The Risks and Opportunities of Translating Terrestrial Biodiversity Offsets to the Marine Realm

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Biodiversity compensation policy programs such as offsetting are increasingly being expanded to the marine realm. We reviewed the literature on biodiversity offsets and related compensatory policy to determine where marine offset policies occur. We also identified the most important differences between marine and terrestrial systems that are likely to have implications for how offsetting is conducted. We found that 77 nations had compensatory policies that enabled the use of offsets in the marine environment. Two important differences between marine and terrestrial offsets emerged: (1) biophysical differences, such as greater marine connectivity, lower likelihood of restoration success, and data paucity, and (2) social or governance differences, such as a lack of private ownership and a greater probability of leakage. We conclude that without better evaluation and innovation, it is premature to conclude that marine offsets can be effective. The lessons learned from the development of terrestrial offsets provide an opportunity to improve their application to marine ecosystems.

Keywords: conservation policy, marine biodiversity offset, marine compensation, no net loss

Billions of people depend on marine and coastal systems for essential ecosystem services, including climate regulation and food resources (Costanza 1999). However, this reliance has meant that marine ecosystems are increasingly being degraded by human activities (Halpern et al. 2008). These impacts vary in their intensity and spatial distribution across the seascape (Halpern et al. 2008), but marine industry and resource extraction is growing, especially in deep water and other remote and frontier areas that were previously inaccessible (Kark et al. 2015).

Industry is increasingly expected not only to minimize the impacts of their activities on the environment but also to act to counterbalance any residual impacts with the goal of achieving "no net loss" of biodiversity (BBOP 2012b). The achievement of no net loss is generally associated with the use of a mitigation hierarchy, in which impacts are sequentially avoided, minimized, restored, and finally, offset. *Biodiversity offsetting* is a mechanism used to mitigate the impacts from development on species and ecosystems, in theory allowing development without net biodiversity loss (Maron et al. 2012). Biodiversity offsetting works by restoring, rehabilitating, or protecting comparable habitat (McKenney and Kiesecker 2010) in order to generate a biodiversity "gain" equivalent to the loss from development (BBOP 2012b, IUCN 2016).

Most offset policy development and research have focused on terrestrial ecosystems and species. Marine biodiversity offsets remain an emerging mechanism for impact mitigation in most parts of the world, even where terrestrial offsets are prevalent. For example, in Australia, terrestrial offsetting has occurred since 2000, with little marine offset policy development until recently (Commonwealth of Australia 2012, Dutson et al. 2015, Maron et al. 2016b). Even in areas where marine offsets have been used for decades (e.g., Canadian fish-habitat mitigation), relevant data on implementation and success have been difficult to obtain (Levrel et al. 2012).

There are major challenges associated with achieving no net loss in biodiversity offsetting (Bull et al. 2013a). These include the definition of appropriate metrics to account for biodiversity losses and gains to achieve commensurate offset exchanges (Maron et al. 2016a), the determination of suitable frames of reference both currently and in the future (Maron et al. 2015), a gap between the theory and implementation of multipliers to account for uncertainty (Bull et al. 2016b), a lack of adherence to the mitigation hierarchy prior to offsetting, and a lack of monitoring of offsets that are already in place (Quigley and Harper 2006). In addition, Maron and colleagues (2016a) have pointed out the ethical and social challenges involved in biodiversity offsetting, such as accurately reflecting societal values toward nature and how trade in nature aligns with moral obligations to protect biodiversity.

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Many of the challenges of terrestrial offsetting are likely also to occur in marine and coastal environments. However, because of key differences in both the ecology and governance of marine ecosystems, several of these challenges are likely to be more or less problematic, and completely new issues may emerge. It is important to identify these challenges before the widespread application of marine offsetting in order to inform the limits to offsetability in the marine realm and to help improve the design of marine offset policy.

We first reviewed the incidence of compensatory policies in the marine environment to determine the scale of marine offsetting globally. On the basis of this literature review and the broader literature on biodiversity offsets and marine ecology and conservation, we identified the potentially important differences in the ecology and governance of terrestrial and marine ecosystems. In each case, we consider how those differences might influence the translation of offsetting to the marine environment in order to understand the unique challenges faced by the achievement of no net loss in marine systems, and we outline the implications for marine offset design and implementation.

The occurrence of marine offsets globally

Data on 148 separate offset or compensatory policies were collected (see supplemental appendix S1 for methodology). These included national, regional, and state policies, as well as businesses' marine offset policies (e.g., Royal Dutch Shell Pearl GTL Project, Qatar). Because offsets are an emerging conservation mechanism, there is a lack of precision in the language used to describe offset policies (Bull et al. 2016a), making the identification of a policy designed to achieve true offsets with a no net loss objective difficult. In many cases, the term *offset* is used synonymously with mitigation or compensation, although compensation may also be a wider range of actions, such as financial compensation or payment for ecosystem services (PES). For example, both wetland mitigation in the United States and fish habitat compensation in Canada occur as part of the mitigation hierarchy and require equivalence between losses and gains, as is required for "strict" offsets (Bull et al. 2016a); however, Argentina's environmental compensation fund allows financial compensation as the final step in the mitigation hierarchy if restoration is not feasible (Madsen et al. 2010). Nevertheless, in all cases, the main objective of the policies considered is to at least partly compensate for impacts on biodiversity.

On the basis of this broad definition, 77 countries had offsets occurring or compensatory policies in place or under development that involve offsets or some similar form of compensatory mechanism and enable the use of offsetting or compensation in the marine environment (figure 1). This includes 22 member states of the European Union that have marine Natura 2000 sites, which require compensation for damage under the EU Birds and Habitats Directives. Only 15 countries had "established" marine compensatory policies, and most of the countries (n = 62) were in the early stages of defining policy goals and objectives and exploring compensatory mechanisms. Marine-specific offset policies, those policies pertaining to marine habitats only, were found for 12 countries, although many of these countries also had multiple offset policies covering both national and subnational jurisdictions. Most of these national-scale marine-specific policies emphasized wetland habitat (n = 7), but other foci include fish and mangrove habitats and biodiversity.

Differences between marine and terrestrial systems

Although terrestrial and marine offsets have the same theoretical basis, we identified important practical differences. These differences in ecological and biological processes can be grouped into two distinct categories: (1) biophysical and (2) social or governance (those influenced by societal, legislative, or management involvement). Several of the inherent differences between marine and terrestrial ecosystems have important implications for offset feasibility and effectiveness, which we discuss in this section.

Biophysical challenge: Strong connectivity between terrestrial and marine environments. Terrestrial systems are highly connected to marine systems through runoff and river flows, delivering materials such as nutrients, sediments, and toxins to marine ecosystems. For example, the Great Barrier Reef contains 35 defined river basins (Furnas 2003), and just one of these (the Burdekin watershed) has been shown to affect nearly 47,000 square kilomeeters of marine area, including 247 different reefs and 73 seagrass beds (Devlin et al. 2012). This high connectivity from land to sea can lead to circumstances in which biodiversity in one system is threatened by impacts in another; for instance, the biological "dead zones" seen in the Gulf of Mexico are a result of nutrient outflows originating from hundreds to thousands of kilometers inland in the Mississippi River system (Stoms et al. 2005). As such, marine systems are highly influenced by human activities occurring at potentially great distances (Devlin et al. 2012).

Because of the strong confounding influences across land–sea gradients, defining and quantifying marine impacts from a terrestrial development could be especially difficult. In addition, separating out the component of biodiversity loss that is specifically attributable to marine development in the face of many other diffuse land–sea impacts is challenging. For example, it would be complex to predict the impact of a single additional farm on the condition of a downstream coral reef in a catchment dominated by farming. The achievement of no net loss in the marine environment must therefore account for both direct and diffuse impacts originating on land, as well as cumulative impacts from multiple stressors occurring in multiple locations.

Few of the policies reviewed explicitly account for indirect or cumulative impacts on biodiversity values. For example, Canada's Policy for the Management of Fish Habitat does not take indirect impacts into account, but a recent Science Advisory Report on the policy has highlighted its importance

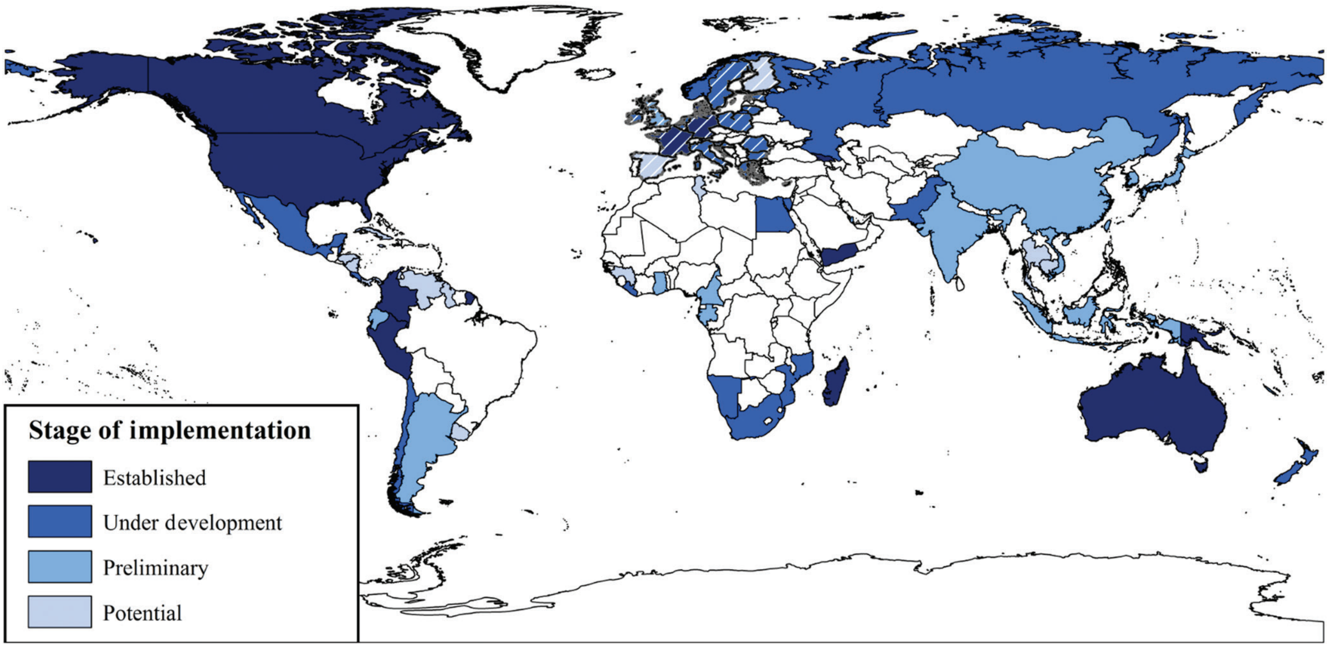

Figure 1. Countries with marine offsets occurring or compensatory policies in place or under development that enable the use of offsetting in the marine environment, where (a)* established *refers to countries with both a policy in place and offsets occurring (*n *= 15); (b)* under development *denotes countries with a compensatory policy in place but no marine offset actions yet occurring (*n *= 16); (c)* preliminary *refers to countries with no compensatory policy in place but policy discussions or development are occurring (*n *= 15); and (d)* potential *denotes countries with an enabling policy framework in place but no offset discussions yet occurring (*n *= 18). The countries with hatching over shading represent EU member nations with marine Natura 2000 sites, which require compensation for damage under the EU Birds and Habitats Directives (*n *= 22).

(FOC 2012). A recent report scoping a marine offsets policy by the UK government emphasized the difficulty of assessing the interactions between nonpoint source pollution, cumulative impacts, and secondary impacts (Dickie et al. 2013). Although these types of impacts may also affect terrestrial offsets, indirect impacts in the marine environment may be more common and more significant than direct impacts, an unusual occurrence in terrestrial environments. For diffuse impacts that occur as a result of decreased water quality (e.g., impacts on seagrass from increased sedimentation), it is theoretically feasible for offsets to be achieved through actions on land or at sea (Bell et al. 2014). For example, offsets could be a direct action, through replanting seagrass, or indirect, through increasing riparian vegetation cover to reduce sedimentation from stream-bank erosion. However, estimates of sediment reductions from actions on land and the response of marine ecosystems to such reductions are highly uncertain (Saunders et al. 2017), so achieving confidence in equivalence between losses and gains is challenging.

Biophysical challenge: Greater connectivity within the marine environment. Spatial and hydrological connectivity dominate the marine environment. The convection process of waves and currents in the ocean leads to more open systems with greater *flow* (movement of water and organisms) than is common in terrestrial systems (Carr et al. 2003). Because of this connectivity, impacts such as indirect, offsite, or cumulative impacts—although important issues in terrestrial systems—may be particularly dominant in the marine environment, where impacts can have substantial effects in adjoining and even distant marine systems. These “enigmatic” impacts (sensu Raiter et al. 2014) can be particularly difficult to estimate and mitigate because they follow diffuse pathways that can be difficult to model and predict. Enhanced evaluation and more extensive assessment of impacts are particularly important for discerning hard-to-detect impacts. Incorporating predicted diffuse and distant impact trends into modeling approaches and the use of decision-support tools such as those used in systematic conservation planning could also aid in accounting for uncertainty, increasing the likelihood that impacts are assessed accurately and no net loss can be achieved (Raiter et al. 2014, Kujala et al. 2015). Of the 77 policies reviewed, only 18 mention indirect and/or cumulative impacts, although none give explicit guidance or discuss the mechanisms in place for offsets to account for the connectivity in marine systems and these complex impacts.

The connectivity of marine systems also presents some opportunities for offsets. There may be multiple options for the location of a conservation intervention within a connected marine system; for example, fish nursery grounds could be enhanced in exchange for impacts on mature fish elsewhere. The direct benefits from marine reserves are known to go beyond the boundaries of the protected areas (Gell and Roberts 2003), and marine offsets could function similarly. This could be advantageous in areas of high cumulative pressure, where offsetting away from those impacts would increase the likelihood of offset success. The United Kingdom's scoping study of marine offsetting was one of the few reviewed that discussed the continuous nature of the marine environment and recognized the need to use a *whole-ecosystem approach* to offsetting, using the country's marine spatial planning system as a framework (Dickie et al. 2013). Nonetheless, for impacts on biodiversity values that are locally important for social or conservation reasons, offsets should continue to occur near the impact site (Ives and Bekessy 2015). In addition, where impacts are diffuse and complicated to predict and measure, an offset close to the source of impact could be more effective, and benefits could propagate in the same way as the impact.

Biophysical challenge: Greater organism dispersal and migration. Marine systems are dominated by species with complex life histories, with most having at least one widely dispersive or migratory phase. This large-scale dispersal, often mediated by advection of ocean currents, ultimately determines species distributions and is important for the maintenance of genetic diversity (Carr et al. 2003, Trakhtenbrot et al. 2005). For example, a large number of sedentary adult marine species produce planktonic young that disperse great distances (Carr et al. 2003): less than 1 kilometer for some sessile species (corals, bryozoans, and tunicates) but 20 kilometers to hundreds or thousands of kilometers for other broadcast spawners (Shanks et al. 2003). Despite this, none of the policies reviewed explicitly discussed how species range or demography should affect the location of offsets relative to the impact site. Although it was common for most policies to state that offsets close to the impact were preferable, there were a few exceptions. Australia's Environment Protection and Biodiversity Conservation Act Offset Policy specifies that offsets should be placed as close as possible to the impact site unless greater conservation benefit can be achieved by locating offsets elsewhere, and US wetland mitigation gives preference to larger, "landscape-scale" offsets within entire watersheds rather than the previous guidance, which favored on-site restoration (US EPA 2008, Madsen et al. 2010, Commonwealth of Australia 2012).

The dominance of large-scale ecological connectivity within the marine environment means that distant offsets might, in theory, achieve better outcomes for a species than offsets near the impact site. Many marine species have long-distance migrations that span numerous countries and jurisdictions and are affected by multiple threats throughout their range. Although this is also true for terrestrial species (Bull et al. 2013b), it is more common in the marine environment (Carr et al. 2003). Applying offsets to highly mobile species anywhere within their range where they are vulnerable to impacts could provide better conservation outcomes than simply offsetting close to the site of impact (Bull et al. 2013b). For example, leatherback sea turtles (*Dermochelys coriacea)* in the eastern Pacific have defined migratory patterns and specific nesting sites (Shillinger et al. 2008), but loss of nesting habitat, overharvest of eggs, and significant mortality from incidental fisheries catch have led to declines of up to 90% (Spotila et al. 2000). Offset options that provide protection in areas where the threat is greatest or more tractable rather than as close as practicable to a development site could generate a greater benefit for these migratory species. International agreements such as the Inter-American Convention for the Protection and Conservation of Sea Turtles could help facilitate this. Offsets could then augment existing conservation interventions in areas of high threat regardless of proximity to the impact rather than ad-hoc or fragmented actions near development sites, which could increase the risk of offset failure (NRC 2001). Integrating offsets into current spatial conservation management planning could then lead to more coordinated conservation networks at a wider spatial scale (BBOP 2012a, Bull et al. 2015).

There are also risks associated with allowing such spatial flexibility (i.e., the implementation of offsets far from the impact site). Equivalence between the biodiversity affected and the benefit from the biodiversity offset could become difficult to evaluate, obfuscating the connection between biodiversity lost from the impact and gains accrued from the offset; offsets could also become difficult to track, monitor, and manage, especially if the impact and the offset occur in different jurisdictions or in a politically challenging environment (Vaissière et al. 2014, Bull et al. 2016a). Allowing offsets that are flexible in space could also increase the complexity for industry in implementing offsets, although increased efficiency could also make offsets less expensive to deliver. Flexible offsets could also lead to the loss of important ecosystem services and cultural values that may be socially unacceptable (Rogers and Burton 2016). Finally, it could exacerbate social inequalities, with developed countries continuing to develop while encouraging offsets in less-developed countries with high biodiversity (McDermott et al. 2013). Explicit and careful consideration of how to incorporate species demography and spatial flexibility into offset management planning is essential.

Biophysical challenge: Ecological limitations to restoration in the marine environment. Active restoration or rehabilitation of already-degraded ecosystems is a key mechanism for achieving biodiversity gains to offset losses from development impacts (Maron et al. 2012). Restoration is crucial to achieving terrestrial offset objectives, although few data are available on the ability of restoration offsets to compensate effectively for impacts in the terrestrial environment (Maron et al. 2012, Thébaud et al. 2015), where the field of ecological restoration is more advanced than in marine environments. In most marine environments, restoration is not yet effective at achieving desired ecological outcomes (Bayraktarov et al. 2016). A review of seagrass restoration projects in New South Wales (NSW), Australia, demonstrated that seagrass restoration was costly, and current techniques were still developmental and could not be relied on for success in any large-scale habitat restoration in NSW, thereby falling short of the marine vegetation compensation policy requirements for the state (Ganassin and Gibbs 2008, Fairfull 2013).

A review of marine coastal restoration worldwide showed that success was highly variable depending on the ecosystem and the project location (coral, 64.5%; mangrove, 51.3%; seagrass, 38%; saltmarsh, 64.8%; Bayraktarov et al. 2016). Rates of success in this study were item based (e.g., the number of seedlings surviving), and most were assessed in the short term (1–5 years). Conversely, the success of offsets through restoration is more likely related to the success of the restoration project overall and the likelihood that it achieves its no net loss objective in the long term. In addition, the average cost of marine restoration for all systems was US$1.6 million per hectare (Bayraktarov et al. 2016). Cost increases and restoration feasibility decreased for ecosystems in deeper water, with one study suggesting that deep-sea restoration could be feasible but orders of magnitude more expensive than current estimates (Van Dover et al. 2014).

The feasibility of restoration in the marine environment relates directly to the offsetability of project impacts (Pilgrim et al. 2013, Bos et al. 2014). There is significant uncertainty that restoration-based offsets can be relied on to achieve no-net-loss objectives or provide genuine gains for marine systems. Therefore, techniques for rehabilitating marine environments and the science underpinning marine restoration need further development before marine restoration can be a reliable offsetting mechanism. In cases in which the level of uncertainty is too high, offsets should be considered a no-go, but proof-of-concept research could be incentivized. Where marine offsetting is attempted, regulators should ensure that multipliers are science based and are used appropriately to account for both rates of success and risks of catastrophic loss from unavoidable natural events (e.g., cyclones and floods; Bull et al. 2016b), and they should also ensure that offsets are not just implemented but also evaluated in the long term to ensure that a no-net-loss outcome is achieved (Bell 2016).

Biophysical challenge: Lack of data and the low resolution of available data. A major challenge in implementing offsets and achieving no net loss in marine environments is the paucity of data compared with those from terrestrial environments (UNEP-WCMC 2015). A recent study mapping global critical habitat in the marine environment revealed that there is a substantial lack of data, limiting how accurately marine biodiversity values can be represented (Martin et al. 2015). Marine habitat maps are typically based on remotely sensed data; mapping is therefore limited to clear or shallow waters, leaving large quantities of ocean floor unsampled. So although deep pelagic marine systems are one of the largest habitats on earth, they are immensely underrepresented in global data (Webb et al. 2010).

There is also a lack of finely resolved data in marine environments. In many terrestrial environments, ecosystems have been delineated at quite fine resolutions, on the basis of community composition (Queensland Herbarium 2016). For instance, in the state of Queensland, Australia, terrestrial mapping of regional ecosystems delineates vegetation communities on the basis of plant community composition, geology, soil, and bioregion, yielding 1540 distinct regional ecosystems in the state (Queensland Herbarium 2016). Conversely, although the Great Barrier Reef is one of the best-monitored and -managed reef systems in the world, comprehensive mapping of coral communities does not yet exist. Although coastal and shallow systems are relatively well studied, finely resolved ecological communities have generally not been mapped. Metrics for the monitoring of coral reefs are generally point measurements or focus on percentage of cover, but they should also include factors such as species assemblages and diversity (Bellwood et al. 2004), based on underwater imagery from divers or remotely operated systems. The ocean is dynamic and three-dimensional, and the spatial boundaries of pelagic systems move in space and time, creating significant challenges for mapping and monitoring that do not exist for terrestrial systems.

Change in biodiversity is difficult to estimate in any system because it is complex and multidimensional, but it is especially so in marine systems, where baseline data are few. Composite metrics, such as those used in habitat equivalence analysis (HEA), are often used in natural-resource damage assessments, such as ship groundings on coral reefs (Dunford et al. 2004). Application of a composite metric relies on extensive supporting research to successfully combine multiple values into a representative ecological value; however, these data are often limited in the marine environment (Viehman et al. 2009). Offsets would require changes in such metrics to be estimated under various future scenarios in order to estimate losses and gains, which adds complexity to the challenge. Compared with complex metrics, surrogate metrics, such as change in water quality, may be easier to measure and estimate changes in, but they are fundamentally less precise in accounting for damage (Quétier and Lavorel 2011). For example, in a case of dredging that affects water quality, end-point biodiversity damage to offshore reefs cannot be directly estimated, so the intermediate factor (water quality) is used. The use of such a surrogate means that the measurements or estimations of the impact and the offset benefit are both one step removed from the biodiversity in question, and the use of surrogates will always be an imprecise way to measure changes in biodiversity. Not only are impacts difficult to define in data-poor systems, but offset outcomes are equally difficult to evaluate, leading to situations in which no net loss is theoretically possible but challenging to measure with any certainty.

Social and governance challenge: Lack of private ownership. Unlike terrestrial environments, private ownership in the marine environment is limited. In terrestrial offsets, proponents can buy and protect land or pay another landowner to manage threats and perform restoration activities on their land and ensure ongoing protection (BBOP 2012a). Private ownership in marine environments is much less common, so this type of offsetting is unlikely to occur. Therefore, the options for how offsets can be accomplished in the marine environment are different. In part, the lack of private ownership may improve the potential effectiveness of offsets, because one entity (usually a government body) can regulate activities without affecting property rights, making the enforcement and monitoring of compliance easier—although lack of offset management could be more challenging in areas of indistinct ownership such as the high seas. Although a government can designate areas for offset implementation, sustained legal protection is difficult to maintain without an ongoing, high level of public support for the initiative (Dutson et al. 2015). For example, although marine parks and areas of marine tender can be designated, they can also be quickly downgraded and degazetted if industry interests object (Mascia and Pailler 2011).

Nations only manage marine systems and resources within 200 nautical miles of the cost, inside the country's exclusive economic zone (EEZ). Outside of this area, there are limited legal biodiversity protections. The "high seas" cover almost half of the Earth's surface, and as resources are exhausted in more accessible regions, increasing technological advances are leading to a surge in exploitation of the deep sea for fishing, minerals exploration, and marine energy production (Kark et al. 2015). How might the offsetting of impacts work in such a context?

Governance in the high seas is complex and based on the UN Convention on the Law of the Sea (UNCLOS), which allows for all states to exploit the resources therein but also includes an obligation to protect the marine environment (UN General Assembly 1982). UNCLOS relegates specific activities to sector-based management by different organizations or conventions, leaving policy in the high seas fragmented, influenced by competing stakeholder interests, and lacking comprehensive management both spatially and across sectors (Gjerde and Rulska-Domino 2012, UNEP-WCMC 2015). For example, in the high seas, shipping and its impacts are managed by the International Maritime Association (IMO), deep-seabed mining is regulated by the International Seabed Authority (ISA), and fishing activities are managed through state-run regional fisheries management organizations (RMFO; Gjerde and Rulska-Domino 2012). Although a UN resolution to develop a marine biodiversity strategy for the high seas is ongoing, expanding resource exploitation outside of national jurisdictions will magnify impacts on marine biodiversity and become increasingly important in the achievement of marine no net loss (UNEP-WCMC 2015). Given the lack of legislative control in areas of the high seas, it is unclear who would regulate offsets, and there is limited potential to ensure the continued monitoring and management of offsets in the global commons over the long term.

Social and governance challenge: Greater likelihood of leakage in marine resource exploitation. *Leakage*, or the displacement of a damaging activity to a new location rather than its complete removal, is a known problem in protected areas and carbon offsetting but has rarely been quantified explicitly in biodiversity offset initiatives (Virah-Sawmy et al. 2014, Moilanen and Laitila 2016). Leakage in the ocean could be a bigger issue than on land, linked to both the connectivity of marine environments and the lack of ownership. Although the concept of leakage is quite prominent in the Business and Biodiversity Offsetting Program (BBOP) *Standard and Guidance Notes* (BBOP 2012a, 2012b), none of the policies reviewed discuss the possibility of leakage or how to account for it. For an extractive industry such as mining, in which the resource is fixed in one location, leakage issues will likely be the same at sea as it is on land. However, other resources in the ocean, such as fish populations, move and migrate unhindered by ownership boundaries, and exploitation is likely to follow that movement. The establishment of a no-take fishing zone as an offset will remove the threat of fishing from that single location but may not reduce overall fish catch, merely shifting the pressure elsewhere in the region to meet persistent demand (Halpern et al. 2004, Ewers and Rodrigues 2008, Helvey et al. 2017). This effect has been documented in the effort to redistribute fishing fleets concentrated around the boundaries of no-take zones, where spillover from the protected areas are likely to be greater (Gell and Roberts 2003).

Because of the difficulty of marine restoration, there is the possibility that *averted-loss offsets* (avoiding future decline in the biodiversity values of a site, such as through legal protection from damage or take) could make up a substantial portion of offset actions in marine areas. However, the types of activities being offset through averted loss are likely to be the types of activities easily moved elsewhere. Vessel traffic removed from a particular area is likely to shift the potential for vessel strikes to elsewhere in the region rather than to reduce it overall. Offset planning may therefore need to involve phasing out that component of industry where exploitation is likely to continue to occur as a result of leakage rather than focusing on the regulation of activities in a particular place. For example, buying back active fishing licenses rather than establishing no-take zones would reduce the likelihood of leakage. If more permanent solutions such asindustry phaseouts are unlikely or unable to occur, the potential for leakage needs to be factored into the additionality of the offset (Virah-Sawmy et al. 2014, Moilanen and Laitila 2016).

Conclusions

Marine biodiversity offsets are occurring or enabled in 77 countries, following rapidly in the wake of their terrestrial counterparts. Although there are few data available on the implementation, frequency, or effectiveness of terrestrial offsets, there are still fewer for marine offsets. We argue that both biophysical and governance differences between marine and terrestrial environments will create significant challenges for translating offsets to the marine environment. We have also identified potential opportunities afforded by the nature of marine systems, such as achieving no-net-loss outcomes more efficiently by incorporating spatial flexibility in offsets. Nevertheless, significant gaps remain in the scientific foundations for marine offsetting.

Many of the theoretical and practical challenges faced in biodiversity offsets are shared by both marine and terrestrial systems, but there are important practical considerations that will present particular challenges to offsetting in the marine environment. The lack of spatially explicit data about marine systems may result in impacts that are difficult to quantify and equally difficult to offset effectively. For example, the European Union's No Net Loss Initiative discusses the challenges of assessing complicated impacts and designing offsets in a dynamic environment and concludes that there remains uncertainty as to whether current knowledge is sufficient to apply no net loss to the marine environment (European Commission 2013). There is also the possibility that other issues may become more important when attempting to achieve no net loss in the marine environment, such as the scale of cumulative impacts or the influence of threshold dynamics and "tipping points" in many marine systems (UNEP-WCMC 2015).

Given the complexity and interconnectedness of marine systems, building spatial flexibility into marine offset actions has the potential to result in better outcomes for species and a greater likelihood of achieving no net loss. This should be approached with consideration of the system-wide dynamics rather than focused narrowly near the impact site. Similarly, many impacts in marine systems are a result of terrestrial based activities, and the integration of both land and sea mitigation activities into offsets could mediate complex impacts more effectively. It is imperative that the science underpinning this land–sea connection be explored more fully. In the terrestrial environment, the integration of offsets with conservation planning has been labeled "strategic" (Kujala et al. 2015, Sochi and Kiesecker 2016), and common sense tells us that it is best to implement offset actions where they will have the greatest chance of achieving gains. In the marine environment, offset options may be limited by lack of data, lack of private ownership, and poor restoration potential. The uncertainty of achieving no net loss, given the compounding biophysical and governance challenges of offsetting in the marine environment, demonstrates the need to focus on the entire mitigation hierarchy. The precautionary principle is key, and more explicit emphasis is needed on the avoidance step of the mitigation hierarchy in achieving marine no net loss (Phalan et al. 2017).

Lack of outcome reporting and transparency is a significant barrier to improving offset outcomes and achieving no net loss of both marine and terrestrial biodiversity. Canada has had mitigation strategies in place since 1986 to achieve no net loss of the "productive capacity" of fish habitat. The policy requires development proponents to address their impacts either directly or through habitat-banking arrangements and to monitor and report offset effectiveness. A review of this policy showed that most offset projects (86%) could not be evaluated because of a lack of monitoring data (Quigley and Harper 2006). It is possible that internal offset management and outcome reports exist, but we found no evidence of such evaluations. Because of these problems, ex-post evaluation of marine offset effectiveness broadly is not possible.

The concept of no net loss has the potential to generate better conservation outcomes as coastal and marine development continues to affect biodiversity. Without emphasis on robust, scientific evaluation of offset outcomes, there remains insufficient evidence to suggest that no net loss can be achieved in practice in the marine environment. Offsetting in the marine environment is high risk and high cost, so avoidance remains the most important step in the mitigation hierarchy in striving for no net loss.

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Supplemental material

Supplementary data are available at *BIOSCI* online.

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