that a move toward a target-based approach is desirable.

<**Table 1**>

DISCUSSION

While in its totality, target-based ecological compensation represents a novel alternative to the prevailing biodiversity offsetting paradigm, its component parts are familiar, with most aspects of existing standards remaining applicable (BBOP, 2012; Gardner et al., 2013; Gelcich, Vargas, Carreras, Castilla, & Donlan, 2017; IUCN, 2016). A target-based system involves changes only to the final step of the well-established mitigation hierarchy, primarily relating to the sizing of compensatory requirements. The on-ground actions (improving or maintaining biodiversity in a particular place) are no different to those in current offsetting practice, and are subject to the same challenges that affect these, and indeed most, applied conservation activities. Biodiversity targets are already central in international and jurisdictional policy. Target-based ecological compensation simply helps to connect project-level responses to these broad biodiversity targets to achieve desirable outcomes for stakeholders and biodiversity. It should be implemented synergistically with other conservation and sustainable development considerations – trading up, landscape-level planning, and impacts to people (see Supporting Information 3).

A shift to the approach we propose carries risks. First, changing existing regulations, which (currently) promote averted loss offsetting, may result in sub-optimal biodiversity outcomes if the biggest gains (in the short-term) can be made by protecting highly-threatened biodiversity from unmanaged pressures. Our framework deals with this by incorporating a 'phased approach' (see above; Supporting Information 1). Second, having outcomes-based targets places a level of accountability on those who set the target, and those who are required to contribute to its achievement. This may encourage the setting of 'easy' or unambitious targets, which may lead to small compensatory requirements. This underscores the need for science-based targets that are established independently of the design of the compensatory scheme. As long as such targets exist, the simplicity of calculating compensatory requirements and the transparency of the contribution this makes to a specific goal, lends itself to higher certainty for all stakeholders, and more straightforward regulatory monitoring and compliance auditing.

Operationalising target-based ecological compensation can draw on lessons from other policy frameworks. For example, REDD+ is a mechanism under the UNFCCC where local forest protection contributes to achieving broader goals (carbon emissions targets). Challenges have been identified regarding multi-level governance, relating to accounting (e.g. carbon crediting, incentives) and implementation (e.g. decision-making) (Cortez et al., 2010; Ravikumar et al., 2015). This has prompted the development of implementation frameworks (e.g. 'nested' approach proposed by Cortez et al. 2010), from which a key lesson is that the achievement of national targets is reliant on actors operating at multiple scales, thus necessitating protocols for their engagement, including in decision-making and benefit sharing. In light of the REDD+ experience, coordination among actors, and especially those undertaking projects 'on the ground', to contribute to the achievement of jurisdictional biodiversity targets, will be crucial for successful implementation of target-based ecological compensation.

In Brazil, requirements for the protection of a minimum proportion of native vegetation on private properties (legal reserves under the 'Forest Code') aim to help achieve bioregional vegetation retention targets. Brazil's overall approach has the benefit of transparency in desired outcomes, with mechanisms designed explicitly to achieve it (Metzger et al., 2019). However, criticism of its restrictiveness for business and landholders have led to relaxations of its requirements over time (e.g. amnesty for illegal deforestation on small properties (Soares-Filho et al., 2014)), and even calls for it to be extinguished (Metzger et al. 2019)). This underscores the risk of implementing any environmental regulation that is reliant on contributions from industry and private individuals to achieve a broader public-good goal (e.g. explicit environmental targets).

A target-based ecological compensation approach would be most effective when developed as a coordinated jurisdictional policy, with both jurisdictional net outcomes set and Improvement/Maintenance compensation ratios calculated at the outset. The main enabling conditions (or conversely, barriers to implementation, where these conditions are lacking) for embedding the approach at the jurisdictional level include basic information on the extent/amount and condition of the biodiversity features that would be the focus of the policy, including how much is considered to be already effectively protected, and regulatory control of at least some sectors that cause biodiversity loss. Taken together, these would allow for the calculation of compensation ratios and identification of valid locations for compensation. Once this (non-trivial) work is done, the project-level process of identifying suitable ecological compensation would be greatly simplified.

In addition to government policy, most multilateral finance institutions reference 'no net loss' and even 'net gain' requirements in relation to escalating biodiversity risks. For example, IFC Performance Standard 6 requires no net loss where feasible in natural habitats, while net gain is required for critical habitats (IFC, 2012). The simplified ratio-based protocol that is embedded in the target-based approach could facilitate investment by these institutions, and, represents a desirable objective for those multilateral finance institutions with mandates to engage the public sector on policy reform to facilitate sustainable development.

Regardless of whether embedded in government policy or industry/corporate standards, this framework does not imply that proponents of development projects are expected to bear the entire burden of a jurisdiction achieving its particular biodiversity targets, nor that compensation alone be used to achieve targets. Indeed, the share that falls on developers is a policy decision for governments (See Results; Supporting Information 2). Fundamentally, it offers a systematic approach to determining project-level compensation that is *consistent with the achievement* of jurisdictional biodiversity targets. The more comprehensive the policy's scope—that is, the more sectors that are regulated and required to compensate for losses to biodiversity arising from their activities—the greater the contribution of proponents of development to meeting a jurisdiction's biodiversity targets.

However, it will rarely, if ever, be the case that a compensatory policy is broad enough in scope to capture all processes that result in the loss of biodiversity. This means that actors other than proponents of development projects (e.g. governments) will need to address losses to biodiversity that are beyond the scope of compensatory policy—the unregulated losses—in combination with a wide suite of other complementary conservation actions that are implemented to contribute to meeting targets. This ecological compensation framework involves setting out clearly the expectation for both proponents of development and jurisdictional authorities as this relates to how to address losses of biodiversity, whereby compensatory actions *alongside other conservation investment* can contribute to achieving biodiversity targets.

Ecological compensation should always be an option of last resort. In instances where the biodiversity features that are exposed to residual project losses are imperilled and irreplaceable—in other words, they cannot be feasibly improved or recreated—ecological compensation is not acceptable, and losses must be avoided altogether. Where residual losses *can* be reasonably addressed through compensatory interventions, this target-based framework provides a pathway towards more transparent and effective outcomes. It explicitly links compensatory actions to broader biodiversity targets, and clarifies and simplifies the expectations on and requirements of developers. In this regard, it represents a step towards the coordinated planning and integrated actions that will be crucial to stem and reverse biodiversity losses in the face of ongoing development pressures.

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AUTHOR CONTRIBUTIONS

This framework was developed in a working group led by M.M. and J.E.M.W. All authors contributed to the development of the framework. J.S.S. led the writing of the manuscript, and all authors contributed to its preparation, and approved the final version for submission.

Table 1. Comparison between counterfactual-based offsetting and target-based ecological compensation.

	Advantages	Risks and challenges
Counterfactual-based offsetting (aiming for no net loss relative to a counterfactual scenario)	• Can be implemented in the absence of any articulated conservation targets • Increases the attention on the difference made by a conservation intervention • Can be implemented for individual projects in poorly-regulated settings • Main concepts and approaches familiar to many practitioners / policy makers	• Outcomes are relative to a dynamic counterfactual trajectory that cannot be known in advance, only estimated • Biodiversity decline continues even though a project may achieve no net loss relative to a declining counterfactual • Constructing robust counterfactuals is conceptually complex and can be data-hungry • The type and amount of offset action required is highly sensitive to assumptions about the counterfactual trajectory • The end point of the biodiversity trajectory is implicit or unknown • Relatively easy to manipulate the counterfactual and thus undermine the net outcome
Target-based ecological compensation (aiming for net jurisdictional outcomes aligned with	• Aligns outcomes of actions regulated by compensatory policy with overarching conservation objectives	• Requires articulation of conservation targets, potentially creating incentive to 'set bar low' to facilitate 'business as usual' compensatory policy (not advocated by this framework)

specific biodiversity targets)	• Outcomes are explicit and relative to a fixed, known point in time • ‘No Net Loss’, ‘Net Gain’ and ‘Managed Net Loss’ have intuitive meanings • Standardises calculation of the type and amount of compensation required • Complex, dynamic counterfactual scenarios are not required	• Requires estimate of the difference between the target state and current state of impacted biodiversity features • When targets are at odds with actions occurring or planned outside the scope of the compensatory policy, target-based actions can be suboptimal • Target-based ecological compensation is a relatively new concept (although similar approaches exist in some jurisdictions) and will take adjustment

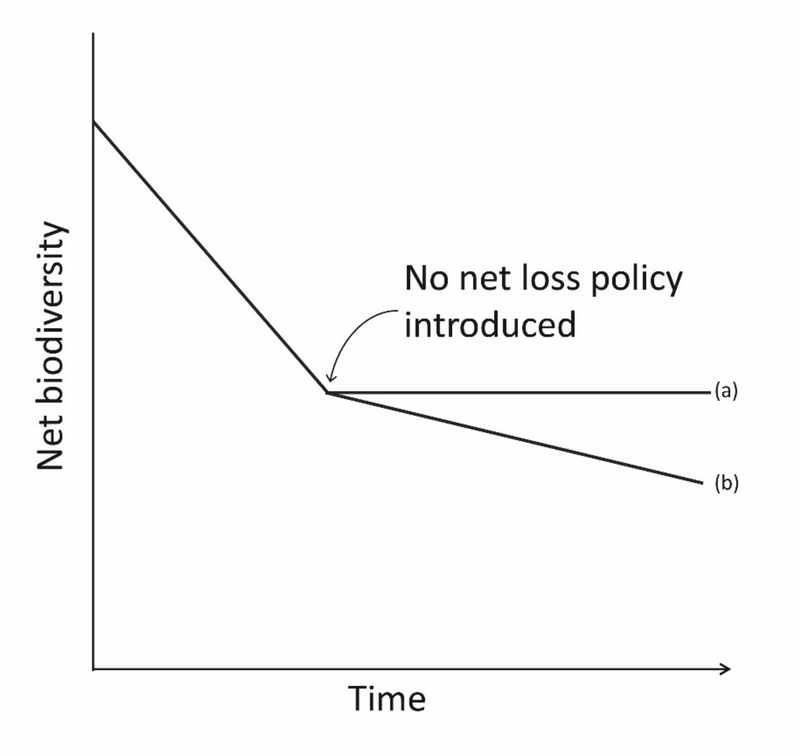

Figure 1. ‘No net loss’ relating to different reference scenarios. No net loss at the jurisdictional level implies that loss is stopped in absolute terms compared to a fixed reference scenario – i.e. that all biodiversity losses are addressed by gains of the same size, thus maintaining biodiversity at the same level compared to before the loss occurred (a). However, in reality, no net loss commitments frequently only require that individual projects achieve no net loss relative to a declining counterfactual, by protecting biodiversity that might otherwise be lost in the future due to unregulated impacts (‘averted loss’) (b). Such project-level no net loss results in ongoing loss of biodiversity at the jurisdictional level, albeit at a slower rate (figure adapted from Maron, Brownlie, et al. (2018)).

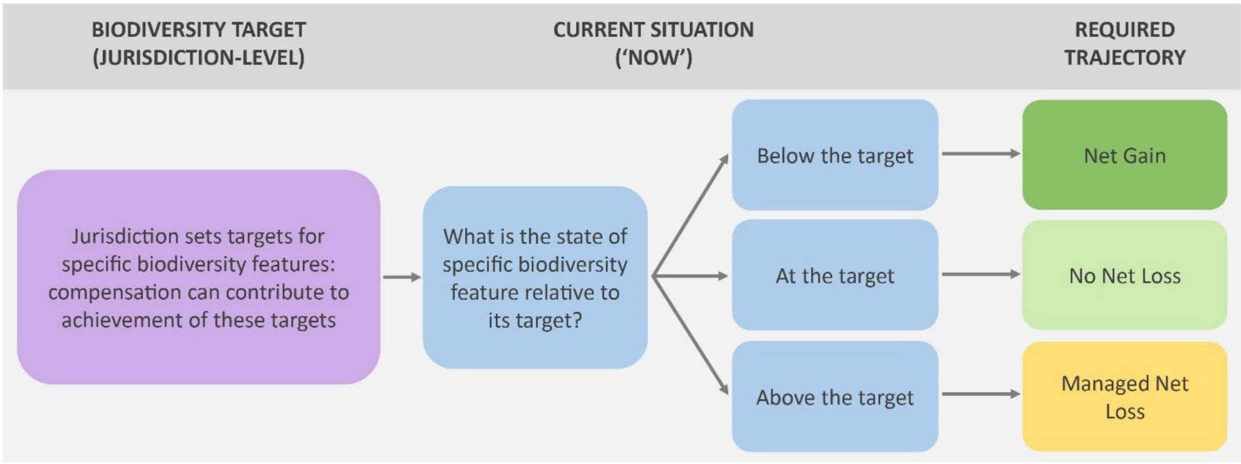

Figure 2. Aligning ecological compensation with jurisdictional biodiversity targets starts with establishing the trajectory required to achieve net target outcomes. The required trajectory depends on whether a biodiversity feature is below, at, or above its jurisdictional biodiversity target at the time the target is set ('now').

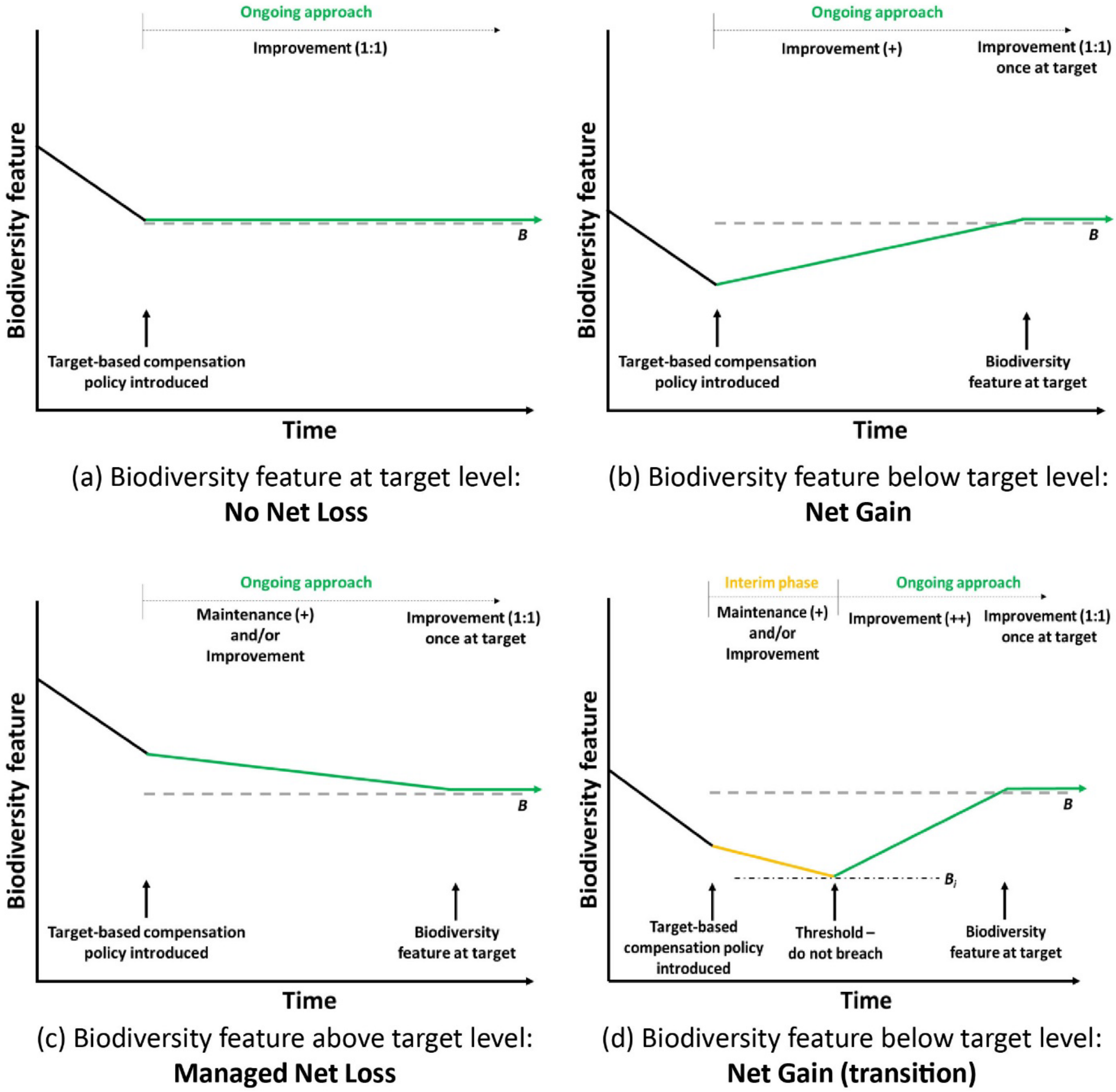

Figure 3. Illustration of the target-based ecological compensation approach for contributing to the achievement of a) No Net Loss; b) Net Gain; c) Managed Net Loss; and d) Net Gain using a transitional approach in which Maintenance actions can be undertaken for a period of time to help stem unregulated losses, before Improvement actions become the default requirement. The dashed line on each plot represents the target level (*B*) for the biodiversity feature. The indicative amount of Improvement and/or Maintenance (denoted by '+') depends on the difference between the level of the biodiversity feature and the target (and in the case of the transitional approach (d)), the threshold (B_i) below which the biodiversity feature cannot decline) (see Supporting Information 1).

Importantly, compensation for residual losses from development is one of a suite of complementary measures to achieve the desired trajectory and ultimately achieve a target. At such time that the target is met, maintaining the biodiversity feature at this level requires losses to be compensated for by Improvement at a ratio of 1:1 (or targets could be revised towards ambitious new objectives).

Moving from biodiversity offsets to a target-based approach for ecological compensation

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Supporting Information 1

Calculating the compensation ratios in target-based ecological compensation

The calculation of an ecological compensation requirement typically factors in a ratio (also called a 'multiplier'). The ratio is a number, usually greater than 1, which tells you how much of a biodiversity feature needs to be replaced/secured per unit of the feature lost. These ratios, in the past, have taken into account issues such as time discounting (biodiversity features produced in the future do not fully compensate for biodiversity features produced now), uncertainty, and risk of failure (Bull, Lloyd, & Strange, 2017; Laitila, Moilanen, & Pouzols, 2014; Moilanen, van Teeffelen, Ben-Haim, & Ferrier, 2009).

Here, we present ratios that accommodate the need to meet target values for various biodiversity features in the landscape – for example, a target for the number of breeding individuals of a species might be a minimum of 10000, a target for the area of suitable habitat for a species might be 5000 home ranges or more, a target for the area of a vegetation community in a region might be at least half of its original extent in good condition, which translates to a minimum area and condition score.

The formulae below assume no time lags (e.g. in the case of Improvement, new features are created instantly). Issues such as time lags will modify the ratios in ways already described (Bull et al., 2017; Laitila et al., 2014; Moilanen & Kotiaho, 2018).

Let $x(t)$ be the state of the biodiversity feature at time t where 0 <= $x(t)$ <= 1 for all t. This is made up of two parts, the part that is permanently and effectively protected $x_p(t)$, which are places that are not available for any compensatory related change, and $x_a(t)$ which is the part that could be destroyed or used for compensation at the end of the mitigation hierarchy. Hence the amount of the biodiversity feature is the sum of the protected and available parts: $x_p(t)$ + $x_a(t)$ = $x(t)$ at all times. Further:

Let B be the target state of the biodiversity feature and we assume this is time independent (constant).

The ratios we present below assume that (1) all sectors that cause loss of biodiversity will provide compensation; and (2) that each sector's compensation will be a proportionate contribution to the achievement of the target (i.e. everyone compensates equally for the losses they cause). However, in some instances, not all causes of biodiversity loss will fall within the scope of policy that regulates implementation of the mitigation hierarchy. That is, the loss of biodiversity will be a function of regulated and unregulated losses. At the inception of a target-based ecological compensation policy, a government may choose to adjust compensation requirements (with implications for the calculation of compensation ratios) on sectors regulated by the mitigation hierarchy, in one of several ways:

- Compensation from regulated development is disproportionately low. The government would need to address shortfalls arising from disproportionately low compensation.
- Compensation from regulated development is disproportionately high. A disproportionately large share of achieving the target is placed on regulated sectors.

- The achievement of the target is solely the responsibility of regulated sectors, by way of the compensation they provide for the losses they cause.

Where there are unregulated losses that are going uncompensated, the requirement to address these in a way that is consistent with achieving targets accrues to other actors (e.g. the government).

We provide examples of how these policy choices affect compensation ratios, and what this means for the responsibility that falls on both regulated sectors *and* governments, in an editable spreadsheet in Supplementary Information 2.

Case 1: No Net Loss; the biodiversity feature is at the target ($\boldsymbol{x(0) = B}$)

If there is no unregulated loss of the biodiversity feature, the compensation ratio (Improvement) is 1. This also applies to all cases once targets are met.

If there is unregulated loss of the biodiversity feature, then either:

- the compensation ratio (Improvement) is 1 and the liability accrues to the authority (e.g. government) to create the biodiversity feature to compensate for unregulated loss; or

- the compensation ratio is adjusted (increased) to enhance the share of the responsibility for achieving the target that falls on regulated sectors.

Case 2: Net Gain; the biodiversity feature is below the target ($\boldsymbol{x(0) < B}$)

The compensation ratio (Improvement) needs to be set so that, once (hypothetically) all of the (available for development) biodiversity feature at $t = 0$ ($x_a(0)$) has been lost, we have met the target. Hence the ratio is $(B - x_p(0))/(x(0) - x_p(0)) = (B - x_p(0))/x_a(0)$, which is the inverse of the fraction of the available biodiversity feature that remains relative to the target. In the special case that none of target is effectively protected $x_p(0) = 0$ then this is $B/x_a(0)$.

For example if the target is $B = 1000$, the effectively protected amount is $x_p(0) = 200$, and the current total biodiversity feature state is $x(0) = 600$ (so the available amount of the biodiversity feature is $x_a(0) = 400$) then the compensation ratio (Improvement) is 2 assuming no unregulated losses.

The compensation ratio (Improvement) can be summarised as follows:

$$\boldsymbol{Compensation\, ratio\ (Improvement)} = \left(\frac{\boldsymbol{B - x_P(0)}}{\boldsymbol{x_a(0)}}\right)$$

Case 3: Managed Net Loss; the biodiversity feature is above the target ($\boldsymbol{x(0) > B}$)

If there is no unregulated loss of the biodiversity feature and $x_p(0) > B$, no compensation is necessary because we already have met our target in fully protected areas.

If $x_p(0) < B$, then the compensation ratio (Maintenance) is:

$$\boldsymbol{Compensation\,ratio\;(Maintenance)} = \left(\frac{\boldsymbol{B - x_p(0)}}{\boldsymbol{x(0) - B}}\right)$$

For example if the target is $B = 1000$, the effectively protected amount is $x_p(0) = 200$, and the current total amount of the biodiversity feature is $x(0)$ = 1400, then the compensation ratio (Maintenance) is 2.

If the current state of the biodiversity feature (at $t = 0$) is only marginally above the target (B), then the compensation ratio (Maintenance) will be very large, and may be unfeasibly high to practically implement. For example, should $x(0) = 10000$, and $B = 9900$ (implying a drawdown of 1% of the biodiversity feature to its target), the compensation ratio (Maintenance) will be 99:1 (assuming no unregulated losses, and no current protection). In such circumstances, a mixture of compensation provided using Maintenance only (as described above), and a separate calculation of compensation where Improvement is used according to a different (Managed Net Loss-specific Improvement) ratio calculation of $\left(B - x_p(0)\right)/x(0)$, may be an option – and if effective Improvement is unfeasible for that biodiversity feature, then avoidance is the only way in which the target can be met.

Provided below is an example of a Managed Net Loss protocol - South Africa's Draft National Biodiversity Offset Policy and provincial guidelines.

Box 1. Example of Managed Net Loss: South Africa Draft National Biodiversity Offset Policy and provincial guidelines

This policy is designed to contribute to achieving specific biodiversity targets for terrestrial ecosystems (Brownlie et al., 2017; Buschke et al., 2017). The minimum extent of each ecosystem that must be retained intact (relative to its original or historical extent) has been determined based on a scientific process (Desmet & Cowling, 2004). These ecosystem extent thresholds – in effect, targets – guide compensation requirements. The amount of compensation for residual losses from development depends on how much of the impacted ecosystem remains, relative to its historical extent and target, and how much of it is formally protected.

Where an ecosystem is below its retention threshold or target, development may not occur, other than under exceptional circumstances. For above-target ecosystems, compensation is done by protecting another place where the impacted ecosystem occurs using a Maintenance ratio scaled based on the difference between the current and desired minimum extent of the ecosystem and how much of it is protected. The net outcome in absolute terms is a Managed Net Loss – because the protected biodiversity existed at the time of the loss from the development. This target-based system carefully manages losses to avoid ecosystem extent falling below scientifically-robust thresholds. This policy avoids the 'no net loss' wording – because it is not designed to achieve no net loss.

Case 4: No Net Loss or Net Gain (transition)

A potential limitation of target-based ecological compensation is that desired No Net Loss or Net Gain outcomes (e.g. Figure 3a and Figure 3b in main review article) may not be immediately feasible in a situation of steep, continued, unaddressed and unregulated biodiversity loss. Indeed, a focus solely on Improvement actions like restoration before large-scale biodiversity loss has ceased could even be counterproductive. In such cases, a phased transition designed to ultimately achieve No Net Loss or Net Gain outcomes, that is embedded in the principles of this target-based framework, may be the most appropriate approach (Figure 3d in main review article).

The phased transition would temporarily accept a strictly controlled interim phase in which Maintenance (plus some Improvement, where feasible) interventions first aim to slow the decline of the biodiversity feature that is the focus of the compensation by securing sites where it currently exists (i.e. resembling a Managed Net Loss). Maintenance ratios in this phase would be designed not to achieve the ultimate desired target for that biodiversity feature, but to avoid breaching a pre-defined threshold limit to loss (Figure 3d in main review article). The threshold would need to be set such that enough of the focal biodiversity (extent of ecosystem; population of species) remained to allow for recovery to be feasible. Well before the threshold is reached, the approach transitions to require an Improvement ratio such that the desired No Net Loss or Net Gain outcome can be approached over time as the trajectory of the focal biodiversity feature reverses. As for all jurisdictional No Net Loss and Net Gain outcomes, this is possible only for biodiversity features that can be 'improved', such as through restoration or interventions that drive population increase. Further, the lower the initial threshold, the larger the subsequent Improvement ratio must be to achieve the target.

The phased transition to target-based compensation carries risks, but where a jurisdiction aims to, and can feasibly (in time) achieve a No Net Loss or Net Gain outcome for a particular biodiversity feature, and that same feature is in steep and ongoing decline, the short-term alternatives are few. They include: (1) immediate prevention of all actions causing biodiversity decline; (2) acceptance of less-ambitious biodiversity targets that allow for further drawdown of biodiversity, with compensatory policy designed to achieve an outcome of Managed Net Loss (i.e. capping ongoing losses at a pre-defined level); (3) use of counterfactual-based offsetting alongside unmanaged ongoing net losses; or (4) no compensation for losses at all – in other words unmanaged loss without limit – which poses serious risks for nature and people.

Calculating compensation requirements where the ultimate outcome of No Net Loss or Net Gain is achieved using a transitional approach involves a combination of Cases 2 and 3, as described above. Compensation using Maintenance (Case 3) is used first, to secure existing elements of the biodiversity feature, in the face of ongoing and severe threats. The approach switches to compensation through Improvement (Case 2), *well before* the biodiversity feature reaches a pre-determined threshold below which it is not permitted to decline. Thus, there is the intermediate threshold below which the biodiversity feature cannot decline (B_I) and the ultimate (No Net Loss or Net Gain) target (B).

Critically, determining the intermediate threshold (B_I) should be based primarily on ecological considerations: the threshold would need to be set such that enough of the focal biodiversity (e.g. extent of ecosystem; population of species) remained to allow for recovery to be feasible. However, establishing a compensation ratio (Maintenance) that can be practically implemented is another consideration here.

The following equation allows for comparison of values for the intermediate threshold (B_I), given input of different compensation ratios (Maintenance) (M_m):

$$B_I = (x_p(0) + x(0)M_m)/(1 + M_m)$$

For example, where $x_p(0) = 200$ and $x(0) = 1080$, compensation ratios (Maintenance) (M_m) of 10, 5 and 1 would mean intermediate threshold values (B_I) of 1000, 933 and 640, respectively.

This calculation provides a means by which to select the intermediate threshold (B_I) value that accounts for what can be practically implemented regarding maximum compensation ratios (Maintenance). Importantly, the lower the compensation ratio (and thus, intermediate threshold (B_I) value), the greater amount of compensation (and thus the higher the compensation ratio) will be when the approach switches to Improvement. Again, the primary consideration must always be the ecological attributes of the specific biodiversity feature, and the landscape context in which that feature occurs. In other words, the intermediate threshold (B_I), and the compensation ratio M_m must never be so low as to render recovery of the biodiversity feature, and enhancement through Improvement to achieve the ultimate No Net Loss or Net Gain target (B), unfeasible.

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Supporting Information 3

Conservation planning and sustainable development considerations in target-based ecological compensation

Trading up to higher conservation imperatives

Target-based ecological compensation is well-aligned with other key conservation imperatives and broader sustainable development considerations. For example, in this target-based framework, 'trading up' may be an option in certain circumstances. Trading up, or 'out-of-kind' trading refers to the practice of compensating for the loss of one particular biodiversity feature (at the development site) by benefiting another type of (generally greater conservation value) biodiversity feature elsewhere (Bull, Milner-Gulland, Suttle, & Singh, 2014; Moilanen & Kotiaho, 2018; Quétier & Lavorel, 2011). Compensation for residual losses affecting biodiversity features that are above their target might be directed to other biodiversity features that are below their target. For example, Improvement actions to increase the amount and/or quality of the focal (below-target) biodiversity feature might be preferred over Maintenance actions focussed on the above-target feature. However, this would mean that the development-related losses of the impacted (above-target) biodiversity feature are not compensated, and so this type of 'trading up' would only be appropriate where these losses are carefully managed and strictly limited (e.g. by other regulatory instruments) to ensure that the 'above target' biodiversity feature does not decline below its target.

Landscape level planning

There is a need to move beyond what can be achieved by site-level planning for individual projects to consider development scenarios at a larger scale and assess the integrated opportunities for achieving better economic, social, and environmental outcomes (Kiesecker & Naugle, 2017). Landscape conservation plans designed to guide application of the mitigation hierarchy (Fitzsimons, Heiner, McKenney, Sochi, & Kiesecker, 2014; Kiesecker, Copeland, Pocewicz, & McKenney, 2010) and optimal habitat protection and restoration strategies (Possingham, Bode, & Klein, 2015) are needed to maintain critical levels of habitat amount and configurations and ensure viable conservation outcomes. The establishment of outcome-based biodiversity targets, and linking ecological compensation to the achievement of these targets, lends itself well to supporting broader, strategic development planning of this nature. Further, embedding mitigation decisions into strategic plans that also consider a range of future development scenarios (Evans & Kiesecker, 2014), can benefit governments, businesses and communities by supporting more informed development decisions. Planning at this larger scale also informs strategies for long-term landscape resilience, such as ensuring functional watersheds for clean drinking water (Evans & Kiesecker, 2014) and connected habitat for species (Monteith, Hayes, Kauffman, Copeland, & Sawyer, 2018) – strategic use of target-based ecological compensation, with its explicit and transparent approach to determining compensatory requirements, has the potential to make important contributions to such endeavours.

Impacts on people

It is also crucial to recognise that biodiversity has social value, and so losses and gains in biodiversity resulting from development (and associated efforts to address biodiversity losses through the mitigation hierarchy), will affect people too—both positively and negatively (Bull, Baker, Griffiths, Jones, & Milner-Gulland, 2018; Griffiths, Bull, Baker, & Milner-Gulland, 2019; Sonter et al., 2018). People's use and non-use values associated with biodiversity therefore need to be considered when (1) setting biodiversity conservation targets; and (2) designing and implementing ecological compensation to ensure they are equitable, socially acceptable and sustainable. Because the rationale behind the type and amount of ecological compensation required using the target-based approach can be readily explained and placed in the context of broader objectives (e.g. biodiversity conservation, ecosystem service provision), stakeholder understanding and engagement with the process may be improved by this framework. Considering people in the design of ecological compensation measures is necessary for moral reasons (e.g. human rights and ethical reasons), practical reasons (e.g. gaining a social licence to operate, or because of the need to ensure involvement of local people to enable compensatory actions to be delivered), and policy or regulatory requirements (BBOP, 2009; Bidaud et al., 2018; Bull et al., 2018; IFC, 2012).

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