The role of 'No Net Loss' policies in conserving biodiversity threatened by the global infrastructure boom

Sophus Olav Sven Emil zu Ermgassen[1,*], Pratiwi Utamiputri[2,3], Leon Bennun[3,4], Stephen Edwards[5], Joseph William Bull[1]

[1] Durrell Institute of Conservation and Ecology, School of Anthropology and Conservation, University of Kent, Canterbury, United Kingdom

[2] The Biodiversity Consultancy, WIMO Building, Jl. Kemang I No.7, Kemang, Jakarta, Indonesia

[3] The Biodiversity Consultancy, Cambridge, United Kingdom

[4] Conservation Science Group, Department of Zoology, University of Cambridge, Cambridge, United Kingdom.

[5] International Union for the Conservation of Nature (IUCN), CH-1196 Gland, Switzerland

*corresponding author (sz251@kent.ac.uk)

Emails (in authorship order): sz251@kent.ac.uk; tami.putri@thebiodiversityconsultancy.com; leon.bennun@thebiodiversityconsultancy.com; steve.edwards@iucn.org; J.W.Bull@kent.ac.uk

Summary

Over US$60 trillion is predicted to be spent on new infrastructure globally by 2040. Is it possible to meet UN Sustainable Development Goal 9 (develop infrastructure networks) without sacrificing Goals 14 and 15 (ending biodiversity loss)? We explore the potential role of No Net Loss (NNL) policies in reconciling these SDGs. Assessing country-level overlaps between planned infrastructure expansion, infrastructure-threatened biodiversity, and national biodiversity compensation policies, around half of predicted infrastructure and infrastructure-threatened biodiversity falls within countries with some form of mandatory compensation policy. However, these policies currently have shortcomings, are unlikely to achieve NNL in biodiversity, and could risk doing more harm than good. We summarise policy transformations required for NNL policies to mitigate all infrastructure impacts on biodiversity. To achieve SDGs 9 alongside 14 and 15, capitalising on the global coverage of mandatory compensation policies and rapidly transforming them into robust NNL policies (emphasising impact avoidance) should be an urgent priority.

Keywords

No net loss, biodiversity offsets, infrastructure expansion, environmental impact assessment, Sustainable Development Goals (SDGs), biodiversity compensation, conservation policy

Biodiversity impacts of the global infrastructure boom

The UN Sustainable Development Goals (SDGs) lay out society's ambition to deliver social and economic prosperity for all, while conserving nature on land and sea (SDGs 14 and 15 respectively). However, 'business-as-usual' approaches to solving social and economic development challenges may compromise our ability to achieve the SDGs that are focused on eliminating our impacts on species and ecosystems [1,2]. One of these potential contradictions relates to infrastructure: is it possible to rapidly expand the world's built infrastructural networks (SDG 9) without harming non-human life on Earth (SDGs 14 and 15)? At this key juncture for the future of biodiversity, the development of the post-2020 framework for the Convention for Biological Diversity (CBD), this is a crucial question to consider.

We are currently experiencing the most rapid expansion of built infrastructure in history ('the basic physical and organizational structures and facilities (e.g. buildings, roads, power supplies) needed for the operation of a society or enterprise'; Lexico Dictionaries) with over US$60 trillion of infrastructure spending predicted between 2019-2040 (estimated for 56 countries totalling 88% of global GDP)[3,4]. It is projected that an additional 1.2 million km^2 of land will be urbanised between 2000-2030 (185% increase)[5], and an additional 3-4.7 million km of roads added to the global network by 2050 (22-34% increase)[6]. In a high-profile example, the ongoing Chinese 'Belt and Road Initiative' might be the most ambitious infrastructure drive in history [7]. The programme aims to link 65 countries, representing two-thirds of the global population, in a network of transport and energy infrastructure, spatially overlapping with 1,700 sites with conservation designations[7].

Infrastructural expansion can be an important mechanism for alleviating poverty and delivering economic growth [8,9], but when unaccompanied by strong environmental safeguards it is also a key global driver of biodiversity and ecosystem service loss [10,11]. Major extractive, transport and energy-production infrastructure projects are planned within some of the world's most biodiverse and carbon-rich regions, including the Congo Basin, the Amazon and Borneo [10,12,13]. Infrastructure can impact on biodiversity in multiple ways, including direct habitat loss within the built infrastructure footprint, alteration of ecosystem properties or fragmentation [14,15], and exacerbation of biological resource consumption [10] by facilitating further economic activity (through e.g. improving road access). At global scales, one third (9,053/27,159) of all assessed threatened species (categorised as Critically Endangered, Endangered or Vulnerable; assessed 14/6/19) on the Red List are threatened by infrastructure, including around half of all threatened amphibians and birds (55% and 46% respectively) [16]. Transport, energy, and residential infrastructure are also key contributors to climate breakdown [17,18], another important driver of biodiversity loss. In addition to the considerable biodiversity implications, much planned mining, transport and urban infrastructure is also predicted to impact heavily on areas of global ecosystem service importance [5,17,19], further exacerbating major environmental challenges including climate breakdown.

Regulation of infrastructure impacts on biodiversity

In committing to SDGs 14 and 15, the international community committed to 'sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts', and 'protect and prevent the extinction of threatened species by 2020'. Given infrastructure's role in driving biodiversity loss, it is worth asking: how close are we to achieving this aspiration for infrastructure, and what else could be done? This perspective extends the conceptual framework of a 'global mitigation hierarchy' outlined in Arlidge et al. (2018) [20], focusing specifically on mitigating the biodiversity impacts of infrastructural expansion.

NNL policies are an increasingly influential set of policies that have emerged specifically with this aspiration at their core, to fully mitigate the biodiversity impacts of infrastructure and, in some cases, land use change. First rising to prominence in response to widespread wetland losses in the USA and loss of natural landscape aesthetic in Germany [21,22], idealised NNL policies are based on the principle that biodiversity is as a minimum left no worse off after development than before (Box 1). NNL is commonly operationalised through the application of a mitigation hierarchy to development impacts (e.g. avoid, minimise, restore, offset [23]) and predicated on a strict preference for the first stage (to avoid biodiversity impacts wherever possible). Most commonly implemented through environmental impact assessment (EIA) frameworks, NNL policies considerably strengthen the treatment of biodiversity in traditional EIA. Traditional EIAs aim to assist with decision-making for developments by providing information on the predicted environmental impacts of development and potentially exploring options for mitigating some of these environmental impacts to 'acceptable' levels, but it is uncommon for EIAs to address impacts on biodiversity per se in quantitative terms [24]. In contrast, NNL policies set a clear overall goal for biodiversity, and following the application of the mitigation hierarchy, set out in quantitative terms what actions need to be taken in order for the expected residual losses from the development to be at least matched through compensatory actions including biodiversity offsetting. They explicitly define which aspects of biodiversity are considered priorities and how they are to be measured, and quantitative targets can then be set to assess whether or not these priorities have been achieved [25]. Additionally, if ecological theory determines that NNL in biodiversity cannot be achieved in a given context, NNL policies give a concrete rationale to when projects should not be permitted to go ahead [26,27]. However as explored later, these core principles often fail to be respected in practice, and the quantitative nature of NNL does not free it from the influence of uneven power dynamics or vested interests [28]. Additionally, one of the main ways that principles of NNL are applied around the world is through the creation of biodiversity compensation policies, which often fall far short of the idealised application of NNL outlined above because of a lack of adherence to the mitigation hierarchy[29] (especially avoidance[27]).

Box 1. Key terms

Biodiversity compensation – actions taken to compensate for negative impacts to biodiversity caused by developments, which may include financial compensation for affected stakeholders. Compensatory actions generate gains that are not necessarily quantified, or equivalent in type or magnitude to losses, and as such are more general than 'biodiversity offsetting'.

Biodiversity offsetting – actions taken to compensate fully for the residual impacts of development following the quantitative assessment of biodiversity losses; gains must be of equivalent or greater ecological value to losses. Offsetting is a 'specific and rigorously quantified type of compensation measure' [30].

No Net Loss policy – policy applied at various spatial scales aiming to achieve a minimum of no net loss in biodiversity across all impacts of development. NNL policies are often operationalised in practice through application of the 'mitigation hierarchy'.

Mitigation hierarchy – a framework for mitigating biodiversity losses from development by sequentially avoiding biodiversity impacts wherever possible, minimising impacts where impacts are unavoidable, restoring following the impact if impacts are time-bound, and finally offsetting any residual impacts to biodiversity [31].

Current uptake of biodiversity compensation policies

To assess progress in achieving NNL of biodiversity from new infrastructure, we first explore the global extent of more general biodiversity compensation policies. Whilst much past research on compensation has focused on outcomes at local scales [32–34], the global implications of compensation policies are only just beginning to emerge. For example, taking just the subset of compensation represented by biodiversity offsets, an estimated $153{,}679^{+25{,}013}_{-64{,}223}$ km^2 of biodiversity offsets were (as of 2018) in the process of being implemented to offset infrastructure and land use change impacts globally, which when summed make the area of biodiversity offsets approximately equivalent in size to a country as large as Bangladesh [35]. Recently, the IUCN and collaborators assembled a global database on biodiversity compensation policies, which documents at country-level (covering 197 countries accounting for 98% of global GDP) the degree to which compensation policies (including but not restricted to offsets) are referenced and embedded into overarching national environmental or EIA legislation (Box 2). This database details that compensation policies including offsetting policies are significantly more widespread than previously reported [36]: 37 countries representing 72% of global GDP represented in the database have mandatory compensation policies for at least certain infrastructure sectors or habitat types (Figure 1(A)), with a further 64 countries providing guidance on compensatory measures or enabling offsets as voluntary practice ('precursor policies'). Despite widespread criticism of offsetting policies [37,38], this global policy adoption indicates that compensation policies could have an important role to play in minimising the biodiversity impacts of the ongoing global infrastructure boom [39].

Box 2. The Global Inventory of Biodiversity Offset Policies

The Global Inventory of Biodiversity Offset Policies (GIBOP) is an open-access global database summarising the degree to which biodiversity compensation policies (including offsetting policies) and the mitigation hierarchy are embedded within national environmental policy frameworks. The database was assembled through an analysis of 197 countries' national environmental or EIA legislation, allocating each country a score representing the 'strength' of biodiversity compensation legislation. Whilst this score was allocated using a standardised process across each country, there remains an unavoidable interpretive element. Scores are defined as:

0) no mention of compensation;

1) countries at an early stage of policy development (minimal regulatory provisions on offset or compensation);

2) countries enabling the use of voluntary offsets (scheme acknowledged in regulatory framework);

3) countries requiring mandatory biodiversity compensation in at least some circumstances.

More information about methods and limitations can be found at https://portals.iucn.org/offsetpolicy/.

Worldwide, the dominant infrastructural threats to biodiversity are residential and commercial development, followed by mining and extraction and then other infrastructure types (linear infrastructure and energy production; Figure 1(B)). According to the Global Infrastructure Hub, US$46 trillion of infrastructure investment by 2040 (74% of predicted infrastructure investment for the 56 countries in the database) is predicted to occur in countries with mandatory compensation policies for at least some infrastructure classes or habitat types (Figure 1(C)) [3,4,29]. These countries are associated with an estimated 568,000 km^2 in additional urban areas (2000-2030; 47% of global total[5]) and over 1.5 million km of new roads (by 2050; 42% of global total[6]). Consequently, around half of the world's new infrastructure up to 2040 can be expected to fall within countries with some existing form of mandatory compensation policy, and this is likely to increase as adoption of compensatory policies including biodiversity offsetting continues to spread globally. If all countries currently enabling (but not requiring) the use of various forms of biodiversity compensation as part of their impact mitigation strategies (n=64) moved to mandatory policies, this coverage would increase considerably (e.g. an additional 35% of projected global road expansion would fall within these countries).

Beyond being applicable in countries in which around half of the world's projected infrastructure will be constructed, compensation policies also cover a sizeable proportion of the world's biodiversity features threatened by infrastructure. We assessed the spatial overlap between infrastructure-threatened bird species extant ranges (N=593, Red List accessed 14/6/19) and regions under different compensation policy strengths (Box 2), using birds to minimise assessment biases between species [40]. The mean percentage of each species' range falling in countries with mandatory compensation policies is 47%, and a further 25% falls under 'precursor' policies (Figure 1(D)). We note here that we are simply describing broad spatial overlaps, and not speculating about causal relationships between biodiversity and compensation policy adoption. Additionally, at the national scale the particular infrastructure impacts threatening these species may not fall under the jurisdiction of current compensation policies (e.g. if the impacts are generated by an industry which is not regulated). Nevertheless, this high-level coverage of threatened biodiversity demonstrates that compensation policies are likely to play a key role at the global scale in the conservation of biodiversity threatened by infrastructure expansion.

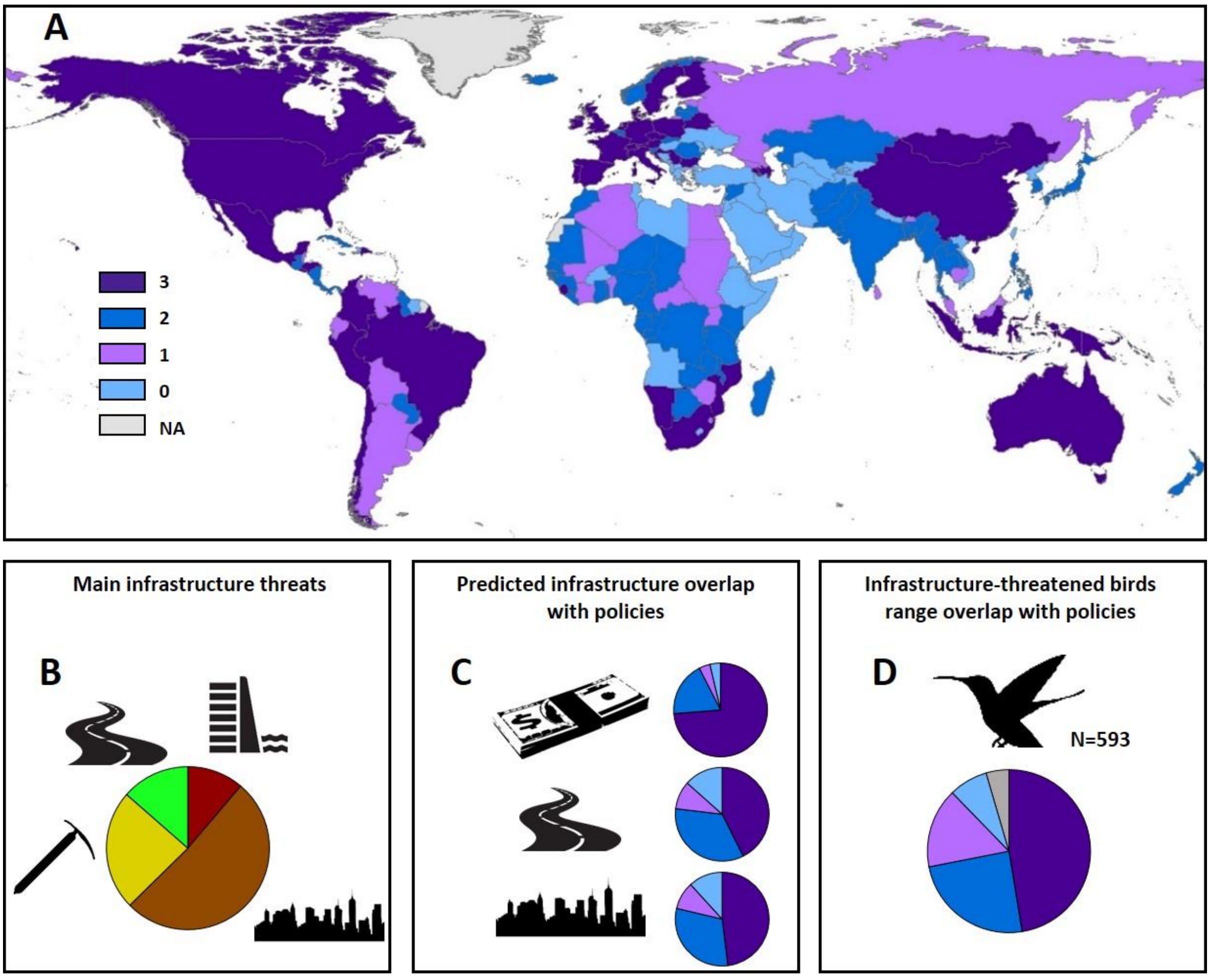

Figure 1. Infrastructure-related threats to species and global coverage of biodiversity compensation policies. Policy scores (see Box 2): 3 = mandatory compensation in some contexts; 2 = enable voluntary offsetting; 1 = minimum regulatory provisions for compensation; 0 = compensation not mentioned in national policy. A) Global map of compensation policy strength [29]. B) Breakdown of the main source of infrastructural threats facing all infrastructure-threatened (CR-VU) species on the IUCN red list (N=9,059 species; pie-chart comprised of 11,475 threats, some species double-counted if facing multiple types of infrastructural threat [16]). Main threats, clockwise from top: dams, residential and commercial development, mining and energy production, transport and transmission networks. C) Overlap between compensation policies [29] and different indicators of global infrastructural expansion. Top: distribution of predicted infrastructure spending 2019-2040 for 56 countries accounting for 88% of global GDP [3,4]. Middle: distribution of predicted road expansion by 2050 for 164 countries [6]. Bottom: distribution of predicted urbanisation 2000-2030 for 189 countries [5]. D) Mean overlap between extant distribution of infrastructure-threatened birds on the Red List (N=596) [41] and biodiversity compensation policies.

Moving from biodiversity compensation to No Net Loss

The widespread integration of biodiversity compensation requirements with national policy frameworks around the world demonstrates policy recognition of the impacts of infrastructural expansion. However, biodiversity compensation policies need to be carefully designed in order to stand a chance of achieving NNL consistent with the aspirations of the SDGs [38], and current biodiversity compensation policies often fall far short of this aspiration. The GIBOP database shows that only 23% of the countries enabling or requiring (scores 2-3) biodiversity compensation (including offsets) require that compensation be used strictly as a 'last resort' after the rest of the mitigation hierarchy, and of these 101 countries, only 10% apply international best practice principles [42]. These shortcomings have several implications. Using offsets or other forms of compensation without sequentially implementing the rest of the mitigation hierarchy risks permitting the loss of irreplaceable biodiversity such as slow-recovering or old-growth ecosystems or threatened species [26,43]. Additionally, it risks facilitating increased damage to natural systems under the logic that offsets might be marginally cheaper than avoidance, trading certain biodiversity losses for uncertain gains [44]. If NNL is to realise its potential to mitigate the impacts of the global infrastructure boom, an essential first step is therefore to transform existing biodiversity compensation policies into true NNL policies through mandatory application of preceding stages of the mitigation hierarchy, and implementation of offsets in line with social and ecological best practice rather than more general biodiversity compensation [42,45].

Such an ambition is not unattainable. Best practice NNL policies applying the mitigation hierarchy already exist in 10 countries, and a substantial amount of international infrastructure investment also falls under the scope of NNL policies through safeguards associated with multilateral development financing, such as the International Finance Corporation's Performance Standard 6 (NNL for impacts to Natural Habitat and Net Gain for impacts to Critical Habitat) and World Bank's Environmental and Social Standard 6. Similar requirements apply in the safeguard frameworks of the Asian Development Bank, Intra-American Development Bank and the African Development Bank [46]. As an example of the extent of this financing, between 2015 and March 2019, the World Bank committed US$83 billion to built infrastructure development projects, of which 81% was invested in countries without mandatory NNL policies (data from World Bank 2019). Major infrastructure projects funded by the World Bank are required (at least in theory) to meet ecological outcomes which are 'materially consistent' with their own NNL policies [48]. In addition to multilateral financing, major private financing sources mandate NNL implicitly under the Equator Principles (a risk management framework for managing socio-environmental risks of project finance, adopted by 97 financial institutions worldwide), which commits them to the International Finance Corporation performance standards including Performance Standard 6[49]. Eighty percent of project finance transactions in emerging markets are now associated with banks that have adopted the Equator Principles [49], although considerable further reforms are needed to enhance implementation of the principles [50].

The combination of national compensation policies and multi-lateral policy coverage indicate that enhancing biodiversity compensation policies to aim for NNL could provide a key tool for mitigating the impacts of the global infrastructure boom. But we argue below that if even existing 'best-practice' NNL policies are to fulfil their potential there is need for a rapid, transformational improvement in their application and effectiveness, or they risk undermining biodiversity conservation outcomes overall.

Expanding the scope of No Net Loss policies

Many NNL policies have historically failed to achieve their intended overarching policy aim [34]: shortcomings are embedded into multiple stages of the NNL policy implementation process from policy down to project scales (Figure 2). Perhaps the most important limitation to most existing NNL policies is that the total infrastructural impacts under their jurisdiction tend to be highly constrained – often the majority of impacts fall outside the scope of existing regulation (referred to by Maron et al. (2018) [38] as Type 2 impacts; Table 1; Figure 2). If NNL is only applied to a subsection of impacts, then even if project-scale mitigation is achieved the policy will inevitably oversee landscape-scale declines in biodiversity [34,38]. There are two main sources of unmitigated infrastructural impacts: deliberate policy choices that leave particular sets of impacts either entirely unaddressed or granted special exemptions from regulation, and illegal, uncompliant or unreported impacts.

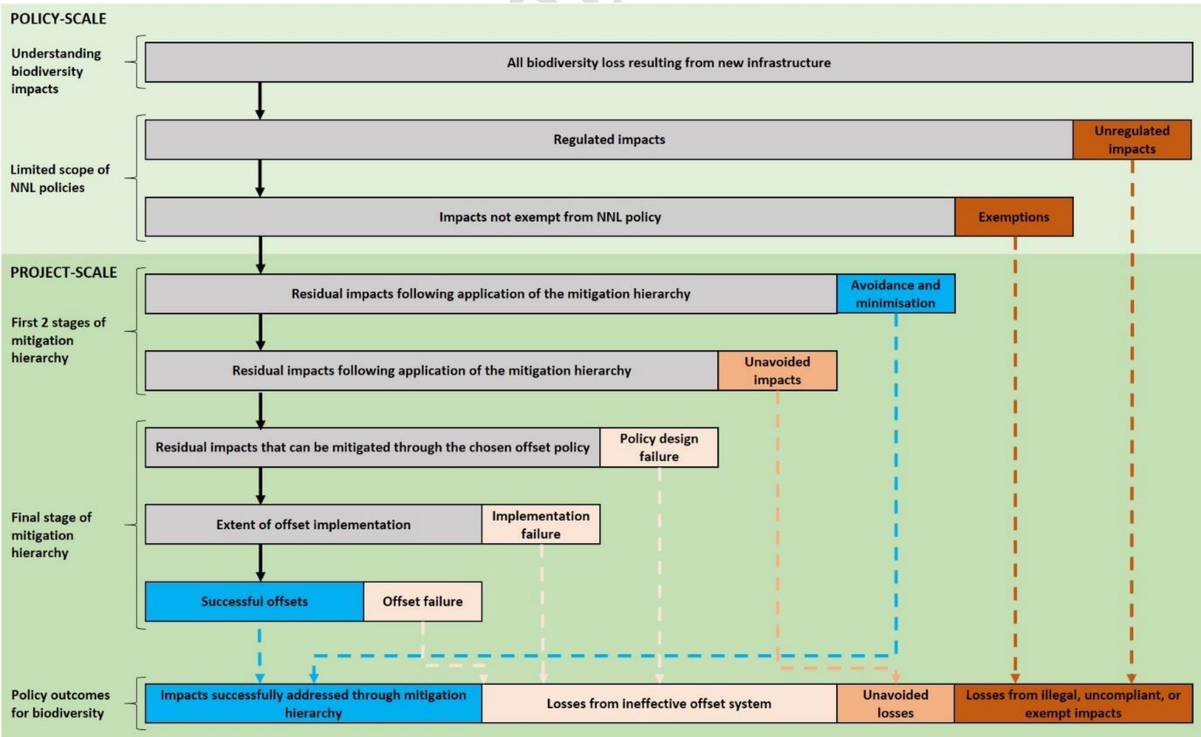

Figure 2. Schematic diagram of the embedded failures to address biodiversity losses from new infrastructure in each implementation stage of the mitigation hierarchy as currently applied in NNL policies. Light green box (top) denotes failures to address the full suite of infrastructure impacts on biodiversity impacts at the policy-scale, darker box (bottom) outlines

failures to address biodiversity loss embedded at project-scale applications of the mitigation hierarchy. Type 2 impacts as referred to by Maron et al. (2018)[38] are impacts which do not come under the scope of existing NNL policies, reflected by the 'unregulated impacts' and 'exemptions' categories. The size of the boxes is arbitrary and likely highly context-specific, so we have insufficient information to demonstrate the relative importance of each of the shortcomings in NNL application at this time

Case study	**Policy context**	**Total impacts captured by NNL**
Wetlands in Florida, USA (2001-2011) [51]	National policy goal of no net loss in 'wetland acreage and function' [52]. Compensatory mitigation allows for compensation for wetland impacts [21]. Mitigation banking is the legislatively favoured and most widely used compensation mechanism	Mitigation banking (which captures most but not all wetland compensation) restored 58,575 ha across the study region, but overall Florida experienced a net loss of over 56,000 ha wetlands across the study period
Wetlands in 20 counties in North Carolina, USA (1994-2001) [53]	As above	4,591 ha and 68 ha of wetlands were restored and created respectively across the study period, whilst the net loss of wetlands was 25,303 ha
Habitat suitable for threatened endemic the southern black-throated finch (*Poephila cincta cincta*), predominantly in Queensland, Australia (2000-2016) [43]	National Environmental Protection and Biodiversity Conservation (EPBC) Act aims to protect 'Matters of National Environmental Significance', which includes threatened species. Where an action might impact on 'Matters of Environmental Significance', a referral to regulators is necessary, and if found to have a significant impact, offsets may be mandated. Simultaneously, Queensland has the Vegetation Management Act (VMA), which aims to maintain biodiversity and ecological processes through regulation of vegetation clearing	631,000 ha of potential black-throated finch habitat (which should have counted as a 'Matter of Environmental Significance' because of the finch's threat status) was cleared across the study period. Of this, 502,391 ha was not associated with a known referral under the EPBC act, despite that the majority was likely cleared for pasture and thus subject to a referral
Native vegetation in New South Wales, Australia (2005-2015) [54]	Aim of New South Wales Native Vegetation Act is to 'prevent broad-scale clearing unless it improves or maintains environmental outcomes'. Offsetting is one mechanism mandated by the policy	Policy included exemptions that enabled circa 87% of vegetation clearing to occur uncompensated

Table 1. Case study examples of the disparity between total infrastructure or land use change impacts and those impacts which are subject to NNL (indicated in the above cases by the degree of offsetting relative to habitat loss)

All biodiversity impact mitigation policy has limitations to its coverage: mitigation policy commonly applies to either a subsection of biodiversity (i.e. only particular habitat types or legal designations: e.g. Indonesian forest policy requires compensation for losses from deforestation of state forests), or a subsection of industries (e.g. Mongolia requires compensation for damages associated with mining, petroleum and mineral extraction projects). However, as the evidence grows for the biodiversity and ecosystem service value of habitats that have not classically received much protection, such as isolated habitat fragments [55], urban nature [56] and abandoned land [57], allowing unmitigated biodiversity loss across any habitats now seems increasingly incompatible with achieving a minimum of NNL of biodiversity at landscape scales [58]. Additionally, even when regulation should in theory apply, many regions grant exemptions for specific infrastructure developments deemed to be strategically important, reflecting an underlying political prioritisation of economic over biodiversity values. For example, numerous national governments have circumvented the EU Habitats Directive's nominal NNL policy for the Natura 2000 network of protected areas by arguing that the associated infrastructures are in the 'overriding public interest', granting them an exemption even though the justifications for this designation often fall far short of what is legally required [59]. Additionally, many impacts are implicitly exempted from policies if they are deemed not to exceed certain impact 'significance' thresholds, which can often be arbitrary or overruled on arbitrary grounds[60,61]. According to government consultation documents, the proposed approach to mandate Biodiversity Net Gain in England comes close to covering all infrastructure impacts [62]. Under the proposals, developments will be required to deliver an improvement in biodiversity (as measured by the UK Department for Environment, Farming and Rural Affairs biodiversity metric [63]) consistent with good practice principles [64]. However, even this policy acknowledges that certain developments are, at this stage, exempt such as 'nationally significant infrastructure' and 'permitted development' [62]. These developments will still adhere to existing UK laws to protect biodiversity, but these laws give consent for developments to proceed with biodiversity loss.

The second major reason why biodiversity loss from infrastructure falls outside the jurisdiction of NNL policy is that many impacts are illegal or unreported. For example, in Queensland, Australia the majority of potential black-throated finch habitat cleared between 2000-2016 was not associated with a referral under the Environmental Protection and Biodiversity Conservation Act (a prerequisite to the application of the mitigation hierarchy), implying that landholders were not reporting their land clearing [43]. In the Brazilian Amazon, approximately 80% of roads are constructed without government approval, and are therefore not subject to environmental regulations [65]. Improving compliance with and enforcement of environmental regulation is a monumental task, which is far from limited to NNL policies [66].

Project-scale implementation and compliance challenges

Even if all infrastructure impacts were fully captured within NNL policy, biodiversity still falls through multiple cracks in the application of the mitigation hierarchy at project scales, both in the implementation of the avoidance and minimisation steps, and the design and implementation of offsetting policies (Figure 2). One overarching technical issue is the choice of biodiversity metric to use in impact assessment processes: metrics are simplified representations of the complex phenomenon of biodiversity, and so aspects of biodiversity that are not explicitly integrated into the metric risk falling outside the project planning process (reviewed comprehensively elsewhere[25,67,68]).

The avoidance step is widely considered the most important, yet understudied, step of the mitigation hierarchy [21,27]. Empirical evidence for the effectiveness of avoidance is severely lacking (but see Pascoe et al. (2019)[69]), and empirically challenging because in some systems much avoidance occurs through unobservable informal communications between developers and regulators, and so the final number of development permits accepted or rejected is a misleading proxy for effectiveness [70]. However, it is clear that many infrastructure projects that receive approval and proceed would not pass simple cost-benefit tests if all negative, long-term, direct and indirect social, environmental and maintenance costs were accounted for [10]. Furthermore, proper application of the mitigation hierarchy implies that any impacts to irreplaceable biodiversity must be avoided [26]; yet, some NNL policies continue to facilitate the clearance of threatened species habitat even when it simply cannot be justified on conservation grounds because it is non-offsettable and risks causing local extinction [43].

Avoidance fails to be implemented satisfactorily for many reasons (reviewed in Phalan et al. 2018) [27], including capacity shortages in public bodies responsible for assessing alternative options, and political prioritisation of economic development over environmental outcomes that often renders ‘no project’ scenarios politically undesirable and undervalues long-term socio-environmental costs [27,71]. Compounding this, EIA processes are often implemented too late in the project planning process to exert significant influence over key aspects of project design such as location, as considerable project costs and planning effort have already accrued [72,73]. Corruption and uneven power dynamics can also play a role [28,74]. Situations where groups with a vested interest in development proceeding hold undue influence over the mitigation hierarchy process are commonplace in EIAs through which many NNL systems are implemented [75]. For example, in some countries companies commissioning EIAs from consultants are permitted to withhold payment until the EIA is delivered, thus holding leverage over consultants to incentivise favourable EIA reports that underestimate negative biodiversity impacts and thus the degree of avoidance required [74]. Application of avoidance can also be suppressed by governments if they perceive strong geopolitical incentives to promote infrastructure development. For example, dam construction in the Brazilian Amazon cannot be reconciled with achieving NNL in biodiversity [12,76,77], however, the government perceives access to hydroelectric energy to be a geopolitical priority that supersedes avoiding impacts to irreplaceable biodiversity [78,79].

Once the avoidance and minimisation steps of the mitigation hierarchy have been applied, any residual impacts of infrastructure on biodiversity are then mitigated through offset policy, with any failures to apply the first two stages of the hierarchy adequately manifesting in additional residual impacts. Losses continue to occur under offsetting policies because of poor offset policy design [38], failure to implement the required offsets [80], and finally through failures of the offsetting interventions themselves[34]. There are multiple design issues that can embed biodiversity losses into NNL policies (reviewed in Maron et al. (2018)[38]), for example when unrealistic counterfactuals are used which imply that unfeasibly high rates of loss would have happened in the absence of the policy [81,82], when offsets do not provide any additionality [33], or when there is a lack of accounting for time lags between development losses and offset ecological improvements [54].

However, even NNL policies that adequately address the theoretical ecological requirements for achieving NNL risk suffering from a number of implementation problems that plague many environmental policies and conservation interventions. A key difficulty is that offsets are often very challenging to organise logistically and contractually [83]. Habitat-based offsets often require the acquisition or conservation management of land that would otherwise not have been contributing to conservation to the same degree. Offsets may be hard to find because landholders are unwilling to restrict their management rights [84], or because enough suitable land is simply unavailable (e.g. in Sabah, Malaysia [85] or France [86]), and instances of land scarcity are likely to increase in the future. This may drive greater emphasis in future on non-site based offsets (e.g. behaviour change interventions to reduce biodiversity loss). Whether site-based or not, offsets have tended to suffer from persistent implementation failures, related to weak compliance or regulatory enforcement, and inconsistencies within interacting governance arrangements [80,83]. At global scales, there are considerable gaps between offset policy and implementation: in 60% of countries that have some form of mandatory biodiversity compensation policy there is no documented evidence of a single offset yet being implemented according to the world's most comprehensive global offset database (Figure 3) [35]. In these countries, ecosystem loss continues to proceed without proper compensation. Lastly, even if conservation interventions are implemented in line with offset obligations, incomplete understanding of restoration ecology or the effectiveness of the implemented offset actions can lead to a failure to achieve NNL in biodiversity or ecosystem function [32,34,87].

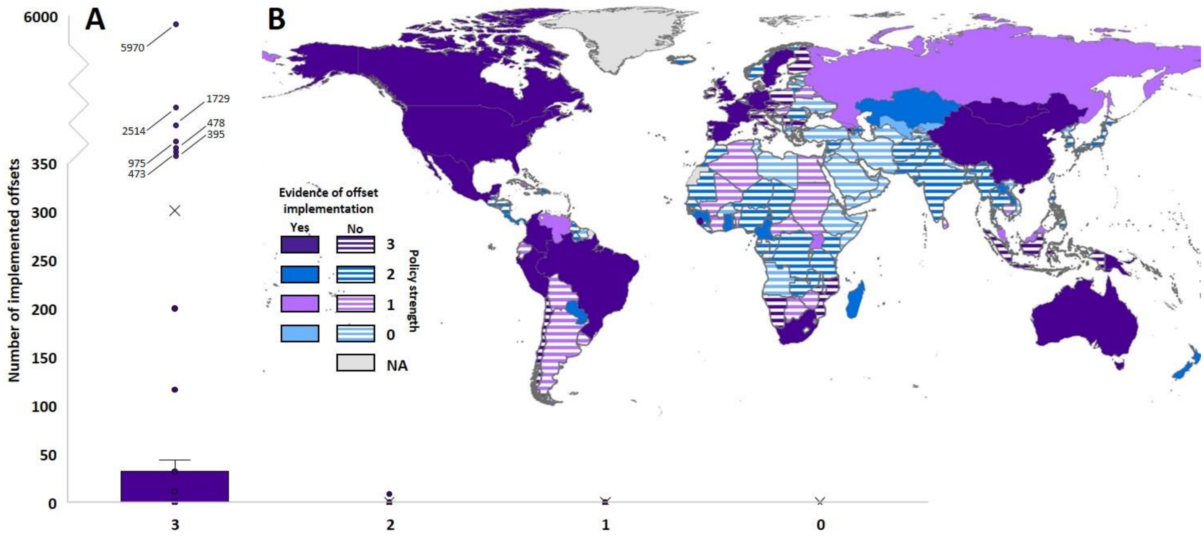

Figure 3. Global disparities between biodiversity compensation policy commitments and offset implementation [29,35], with the boxplots denoting the total number of offsets recorded as implemented in each country, and the map highlighting countries with no recorded implementation of offsets despite policy commitments. Policy scores (see Box 2): 3 = mandatory compensation in some contexts; 2 = enable voluntary offsetting; 1 = minimum regulatory provisions for compensation; 0 = compensation not mentioned in national policy. A) Box and whisker plots showing upper and lower quartiles and medians of the number of offsets implemented globally under different policy strengths. Crosses denote sample means (adjacent to x-axis for policy strength values 2-0). Whiskers denote the minimum/maximum values that fall within the lower/upper bound of the interquartile range -/+ 1.5 interquartile range. Outliers falls outside that range. B) Map of global biodiversity compensation policies strengths and evidence for offset implementation (defined as the presence of at least 1 offset or a non-zero area of offset implementation in-country from the most comprehensive global offset implementation database [35]). Note that offset implementation displayed may be the result of national policy, voluntary commitments or international financing requirements*

The future of No Net Loss

Over the last decade, there has been fierce debate about the merits of NNL and biodiversity offsetting and the degree to which it can help achieve or potentially unintentionally undermine conservation outcomes [37,88,89]. Empirical explorations of unintended outcomes remain scarce and largely inconclusive so far (e.g. no evidence for 'license to trash' in Levrel et al. (2017) or Gibbons et al. (2018) [51,54]); nevertheless, there is clearly in some contexts merit to the idea that NNL and offsetting policies have been designed by policymakers and influenced by the private sector to ‘sell’ the narrative that infrastructural expansion and environmental protection can go hand-in-hand [75,90], without deep reflection on the considerable barriers to achieving true NNL in practice or the place-based nature of biodiversity and cultural value [37,89]. There are also legitimate concerns that governments may use offset systems as excuses to reduce their own spending on conservation (‘cost-shifting’[88]); and that offsetting masks the fundamentally political assertion that infrastructure expansion is desirable even in wealthy countries despite that we already risk overshooting on planetary boundaries and that further economic expansion does not necessarily yield wellbeing increases [89,91]. The social justice of current NNL policies has also been rightfully questioned, with evidence that the most marginalised people tend to be those who bear the largest livelihood costs and see fewest benefits from offset delivery [92] – for offsets to be ecologically successful and socially defensible, these shortcomings must be addressed through improved legitimate community participation in both infrastructure and offset planning and negotiation processes [45]. These criticisms point to the risk that poorly designed and implemented NNL and offsetting policies could do more harm than good for conservation and people. However, enthusiastic uptake of compensation policies by policymakers does create a large opportunity for conservation globally: if implementation is improved and the benefits of NNL can be maximised, then NNL is potentially an avenue to mitigating damage on natural systems caused by trillions of dollars' worth of infrastructure, in addition to efficiently addressing global gaps in conservation financing through 'polluter-pays' [90]. To achieve this potential, the points of failure in each stage of the infrastructural impact mitigation process need to be addressed.

In order to make progress towards achieving NNL at policy scales, the jurisdiction of NNL policies must be expanded across all impacts (converting Type 2 into Type 1 impacts [38]) and exemptions from NNL requirements eliminated. As a first step, we recommend that countries audit their recent infrastructure impacts, assess what proportion of these came under NNL policy, and identify the main reasons for disparities between total and potentially mitigated impacts. This can help highlight the exact policies and exemptions that facilitate the loss of biodiversity from infrastructure development. The enduring problem of limiting illegal infrastructure and biodiversity impacts is key. This remains an enormous challenge, but emerging technologies allowing for near real-time monitoring of land use change may be an important component of the solution [93].

NNL may be intrinsically unfeasible for projects that damage invaluable or irreplaceable biodiversity[26]. NNL policies thus need to define 'no go' situations, and ensure that these are integrated with, and do not undermine, existing strict protections (although in practice, such protections are often over-ridden where projects are considered economic or political imperatives: e.g. dams in megadiverse tropical forest regions[76]). It is necessary to enhance macro-scale avoidance through strengthening Strategic Environmental Assessment, integrating development objectives and systematic conservation planning to clearly highlight where impacts to biodiversity must be avoided, such as in South Africa's planning policy and biodiversity offsetting implementation strategy [94]. Additionally, there are ecosystem-specific constraints on whether policies requiring NNL at project scales can achieve NNL at the landscape level. In biodiverse, spatially-constrained regions undergoing rapid infrastructure growth there may simply be insufficient space for the offsets required[85]. NNL at the landscape level requires habitat restoration to compensate for project damage, so may also be unachievable in ecosystems where restoration is very slow or otherwise unfeasible[95]. In such situations, policies can nevertheless set project compensation requirements so that biodiversity remains above a set threshold at the landscape level (Simmonds et al. in review; Maron et al. in review).

At project scales, NNL will only be achieved if the incentives of the actors in the system are aligned. NNL needs to be set as a project deliverable from the start of the project lifecycle and the project designed in ways that make tangible, measurable and meaningful outcomes for both biodiversity and for people[64]. Governments need to set clear and well-enforced NNL legislation, to ensure that developers seeking to deliver NNL are not undercut by competition. Developers need to be incentivised to achieve NNL by being convinced that positive biodiversity impacts do deliver social license to operate and competitive advantage. Commissioners of new infrastructure must demonstrate that they truly value those biodiversity outcomes.

Unfortunately, in many countries these conditions are not present. Central to the misapplication of NNL policy is the underlying political philosophy that short-term economic and security considerations outweigh long-term environmental ones. It is hard to address this in democracies through improved regulatory procedures or transparency; political philosophies will only shift when underlying cultures – voters and their values – change to demand these alternative priorities. However, good policy can help constrain gross violations by setting clear boundaries that cannot be overstepped without triggering comprehensive public scrutiny. NNL policy can potentially play an important role by clarifying what is and is not acceptable at both the avoidance and offsetting stages. For example, the IFC's guidance note for Performance Standard 6 very clearly states that no financing will be permitted for projects that impact UNESCO World Heritage Sites, or sites fitting the designation criteria of the Alliance for Zero Extinction [96]. Clear boundaries such as these should help constrain some of the worst potential outcomes of NNL policies if implementation standards still fall short.

There are multiple more specific policy enhancements that could help deliver NNL across infrastructure impacts. To improve implementation of the first step of the mitigation hierarchy, more resources are needed for planners, with an amelioration of power imbalances that distort planning processes. This is politically challenging, but simply providing environmental information consistent with the 'rational decision-making' model is unlikely to deliver adequate avoidance [72]: more systemic changes to planning systems are necessary. These include ensuring that information on biodiversity risks is genuinely provided early enough in the project planning process for 'no-project' to be a seriously considered option; severing the leverage of developers over the assessment of potential impacts (potentially through the establishment of independent public impact assessors[61]), and improving resourcing for planning departments so that they can cope with their case load in areas of rapid development [97]. To improve the capacity of planners overseeing NNL systems, a portion of offset financing should be reinvested in strengthening institutional capacity and developing the biodiversity information base (including high-quality baseline biodiversity data), helping improve the effectiveness of biodiversity planning and NNL policies over time.

Finally, there are many ways to improve design of offset systems, so as to mitigate the residual impacts of infrastructure expansion. It is necessary to design policy so that NNL is at least theoretically achievable at programme and landscape, not just project scales [38], which requires integrating state-of-the-art understanding of multipliers, time lags, biodiversity metrics, and cumulative impacts (not just cumulative impacts of portfolios of infrastructure projects, but also considering the way that infrastructure might interact with other drivers of biodiversity loss such as climate breakdown) [54,67,81,98]. Gaining the acceptance and support of local communities is essential to the success of conservation interventions, and offsetting is no exception: ecological and social outcomes would be considerably improved if offsets ensured that nobody affected by the initial development and paired offset was worse off as a result of the development-offset pairing than in their absence [45]. Using the best available evidence for the success of the implemented offset interventions is also essential to achieving NNL, and resources for supporting local-scale evidence-based restoration initiatives are growing (e.g. Conservation Evidence (www.conservationevidence.com)). Monitoring and evaluation should be central to offset systems, with outcomes fed back into processes for synthesising evidence so that the effectiveness of ecological enhancement and restoration can be improved over time. Additionally, measures must be put into place to address the identified global gap between the policy and implementation of biodiversity offsets (Figure 3). Again, an important solution may well be capacity-building and enhanced powers and independence of regulatory bodies. There are very few recorded examples of developers receiving financial penalties for failing to achieve their biodiversity offset obligations [99]. Thus, a simple step likely to improve compliance would be to increase the powers of regulators to prosecute non-compliance. In the context of other environmental policies this is shown to improve compliance not just within the firms prosecuted but more broadly across polluting industries [100].

If expanding the world’s infrastructure networks is socially desirable, can it be done in a way that meets SDGs 9, 14 and 15 simultaneously? Not if business-as-usual environmental practices continue during the ongoing expansion of the global infrastructure networks. However, existing biodiversity compensation policies could feasibly be transformed into robust NNL policies to close this gap. Enthusiastic policy uptake globally has created an opportunity to limit further extensive damage to biodiversity, if policy design and implementation can be improved. Transforming the scope and implementation of biodiversity compensation policies (and especially emphasising avoidance of irreversible impacts) should therefore be considered a global policy priority, with potential for integration into the post-2020 framework of the CBD.

Author contributions

Conceptualisation, all authors; Formal Analysis, S.O.S.E.z.E.; Data Curation, P.U. and J.W.B.; Writing – Original Draft, S.O.S.E.z.E; Writing – Review & Editing, all authors.

Acknowledgements

S.O.S.E.z.E is supported through NERC's EnvEast Doctoral Training Partnership [grant NE/L002582/1], in partnership with Balfour Beatty. We thank Laura Sonter, Richard Griffiths, Julia Baker, Niels Strange and two anonymous reviewers for helpful comments that substantially improved the manuscript.

Literature cited

1. Spaiser, V., Ranganathan, S., Swain, R.B., and Sumpter, D.J. (2017). The sustainable development oxymoron: quantifying and modelling the incompatibility of sustainable development goals. Int. J. Sustain. Dev. World Ecol. *24*, 457–470.

2. Hickel, J. (2019). The contradiction of the sustainable development goals: Growth versus ecology on a finite planet. Sustain. Dev.

3. Global Infrastructure Hub (2017). Global Infrastructure Outlook: Infrastructure Investment Needs 50 Countries, 7 Sectors to 2040. Glob. Infrastruct. Hub Syd. Available at: https://outlook.gihub.org/methodology.

4. Global Infrastructure Hub (2018). Global Infrastructure Outlook: Infrastructure investment need in the Compact with Africa countries. Available at: https://cdn.gihub.org/outlook/live/methodology/Global+Infrastructure+Outlook+CWA+update+-+June+2018.pdf [Accessed August 20, 2019].

5. Seto, K.C., Güneralp, B., and Hutyra, L.R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proc. Natl. Acad. Sci. *109*, 16083–16088.

6. Meijer, J., Huijbregts, M.A., Schotten, K., and Schipper, A. (2018). Global patterns of current and future road infrastructure. Environ. Res. Lett.

7. Ascensão, F., Fahrig, L., Clevenger, A.P., Corlett, R.T., Jaeger, J.A., Laurance, W.F., and Pereira, H.M. (2018). Environmental challenges for the Belt and Road Initiative. Nat. Sustain. *1*, 206–9.

8. Agénor, P.-R., and Moreno-Dodson, B. (2006). Public infrastructure and growth: New channels and policy implications (The World Bank).

9. Donaldson, D. (2018). Railroads of the Raj: Estimating the impact of transportation infrastructure. Am. Econ. Rev. *108*, 899–934.

10. Laurance, W.F., Peletier-Jellema, A., Geenen, B., Koster, H., Verweij, P., Van Dijck, P., Lovejoy, T.E., Schleicher, J., and Van Kuijk, M. (2015). Reducing the global environmental impacts of rapid infrastructure expansion. Curr. Biol. *25*, R259–R262.

11. Maxwell, S.L., Fuller, R.A., Brooks, T.M., and Watson, J.E. (2016). Biodiversity: The ravages of guns, nets and bulldozers. Nature *536*, 143–145.

12. Latrubesse, E.M., Arima, E.Y., Dunne, T., Park, E., Baker, V.R., d'Horta, F.M., Wight, C., Wittmann, F., Zuanon, J., and Baker, P.A. (2017). Damming the rivers of the Amazon basin. Nature *546*, 363.

13. Alamgir, M., Campbell, M.J., Sloan, S., Suhardiman, A., Supriatna, J., and Laurance, W.F. (2019). High-risk infrastructure projects pose imminent threats to forests in Indonesian Borneo. Sci. Rep. *9*, 140.

14. Torres, A., Jaeger, J.A., and Alonso, J.C. (2016). Assessing large-scale wildlife responses to human infrastructure development. Proc. Natl. Acad. Sci. *113*, 8472–8477.

15. Tulloch, A.I., Gordon, A., Runge, C.A., and Rhodes, J.R. (2019). Integrating spatially realistic infrastructure impacts into conservation planning to inform strategic environmental assessment. Conserv. Lett., e12648.

16. IUCN (2019). The IUCN Red List of Threatened Species. Version 2019-1. Available at: http://www.iucnredlist.org [Accessed June 14, 2019].

17. Laurance, W.F., Clements, G.R., Sloan, S., O'connell, C.S., Mueller, N.D., Goosem, M., Venter, O., Edwards, D.P., Phalan, B., and Balmford, A. (2014). A global strategy for road building. Nature *513*, 229.

18. Tong, D., Zhang, Q., Zheng, Y., Caldeira, K., Shearer, C., Hong, C., Qin, Y., and Davis, S.J. (2019). Committed emissions from existing energy infrastructure jeopardize 1.5 C climate target. Nature, 1.

19. Harfoot, M.B., Tittensor, D.P., Knight, S., Arnell, A.P., Blyth, S., Brooks, S., Butchart, S.H., Hutton, J., Jones, M.I., and Kapos, V. (2018). Present and future biodiversity risks from fossil fuel exploitation. Conserv. Lett. *11*, e12448.

20. Arlidge, W.N., Bull, J.W., Addison, P.F., Burgass, M.J., Gianuca, D., Gorham, T.M., Jacob, C., Shumway, N., Sinclair, S.P., and Watson, J.E. (2018). A global mitigation hierarchy for nature conservation. BioScience *68*, 336–347.

21. Hough, P., and Robertson, M. (2009). Mitigation under Section 404 of the Clean Water Act: where it comes from, what it means. Wetl. Ecol. Manag. *17*, 15–33.

22. Wende, W., Tucker, G.-M., Quétier, F., Rayment, M., and Darbi, M. (2018). Biodiversity Offsets: European Perspectives on No Net Loss of Biodiversity and Ecosystem Services (Springer).

23. Bennett, G., Gallant, M., and ten Kate, K. (2017). State of biodiversity mitigation 2017: Markets and compensation for global infrastructure development. Wash. DC For. Trends Ecosyst. Marketpl.

24. Bigard, C., Pioch, S., and Thompson, J.D. (2017). The inclusion of biodiversity in environmental impact assessment: Policy-related progress limited by gaps and semantic confusion. J. Environ. Manage. *200*, 35–45.

25. Bull, J.W., Suttle, K.B., Gordon, A., Singh, N.J., and Milner-Gulland, E. (2013). Biodiversity offsets in theory and practice. Oryx *47*, 369–380.

26. Pilgrim, J.D., Brownlie, S., Ekstrom, J.M., Gardner, T.A., von Hase, A., Kate, K. ten, Savy, C.E., Stephens, R.T., Temple, H.J., and Treweek, J. (2013). A process for assessing the offsetability of biodiversity impacts. Conserv. Lett. *6*, 376–384.

27. Phalan, B., Hayes, G., Brooks, S., Marsh, D., Howard, P., Costelloe, B., Vira, B., Kowalska, A., and Whitaker, S. (2018). Avoiding impacts on biodiversity through strengthening the first stage of the mitigation hierarchy. Oryx *52*, 316–324.

28. Carver, L., and Sullivan, S. (2017). How economic contexts shape calculations of yield in biodiversity offsetting. Conserv. Biol. *31*, 1053–1065.

29. GIBOP (2019). Global Inventory of Biodiversity Offset Policies (GIBOP). Available at: https://portals.iucn.org/offsetpolicy/policy-reviews [Accessed May 27, 2019].

30. Bull, J.W., Gordon, A., Watson, J.E., and Maron, M. (2016). Seeking convergence on the key concepts in 'no net loss' policy. J. Appl. Ecol. *53*, 1686–1693.

31. Gardner, T.A., HASE, A., Brownlie, S., Ekstrom, J.M., Pilgrim, J.D., Savy, C.E., Stephens, R.T., Treweek, J., Ussher, G.T., and Ward, G. (2013). Biodiversity offsets and the challenge of achieving no net loss. Conserv. Biol. *27*, 1254–1264.

32. Lindenmayer, D.B., Crane, M., Evans, M.C., Maron, M., Gibbons, P., Bekessy, S., and Blanchard, W. (2017). The anatomy of a failed offset. Biol. Conserv. *210*, 286–292.

33. Thorn, S., Hobbs, R.J., and Valentine, L.E. (2018). Effectiveness of biodiversity offsets: An assessment of a controversial offset in Perth, Western Australia. Biol. Conserv. *228*, 291–300.

34. zu Ermgassen, S.O., Baker, J., Griffiths, R.A., Strange, N., Struebig, M.J., and Bull, J.W. (2019). The ecological outcomes of biodiversity offsets under "no net loss" policies: A global review. Conserv. Lett., e12664.

35. Bull, J.W., and Strange, N. (2018). The global extent of biodiversity offset implementation under no net loss policies. Nat. Sustain. *1*, 790.

36. Madsen, B. (2011). State of biodiversity markets report: offset and compensation programs worldwide. Httpwww Ecosyst. Comdocumentsacrobatsbdmr Pdf.

37. Moreno-Mateos, D., Maris, V., Bechet, A., and Curran, M. (2015). The true loss caused by biodiversity offsets. Biol. Conserv. *192*, 552–559.

38. Maron, M., Brownlie, S., Bull, J.W., Evans, M.C., von Hase, A., Quétier, F., Watson, J.E., and Gordon, A. (2018). The many meanings of no net loss in environmental policy. Nat. Sustain. *1*, 19.

39. Quintero, J.D., and Mathur, A. (2011). Biodiversity offsets and infrastructure. Conserv. Biol. *25*, 1121–1123.

40. Butchart, S.H., Stattersfield, A.J., Bennun, L.A., Shutes, S.M., Akçakaya, H.R., Baillie, J.E., Stuart, S.N., Hilton-Taylor, C., and Mace, G.M. (2004). Measuring global trends in the status of biodiversity: Red List Indices for birds. PLoS Biol. *2*, e383.

41. BirdLife (2018). BirdLife International and Handbook of the Birds of the World: Bird species distribution maps of the world. Version 2018.1. Available at: http://datazone.birdlife.org/species/requestdis.

42. BBOP (2013). Standard on Biodiveristy Offsets, Business and Biodiversity Offsets Programme. Available at: https://www.forest-trends.org/wp-content/uploads/imported/BBOP_Standard_on_Biodiversity_Offsets_1_Feb_2013.pdf [Accessed August 21, 2019].

43. Reside, A.E., Cosgrove, A.J., Pointon, R., Trezise, J., Watson, J.E., and Maron, M. (2019). How to send a finch extinct. Environ. Sci. Policy *94*, 163–173.

44. Spash, C.L. (2015). Bulldozing biodiversity: The economics of offsets and trading-in Nature. Biol. Conserv. *192*, 541–551.

45. Griffiths, V.F., Bull, J.W., Baker, J., and Milner-Gulland, E. (2018). No net loss for people and biodiversity. Conserv. Biol.

46. Himberg, H. (2015). Comparative Review of Multilateral Development Bank Safeguard Systems. Wash. DC World Bank Group Httpsconsultations Worldbank OrgDatahubfilesconsultation-Templatereviewand-Update-World-Bank-Safeguard-Policiesenphasesmdbsafeguardcomparisonmainreportandannexesmay2015 Pdf.

47. World Bank (2019). Projects & Operations | Data Catalog. Available at: https://datacatalog.worldbank.org/dataset/world-bank-projects-operations [Accessed May 30, 2019].

48. World Bank (2018). ESF Guidance Note 1 -Assessment and Management of Environmental and Social Risks and Impacts. Available at: http://documents.worldbank.org/curated/en/142691530216729197/ESF-Guidance-Note-1-Assessment-and-Management-of-Environmental-and-Social-Risks-and-Impacts-English.pdf [Accessed May 30, 2019].

49. IFC (2018). The Equator Principles at 15. Available at: https://www.ifc.org/wps/wcm/connect/NEWS_EXT_CONTENT/IFC_External_Corporate_Site/News+and+Events/News/Perspectives/Perspectives-i2c2 [Accessed May 30, 2019].

50. Wörsdörfer, M. (2015). 10 Years' Equator Principles: A Critical Appraisal. In Responsible investment banking (Springer), pp. 473–501.

51. Levrel, H., Scemama, P., and Vaissière, A.-C. (2017). Should we be wary of mitigation banking? Evidence regarding the risks associated with this wetland offset arrangement in Florida. Ecol. Econ. *135*, 136–149.

52. EPA (2008). Compensatory mitigation for losses of aquatic resources, final rule. Available at: https://www.epa.gov/sites/production/files/2015-03/documents/2008_04_10_wetlands_wetlands_mitigation_final_rule_4_10_08.pdf [Accessed June 10, 2019].

53. Carle, M.V. (2011). Estimating wetland losses and gains in coastal North Carolina: 1994–2001. Wetlands *31*, 1275–1285.

54. Gibbons, P., Macintosh, A., Constable, A.L., and Hayashi, K. (2018). Outcomes from 10 years of biodiversity offsetting. Glob. Change Biol. *24*, e643–e654.

55. Wintle, B.A., Kujala, H., Whitehead, A., Cameron, A., Veloz, S., Kukkala, A., Moilanen, A., Gordon, A., Lentini, P.E., and Cadenhead, N.C. (2019). Global synthesis of conservation studies reveals the importance of small habitat patches for biodiversity. Proc. Natl. Acad. Sci. *116*, 909–914.

56. Goddard, M.A., Dougill, A.J., and Benton, T.G. (2010). Scaling up from gardens: biodiversity conservation in urban environments. Trends Ecol. Evol. *25*, 90–98.

57. Navarro, L.M., and Pereira, H.M. (2012). Rewilding abandoned landscapes in Europe. Ecosystems *15*, 900–912.

58. Bull, J.W., Milner-Gulland, E.J., Addison, P.F.E., Arlidge, W.N.S., Baker, J., Brooks, T.M., Burgass, M.J., Hinsley, A., Maron, M., Robinson, J.G., *et al.* (in press). Net positive outcomes for nature. Nat. Ecol. Evol.

59. Krämer, L. (2009). The European Commission's Opinions under Article 6 (4) of the Habitats Directive. J. Environ. Law *21*, 59–85.

60. Jacob, C., Pioch, S., and Thorin, S. (2016). The effectiveness of the mitigation hierarchy in environmental impact studies on marine ecosystems: A case study in France. Environ. Impact Assess. Rev. *60*, 83–98.

61. Murray, C.C., Wong, J., Singh, G.G., Mach, M., Lerner, J., Ranieri, B., St-Laurent, G.P., Guimaraes, A., and Chan, K.M. (2018). The insignificance of thresholds in environmental impact assessment: an illustrative case study in Canada. Environ. Manage. *61*, 1062–1071.

62. Defra (2019). Net gain: summary of responses and government response (Department for Environment, Farming and Rural Affairs) Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/819823/net-gain-consult-sum-resp.pdf.

63. Defra (2018). Updating the Defra Biodiversity Metric (London: Department for Environment, Farming and Rural Affairs) Available at: http://publications.naturalengland.org.uk/publication/6020204538888192.

64. Baker, J., Hoskin, R., and Butterworth, T. (2019). Biodiversity Net Gain: good practice principles for development - a practical guide (CIEEM) Available at: https://cieem.net/wp-content/uploads/2019/02/C776a-Biodiversity-net-gain.-Good-practice-principles-for-development.-A-practical-guide-web.pdf [Accessed August 20, 2019].

65. Brandão Jr, A., and Souza Jr, C. (2006). Mapping unofficial roads with Landsat images: a new tool to improve the monitoring of the Brazilian Amazon rainforest. Int. J. Remote Sens. *27*, 177–189.

66. UNEP (2019). Environmental rule of law: first global report Available at: https://www.unenvironment.org/resources/assessment/environmental-rule-law-first-global-report [Accessed July 4, 2019].

67. Quétier, F., and Lavorel, S. (2011). Assessing ecological equivalence in biodiversity offset schemes: key issues and solutions. Biol. Conserv. *144*, 2991–2999.

68. Bas, A., Jacob, C., Hay, J., Pioch, S., and Thorin, S. (2016). Improving marine biodiversity offsetting: A proposed methodology for better assessing losses and gains. J. Environ. Manage. *175*, 46–59.

69. Pascoe, S., Cannard, T., and Steven, A. (2019). Offset payments can reduce environmental impacts of urban development. Environ. Sci. Policy.

70. Sinclair, S.P. (2018). The Role of Social Factors in Complex Decision-Making Processes. Imp. Coll. Lond. PhD Thesis. Available at: https://www.iccs.org.uk/sites/www.iccs.org.uk/files/inline-files/Sinclair-S-2018-PHD-thesis_0.pdf.

71. Clare, S., Krogman, N., Foote, L., and Lemphers, N. (2011). Where is the avoidance in the implementation of wetland law and policy? Wetl. Ecol. Manag. *19*, 165–182.

72. Cashmore, M., Gwilliam, R., Morgan, R., Cobb, D., and Bond, A. (2004). The interminable issue of effectiveness: substantive purposes, outcomes and research challenges in the advancement of environmental impact assessment theory. Impact Assess. Proj. Apprais. *22*, 295–310.

73. Arts, J., Runhaar, H.A., Fischer, T.B., Jha-Thakur, U., Laerhoven, F.V., Driessen, P.P., and Onyango, V. (2016). The effectiveness of EIA as an instrument for environmental governance: reflecting on 25 years of EIA practice in the Netherlands and the UK. In Progress in Environmental Assessment Policy, and Management Theory and Practice (World Scientific), pp. 171–210.

74. Williams, A., and Dupuy, K. (2017). Deciding over nature: Corruption and environmental impact assessments. Environ. Impact Assess. Rev. *65*, 118–124.

75. Walker, S., Brower, A.L., Stephens, R., and Lee, W.G. (2009). Why bartering biodiversity fails. Conserv. Lett. *2*, 149–157.

76. Jones, I.L., and Bull, J.W. (2019). Major dams and the challenge of achieving “No Net Loss” of biodiversity in the tropics. Sustain. Dev.

77. Forsberg, B.R., Melack, J.M., Dunne, T., Barthem, R.B., Goulding, M., Paiva, R.C., Sorribas, M.V., Silva Jr, U.L., and Weisser, S. (2017). The potential impact of new Andean dams on Amazon fluvial ecosystems. PLoS One *12*, e0182254.

78. Fearnside, P.M. (2016). Brazilian politics threaten environmental policies. Science *353*, 746–748.

79. Gerlak, A.K., Saguier, M., Mills-Novoa, M., Fearnside, P.M., and Albrecht, T.R. (2019). Dams, Chinese investments, and EIAs: A race to the bottom in South America? Ambio, 1–9.

80. Bezombes, L., Kerbiriou, C., and Spiegelberger, T. (2019). Do biodiversity offsets achieve No Net Loss? An evaluation of offsets in a French department. Biol. Conserv. *231*, 24–29.

81. Bull, J., Gordon, A., Law, E., Suttle, K., and Milner-Gulland, E. (2014). Importance of baseline specification in evaluating conservation interventions and achieving no net loss of biodiversity. Conserv. Biol. *28*, 799–809.

82. Maron, M., Bull, J.W., Evans, M.C., and Gordon, A. (2015). Locking in loss: baselines of decline in Australian biodiversity offset policies. Biol. Conserv. *192*, 504–512.

83. Evans, M.C. (2017). Opportunities and risks in the implementation of biodiversity offset policy in Australia, in: Public Policy for Biodiversity Conservation: Evaluating Outcomes, Opportunities and Risks.

84. Vaissière, A.-C., Tardieu, L., Quétier, F., and Roussel, S. (2018). Preferences for biodiversity offset contracts on arable land: a choice experiment study with farmers. Eur. Rev. Agric. Econ. *45*, 553–582.

85. von Hase, A., and Parham, E. (2018). Forest Loss-gain Analysis for Sabah: A Briefing Report (Prepared for the Sabah Forestry Department.).

86. Guillet, F., and Semal, L. (2018). Policy flaws of biodiversity offsetting as a conservation strategy. Biol. Conserv. *221*, 86–90.

87. Theis, S., Ruppert, J.L., Roberts, K.N., Minns, C.K., Koops, M., and Poesch, M.S. (2019). Compliance with and ecosystem function of biodiversity offsets in North American and European freshwaters. Conserv. Biol.

88. Maron, M., Gordon, A., Mackey, B.G., Possingham, H.P., and Watson, J.E. (2016). Interactions between biodiversity offsets and protected area commitments: avoiding perverse outcomes. Conserv. Lett. *9*, 384–389.

89. Apostolopoulou, E., and Adams, W.M. (2017). Biodiversity offsetting and conservation: reframing nature to save it. Oryx *51*, 23–31.

90. Calvet, C., Napoléone, C., and Salles, J.-M. (2015). The biodiversity offsetting dilemma: Between economic rationales and ecological dynamics. Sustainability *7*, 7357–7378.

91. Jebb, A.T., Tay, L., Diener, E., and Oishi, S. (2018). Happiness, income satiation and turning points around the world. Nat. Hum. Behav. *2*, 33.

92. Bidaud, C., Schreckenberg, K., and Jones, J.P. (2018). The local costs of biodiversity offsets: Comparing standards, policy and practice. Land Use Policy *77*, 43–50.

93. Finer, M., Novoa, S., Weisse, M.J., Petersen, R., Mascaro, J., Souto, T., Stearns, F., and Martinez, R.G. (2018). Combating deforestation: from satellite to intervention. Science *360*, 1303–1305.

94. Brownlie, S., von Hase, A., Botha, M., Manuel, J., Balmforth, Z., and Jenner, N. (2017). Biodiversity offsets in South Africa–challenges and potential solutions. Impact Assess. Proj. Apprais. *35*, 248–256.

95. Gibbons, P., Evans, M.C., Maron, M., Gordon, A., Le Roux, D., von Hase, A., Lindenmayer, D.B., and Possingham, H.P. (2016). A loss-gain calculator for biodiversity offsets and the circumstances in which no net loss is feasible. Conserv. Lett. *9*, 252–259.

96. IFC (2019). International Finance Corporation's updated Guidance Note 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources. Available at: https://www.ifc.org/wps/wcm/connect/5e0f3c0c-0aa4-4290-a0f8-4490b61de245/GN6_English_June-27-2019.pdf?MOD=AJPERES&CVID=mKqG85z [Accessed August 4, 2019].

97. Laurance, W.F., and Arrea, I.B. (2017). Roads to riches or ruin? Science *358*, 442–444.

98. Sonter, L., Tomsett, N., Wu, D., and Maron, M. (2017). Biodiversity offsetting in dynamic landscapes: influence of regulatory context and counterfactual assumptions on achievement of no net loss. Biol. Conserv. *206*, 314–319.

99. Hahn, R., and Richards, K. (2013). Understanding the effectiveness of environmental offset policies. J. Regul. Econ. *44*, 103–119.

100. Gray, W.B., and Shimshack, J.P. (2011). The effectiveness of environmental monitoring and enforcement: A review of the empirical evidence. Rev. Environ. Econ. Policy *5*, 3–24.